

Metal Casting

By S K Mondal

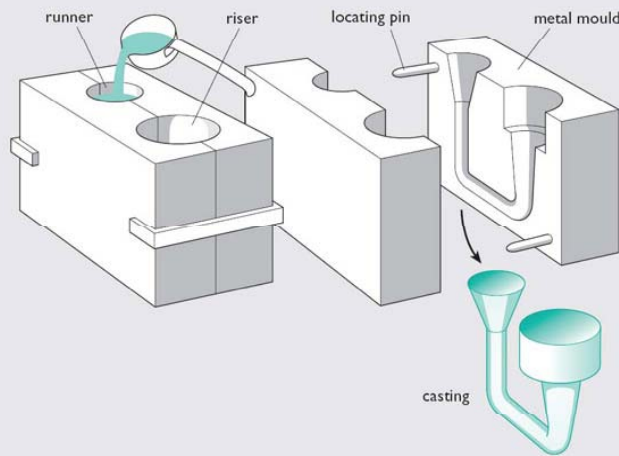
Sand casting

- Sand casting uses ordinary sand as the primary mould material.
- The sand grains are mixed with small amounts of other materials, such as clay and water, to improve mouldability and cohesive strength, and are then packed around a pattern that has the shape of the desired casting.
- The pattern must be removed before pouring, the mold is usually made in two or more pieces.
- An opening called a *sprue hole* is cut from the top of the mold through the sand and connected to a system of channels called *runners*.

Contd....

- The molten metal is poured into the sprue hole, flows through the runners, and enters the mold cavity through an opening called a *gate*.
- Gravity flow is the most common means of introducing the metal into the mold.
- After solidification, the mold is broken and the finished casting is removed.
- The casting is then "fettled" by cutting off the ingate and the feeder head.
- Because the mold is destroyed, a new mold must be made for each casting.

Contd...

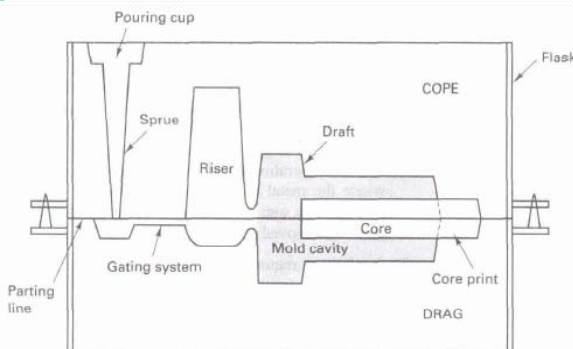


Sequential steps in making a sand casting

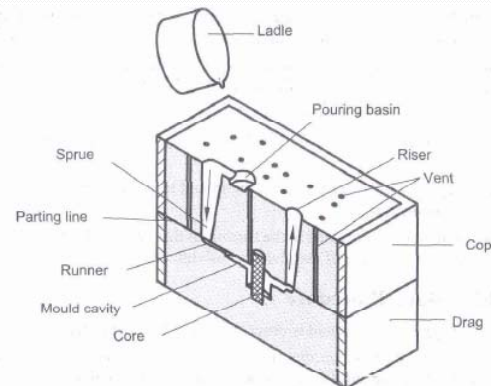
- A pattern board is placed between the bottom (drag) and top (cope) halves of a flask, with the bottom side up.
- Sand is then packed into the drag half of the mold.
- A bottom board is positioned on top of the packed sand, and the mold is turned over, showing the top (cope) half of pattern with sprue and riser pins in place.
- The cope half of the mold is then packed with sand.

Contd...

- The mold is opened, the pattern board is drawn (removed), and the runner and gate are cut into the surface of the sand.
- The mold is reassembled with the pattern board removed, and molten metal is poured through the sprue.
- The contents are shaken from the flask and the metal segment is separated from the sand, ready for further processing.



For-2015 (IES, GATE & PSUs)



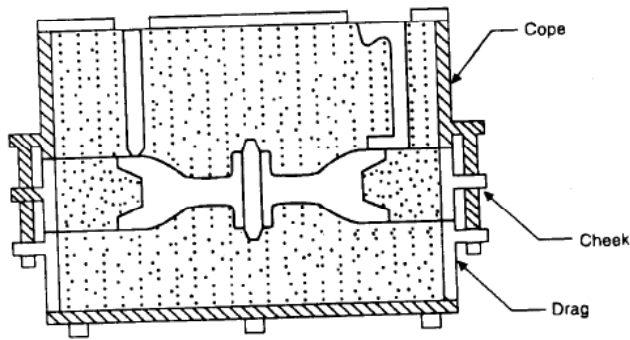
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Casting Terms

- **Flask:** A moulding flask is one which holds the sand mould intact. It is made up of wood for temporary applications or metal for long-term use.
- **Drag:** Lower moulding flask.
- **Cope:** Upper moulding flask.
- **Cheek:** Intermediate moulding flask used in three-piece moulding.

Rev.0

Contd...



Three flask mould

- **Pattern:** Pattern is a replica of the final object to be made with some modifications.
- **Parting line:** This is the dividing line between the two moulding flasks that makes up the sand mould.
- **Bottom board:** This is a board normally made of wood, which is used at the start of the mould making.

Contd...

- **Moulding sand:** The freshly prepared refractory material used for making the mould cavity. It is a mixture of silica, clay and moisture in appropriate proportions.
- **Backing sand:** This is made up of used and burnt sand.
- **Core:** Used for making hollow cavities in castings.

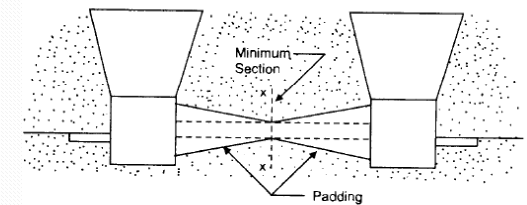
- **Pouring basin:** A small funnel-shaped cavity at the top of the mould into which the molten metal is poured.
- **Sprue:** The passage through which the molten metal from the pouring basin reaches the mould cavity.
- **Runner:** The passage ways in the parting plane through which molten metal flow is regulated before they reach the mould cavity.
- **Gate:** The actual entry point through which molten metal enters the mould cavity in a controlled rate. Contd...

- **Chaplet:** Chaplets are used to support cores inside the mould cavity.
- **Chill:** Chills are metallic objects, which are placed in the mould to increase the cooling rate of castings.
- **Riser:** It is a reservoir of molten metal provided in the casting so that hot metal can flow back into the mould cavity when there is a reduction in volume of metal due to solidification

Contd...

Padding

- Tapering of thinner section towards thicker section is known as 'padding'.
- This will require extra material.
- If padding is not provided, centre line shrinkage or porosity will result in the thinner section.



IES-2001

The main purpose of chaplets is

- To ensure directional solidification
- To provide efficient venting
- For aligning the mold boxes
- To support the cores

For-2015 (IES, GATE & PSUs)

IES-1996

Which of the following methods are used for obtaining directional solidification for riser design

- Suitable placement of chills
- Suitable placement of chaplets
- Employing padding

Select the correct answer.

- (a) 1 and 2 (b) 1 and 3 (c) 2 and 3 (d) 1, 2 and 3
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IES 2007

Which one of the following is the correct statement?

Gate is provided in moulds to

- Feed the casting at a constant rate
- Give passage to gases
- Compensate for shrinkage
- Avoid cavities

Rev.0

GATE-2009

Match the items in Column I and Column II.

Column I

P. Metallic Chills

Q. Metallic Chaplets

R. Riser

S. Exothermic Padding 4. Progressive solidification

(a) P-1, Q-3, R-2, S-4

(c) P-3, Q-4, R-2, S-1

Column II

1. Support for the core

2. Reservoir of the molten metal

3. Control cooling of critical sections

4. Progressive solidification

(b) P-1, Q-4, R-2, S-3

(d) P-4, Q-1, R-2, S-3

GATE-1992

In a green-sand moulding process, uniform ramming leads to

- (a) Less chance of gas porosity
- (b) Uniform flow of molten metal into the mould cavity
- (c) Greater dimensional stability of the casting
- (d) Less sand expansion type of casting defect

GATE 2011

Green sand mould indicates that

- (a) polymeric mould has been cured
- (b) mould has been totally dried
- (c) mould is green in colour
- (d) mould contains moisture

Pattern

A pattern is a replica of the object to be made by the casting process, with some modifications.

The main modifications are

- The addition of pattern allowances,
- The provision of core prints, and
- Elimination of fine details, which cannot be obtained by casting and hence are to be obtained by further processing

Pattern Allowances

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

Shrinkage allowance

- All metals shrink when cooling except perhaps bismuth.
- This is because of the inter-atomic vibrations which are amplified by an increase in temperature.
- The shrinkage allowance is always to be added to the linear dimensions. Even in case of internal dimensions.

Contd...

Liquid shrinkage and solid shrinkage

- **Liquid shrinkage** refers to the reduction in volume when the metal changes temperature from pouring to solidus temperature in liquid state. To account for this, risers are provided in the moulds.
- **Solidification shrinkage** refers to the reduction in volume when metal changes from liquid to solid state at the solidus temperature. To account for this, risers are provided in the moulds.
- **Solid shrinkage** is the reduction in volume caused, when a metal loses temperature in the solid state. The shrinkage allowance is provided to take care of this reduction.

- Gray CI with a carbon equivalent of 4.3% has negative shrinkage, that is, it actually expands upto 2.5% because of graphite precipitation. So, for this, no riser is needed.

• Pattern Allowances

Cast Iron	10 mm/m
Brass, Copper, Aluminium	15 mm/m
Steel	20 mm/m
Zinc, Lead	25 mm/m

IES-1995

Which one of the following materials will require the largest size of riser for the same size of casting?

- (a) Aluminium
- (b) Cast iron
- (c) Steel
- (d) Copper.

GATE-1999

Which of the following materials requires the largest shrinkage allowance, while making a pattern for casting?

- (a) Aluminium
- (b) Brass
- (c) Cast Iron
- (d) Plain Carbon Steel

IES-1999

In solidification of metal during casting, compensation for solid contraction is

- (a) Provided by the oversize pattern
- (b) Achieved by properly placed risers
- (c) Obtained by promoting directional solidification
- (d) Made by providing chills

ISRO-2007

Shrinkage allowance is made by

- (a) Adding to external and internal dimensions
- (b) Subtracting from external and internal dimensions
- (c) Subtracting from external dimensions and adding to internal dimensions
- (d) Adding to external dimensions and subtracting from internal dimensions

GATE-2001

Shrinkage allowance on pattern is provided to compensate for shrinkage when

- (a) The temperature of liquid metal drops from pouring to freezing temperature
- (b) The metal changes from liquid to solid state at freezing temperature
- (c) The temperature of solid phase drops from freezing to room temperature
- (d) The temperature of metal drops from pouring to room temperature

GATE-2004

Gray cast iron blocks 200 x 100 x 10 mm are to be cast in sand moulds. Shrinkage allowance for pattern making is 1%. The ratio of the volume of pattern to that of the casting will be

- (a) 0.97 (b) 0.99 (c) 1.01 (d) 1.03

GATE-2008

While cooling, a cubical casting of side 40 mm undergoes 3%, 4% and 5% volume shrinkage during the liquid state, phase transition and solid state, respectively. The volume of metal compensated from the riser is

- (a) 2% (b) 7% (c) 8% (d) 9%

GATE 2011

A cubic casting of 50 mm side undergoes volumetric solidification shrinkage and volumetric solid contraction of 4% and 6% respectively. No riser is used. Assume uniform cooling in all directions. The side of the cube after solidification and contraction is

- (a) 48.32 mm
- (b) 49.90 mm
- (c) 49.94 mm
- (d) 49.96 mm

IAS-1995

Assertion (A): A pattern is made exactly similar to the part to be cast.

Reason (R): Pattern is used to make the mould cavity for pouring in molten for casting.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IAS-2003

Match List I (Material to be cast) with List II (Shrinkage Allowance in mm/m) and select the correct answer using the codes given below the lists:

List-I

List-II

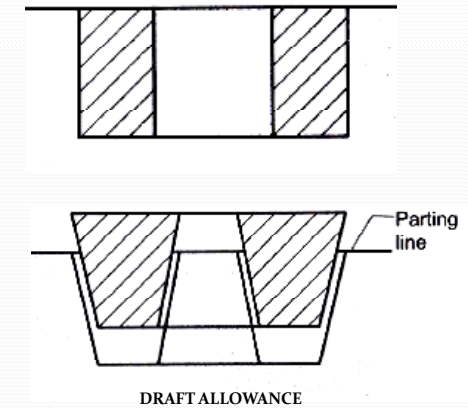
(Material to Cast) (Shrinkage Allowance in mm/m)

- | | | |
|--------------------|----|--------|
| (A) Grey cast iron | 1. | 7 - 10 |
| (B) Brass | 2. | 15 |
| (C) Steel | 3. | 20 |
| (D) Zinc | 4. | 24 |

Codes: A	B	C	D	A	B	C	D
(a) 1	2	3	4	(b) 3	4	1	2
(c) 1	4	3	2	(d) 3	2	1	4

Draft

- To reduce the chances of the damage of the mould cavity at the time of pattern removal, the vertical faces of the pattern are always tapered from the parting line. This provision is called draft allowance.
- Inner surfaces of the pattern require higher draft than outer surfaces.
- Draft is always provided as an extra metal.



DRAFT ALLOWANCE

Shake Allowance

- At the time of pattern removal, the pattern is rapped all around the vertical faces to enlarge the mould cavity slightly to facilitates its removal.
- It is a **negative allowance** and is to be applied only to those dimensions, which are parallel to the parting plane.

Distortion Allowance

- A metal when it has just solidified is very weak and therefore is likely to be distortion prone.
- This is particularly so for weaker sections such as long flat portions, V, U sections or in a complicated casting which may have thin and long sections which are connected to thick sections.
- The foundry practice should be to make extra material provision for reducing the distortion.

Pattern Materials

- Wood** patterns are relatively easy to make. Wood is not very dimensionally stable. Commonly used teak, white pine and mahogany wood.
- Metal** patterns are more expensive but are more dimensionally stable and more durable. Commonly used CI, Brass, aluminium and white metal.
- Hard plastics**, such as urethanes, and are often preferred with processes that use strong, organically bonded sands that tend to stick to other pattern materials.
- In the full-mold process, **expanded polystyrene (EPS)** is used.
- Investment casting uses **wax** patterns.

The pattern material should be

- Easily worked, shaped and joined
- Light in weight
- Strong, hard and durable
- Resistant to wear and abrasion
- Resistant to corrosion, and to chemical reactions
- Dimensionally stable and unaffected by variations in temperature and humidity.
- Available at low cost.

For 2015 (IES, GATE & PSUs)

IES-1994

Which of the following materials can be used for making patterns?

1. Aluminium 2. Wax 3. Mercury 4. Lead

Select the correct answer using the codes given below:

Codes:

- (a) 1,3 and 4 (b) 2,3 and 4 (c) 1, 2 and 4 (d) 1, 2 and 3

GATE-2000

Disposable patterns are made of

- (a) Wood
(b) Rubber
(c) Metal
(d) Polystyrene

Types of Pattern

Single Piece Pattern

These are inexpensive and the simplest type of patterns. As the name indicates, they are made of a single piece.

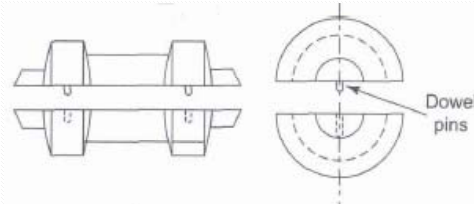
Gated Pattern

Gating and runner system are integral with the pattern. This would eliminate the hand cutting of the runners and gates and help in improving the productivity of a moulding.

Types of Pattern

Split Pattern or Two Piece Pattern

This is the most widely used type of pattern for intricate castings. When the contour of the casting makes its withdrawal from the mould difficult, or when the depth of the casting is too high, then the pattern is split into two parts so that one part is in the drag and the other in the cope.



Types of Pattern

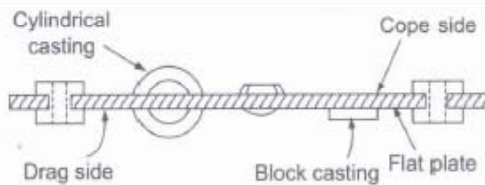
• Cope and Drag Pattern

These are similar to split patterns. In addition to splitting the pattern, the cope and drag halves of the pattern are attached separately to the metal or wooden plates along with the alignment pins. They are called the cope and drag patterns.

Types of Pattern

• Match Plate Pattern

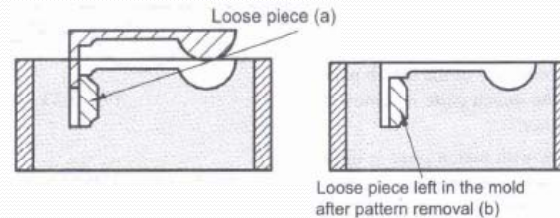
The cope and drag patterns along with the gating and the risering are mounted on a single matching metal or wooden plate on either side.



Types of Pattern

• Loose Piece Pattern

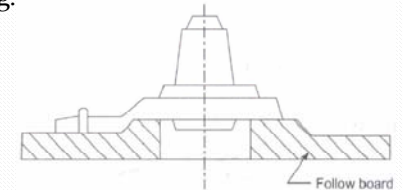
This type of pattern is also used when the contour of the part is such that withdrawing the pattern from the mould is not possible.



Types of Pattern

• Follow Board Pattern

This type of pattern is adopted for those castings where there are some portions, which are structurally weak and if not supported properly are likely to break under the force of ramming.



IES-2008

The pattern adopted for those castings where there are some portions which are structurally weak and are likely to break by the force of ramming are called:

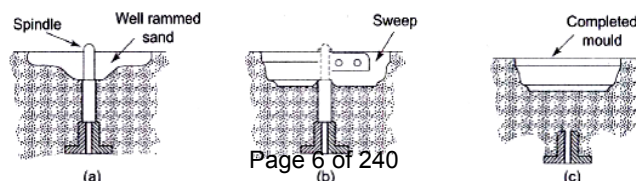
- Loose piece pattern
- Follow board pattern
- Skelton pattern
- Single piece pattern

For-2015 (IES, GATE & PSUs)

Types of Pattern

• Sweep Pattern

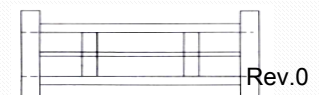
It is used to sweep the complete casting by means of a plane sweep. These are used for generating large shapes, which are axi-symmetrical or prismatic in nature such as bell-shaped or cylindrical.



Types of Pattern

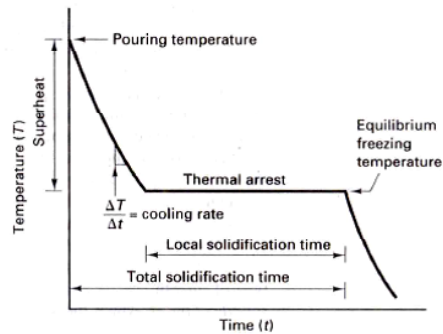
• Skeleton Pattern

A skeleton of the pattern made of strips of wood is used for building the final pattern by packing sand around the skeleton. After packing the sand, the desired form is obtained with the help of a strickle. This type of pattern is useful generally for very large castings, required in small quantities where large expense on complete wooden pattern is not justified.



Rev.0

Cooling Curve



Fluidity

The ability of a metal to flow and fill a mold is known as fluidity.

Pouring Temperature

- The most important controlling factor of fluidity is the pouring temperature or the amount of superheat.
- Higher the pouring temperature, the higher the fluidity.
- Excessive temperatures should be avoided, however. At high pouring temperatures, metal-mold reactions are accelerated and the fluidity may be so great as to permit penetration.
- Penetration is a defect where the metal not only fills the mold cavity but also fills the small voids between the sand particles in a sand mold.

GATE 2012 (PI)

In sand casting, fluidity of the molten metal increases with

- (A) increase in degree of superheat
- (B) decrease in pouring rate
- (C) increase in thermal conductivity of the mould
- (D) increase in sand grain size

ISRO-2011

Fluidity in casting (CI) operation is greatly influenced by

- a) Melting temperature of molten metal
- b) Pouring temperature of molten metal
- c) Finish of the mould
- d) Carbon content of molten metal

Core

- Used for making cavities and hollow projections.
- All sides of core are surrounded by the molten metal and are therefore subjected to much more severe thermal and mechanical conditions and as a result the core sand should be of higher strength than the moulding sand.

Desired characteristics of a core

- **Green Strength:** A core made of green sand should be strong enough to retain the shape till it goes for baking.
- **Dry Strength:** It should have adequate dry strength so that when the core is placed in the mould, it should be able to resist the metal pressure acting on it.
- **Refractoriness:** Since in most cases, the core is surrounded all around it is desirable that the core material should have higher refractoriness.

Contd...

- **Permeability:** Gases evolving from the molten metal and generated from the mould may have to go through the core to escape out of the mould. Hence cores are required to have higher permeability.
- **Permeability Number:** The rate of flow of air passing through a standard specimen under a standard pressure is termed as permeability number.
- The standard permeability test is to measure time taken by a 2000 cu cm of air at a pressure typically of 980 Pa (10 g/cm²), to pass through a standard sand specimen confined in a specimen tube. The standard specimen size is 50.8 mm in diameter and a length of 50.8 mm. For-2015 (IES, GATE & PSUs)

Then, the permeability number, R is obtained by

$$R = \frac{VH}{pAT}$$

Where V = volume of air = 2000 cm³

H = height of the sand specimen = 5.08 cm

p = air pressure, g/cm²

A = cross sectional area of sand specimen = 20.268 cm²

T = time in minutes for the complete air to pass through

Inserting the above standard values into the expression, we get

$$R = \frac{501.28}{5 \times 1.417}$$

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- Calculate the permeability number of sand if it takes 1 min 25 s to pass 2000 cm³ of air at a pressure of 5 g/cm² through the standard sample.

$$p = 5.0 \text{ g / cm}^2$$

$$T = 1 \text{ min } 25 \text{ s} = 1.417 \text{ min}$$

$$R = \frac{501.28}{5 \times 1.417} = 70.75$$

Rev.0

IES 2007

What is permeability? Permeability is more important in the basic process of sand casting than porosity. Give one important reason for this feature.

[2 marks]

- **Collapsibility:** At the time of cooling, casting shrinks, and unless the core has good collapsibility (ability to decrease in size) it is likely to provide resistance against shrinkage and thus can cause hot tears.

- **Friability:** The ability to crumble should be a very important consideration at the time of removal.
- **Smoothness:** Surface of the core should be smooth for good finish to the casting.
- **Low Gas Emission**

Core Sands

- Used clay free silica sand.
- Binders used are linseed oil, core oil, resins, dextrin, molasses, etc.
- Core oils are mixtures of linseed, soy, fish and petroleum oils and coal tar.
- The general composition of a core sand mixture could be core oil (1%) and water (2.5 to 6%).

Carbon Dioxide Moulding

- Sodium silicate (water glass, $\text{SiO}_2 \cdot \text{Na}_2\text{O}$) is used as a binder. This is essentially a quick process of core or mould preparation.
- The mould is prepared with a mixture of sodium silicate and sand and then treated with carbon dioxide for two to three minutes such that a dry compressive strength of over 1.4 MPa is arrived.
- The carbon dioxide is expected to form a weak acid, which hydrolyses the sodium silicate resulting in amorphous silica, which forms the bond.
- The introduction of CO_2 gas starts the reaction by forming hydrated sodium carbonate ($\text{Na}_2\text{CO}_3 + \text{H}_2\text{O}$).

Contd...

- The compressive strength of the bond increases with standing time due to dehydration.
- Because of the high strength of the bond, the core need not be provided with any other reinforcements.
- It does not involve any distortions due to baking and also better dimensional accuracies are achieved.
- The sand mixture does not have good shelf life and therefore should be used immediately after preparation.

IES-2002

Assertion (A): In CO_2 casting process, the mould or core attains maximum strength.

Reason (R): The optimum gassing time of CO_2 through the mould or core forms Silica Gel which imparts sufficient strength to the mould or core.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

For-2015 (IES, GATE & PSUs)

GATE – 2008 (PI)

In sand casting of a hollow part of lead, a cylindrical core of diameter 120 mm and height 180 mm is placed inside the mould cavity. The densities of core material and lead are 1600 kg/m^3 and $11,300 \text{ kg/m}^3$ respectively. The net force (in N) that tends to lift the core during pouring of molten metal will be

- (a) 19.7 (b) 64.5 (c) 193.7 (d) 257.6

GATE-2014

An aluminium alloy (density 2600) casting is to be produced. A cylindrical hole of 100 mm diameter and 100 mm length is made in the casting using sand core (density 1600). The net buoyancy force (in Newton) acting on the core is

Moulding Sand Composition

- **Sand:** Ordinary silica Sand (SiO_2), zircon, or olivine sands.
- **Clay:** Acts as binding agents mixed to the moulding sands
Kaolinite or fire clay ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$), and
Bentonite ($\text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O} \cdot n\text{H}_2\text{O}$).
- **Water:** Clay is activated by water.

Other Additives

- **Cereal binder** up to 2% increases the strength.
- **Pitch** if used up to 3% would improve the hot strength.
- **Saw dust** up to 2% may improve the collapsibility by slowly burning, and increase the permeability.
- **Other materials:** sea coal, asphalt, fuel oil, graphite, molasses, iron oxide, etc.

Moulding Sand Properties

- **Porosity or Permeability:** Permeability or porosity of the moulding sand is the measure of its ability to permit air to flow through it.
- **Strength:** It is defined as the property of holding together of sand grains. A moulding sand should have ample strength so that the mould does not collapse or get partially destroyed during conveying, turning over or closing.
- **Refractoriness:** It is the ability of the moulding sand mixture to withstand the heat of melt without showing any signs of softening or fusion.

Contd...

- **Plasticity:** It is the measure of the moulding sand to flow around and over a pattern during ramming and to uniformly fill the flask.
- **Collapsibility:** This is the ability of the moulding sand to decrease in volume to some extent under the compressive forces developed by the shrinkage of metal during freezing and subsequent cooling.
- **Adhesiveness:** This is the property of sand mixture to adhere to another body (here, the moulding flasks). The moulding sand should cling to the sides of the moulding boxes so that it does not fall out when the flasks are lifted and turned over. This property depends on the type and amount of binder used in the sand mix.

Other Sands

- **Facing sand:** The small amount of carbonaceous material sprinkled on the inner surface of the mold cavity to give a better surface finish to the castings.
- **Backing sand:** It is what constitutes most of the refractory material found in the mould. This is made up of used and burnt sand.
- **Green Sand:** The molding sand that contains moisture is termed as green sand. The green sand should have enough strength so that the constructed mould retains its shape.
- **Dry sand:** When the moisture in the moulding sand is completely expelled, it is called dry sand.

IES-2008

Small amount of carbonaceous material sprinkled on the inner surface of mould cavity is called

- Backing sand
- Facing sand
- Green sand
- Dry sand

Grain size number

- ASTM (American Society for Testing and Materials) grain size number, defined as
$$N \equiv 2^{n-1}$$
- Where N is the number of grains per square inch visible in a prepared specimen at 100X and n is the ASTM grain-size number.
- Low ASTM numbers mean a few massive grains; high numbers refer to many small grains.

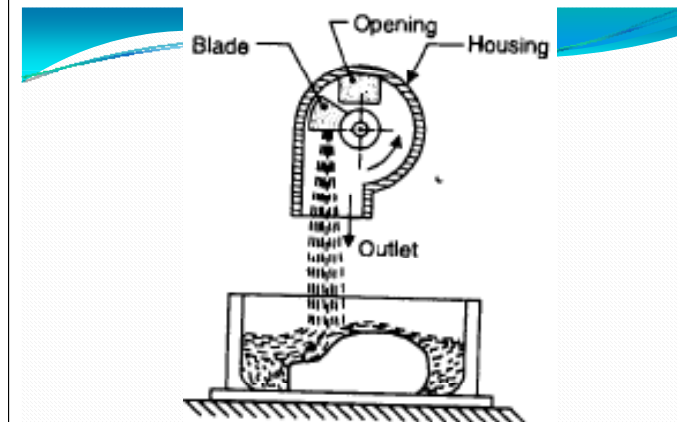
For-2015 (IES, GATE & PSUs)

IES-2002

In the grain -size determination using standard charts, the relation between the given size number n and the average number of grains 'N' per square inch at a magnification of 100 X is

- $N = 2^n$
- $N = 2^{n-1}$
- $N = 2^{n+1}$
- $N = 2^n + 1$

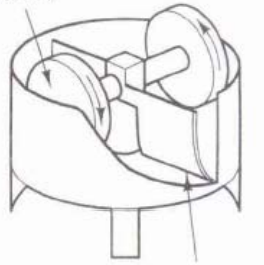
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Sand Slinger

Rev.0

Muller wheel
(1 of 2)



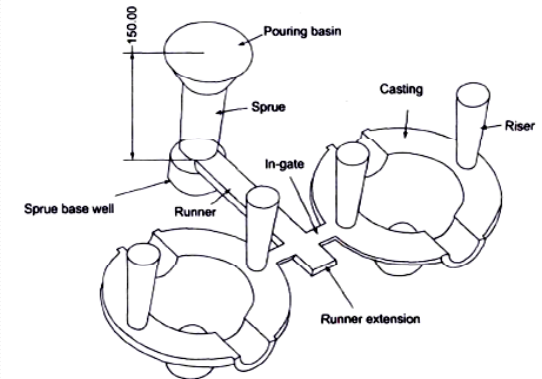
Plow blade
(1 of 2)

Casting Yield

The casting yield is the proportion of the actual casting mass, w , to the mass of metal poured into the mould, W , expressed as a percentage.

$$\text{Casting yield} = \frac{w}{W} \times 100$$

Gating System



Contd...

Gating System

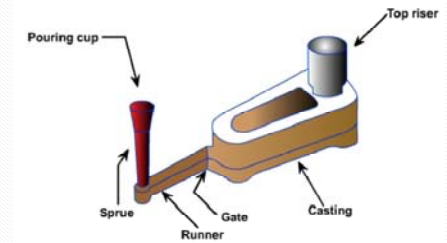
- **Pouring basin:** A small funnel shaped cavity at the top of the mould into which the molten metal is poured.
- **Sprue:** The passage through which the molten metal, from the pouring basin, reaches the mould cavity. In many cases it controls the flow of metal into the mould.

Contd...

- **Runner:** A runner is commonly a horizontal channel which connects the sprue with gates, thus allowing the molten metal to enter the mould cavity. The runners are of larger cross-section and often streamlined to slow down and smooth out the flow, and are designed to provide approximately uniform flow rates to the various parts of the mould cavity. Runners are commonly made trapezoidal in cross-section.

Contd...

- **Ingate:** A channel through which the molten metal enters the mould cavity.
- **Vent:** Small opening in the mould to facilitate escape of air and gases.



Types of Gate or In-gate

Top gate: Causes turbulence in the mould cavity, it is prone to form dross, favourable temperature gradient towards the gate, only for ferrous alloys.

Bottom gate: No mould erosion, used for very deep moulds, higher pouring time, Causes unfavourable temperature gradients.

Parting Gate: most widely used gate, easiest and most economical in preparation.

Step Gate: Used for heavy and large castings, size of ingates are normally increased from top to bottom.

IES 2011

In light metal casting, runner should be so designed that:

1. It avoids aspiration
2. It avoids turbulence
3. The path of runner is reduced in area so that unequal volume of flow through each gate takes place

(a) 1 and 2 only

(b) 1 and 3 only

(c) 2 and 3 only

(d) 1, 2 and 3

GATE – 2010 (PI)

During the filling process of a given sand mould cavity by molten metal through a horizontal runner of circular cross-section the frictional head loss of the molten metal in the runner will increase with the

- (a) increase in runner diameter
- (b) decrease in internal surface roughness of runner
- (c) decrease in length of runner
- (d) increase in average velocity of molten metal

IES 2011

Match List -I with List -II and select the correct answer using the code given below the lists :

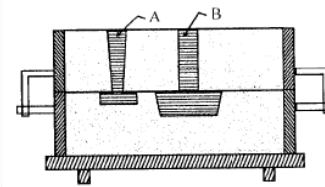
List -I	List -II
A. Top gate	1. Heavy and large castings
B. Bottom gate	2. Most widely used and economical
C. Parting gate	3. Turbulence
D. Step gate	4. Unfavourable temperature gradient

Codes

	A	B	C	D		A	B	C	D
(a)	3	4	2	1	(b)	1	4	2	3
(c)	3	2	4	1	(d)	1	2	4	3

IES-1998

A sand casting mould assembly is shown in the above figure. The elements marked A and B are respectively



- (a) Sprue and riser
(b) Ingate and riser
(c) Drag and runner
(d) Riser and runner

GATE-2002

The primary purpose of a sprue in a casting mould is to

- (a) Feed the casting at a rate consistent with the rate of solidification
(b) Act as a reservoir for molten metal
(c) Feed molten metal from the pouring basin to the gate
(d) Help feed the casting until all solidification takes place

The goals for the gating system

- To minimize turbulence to avoid trapping gasses into the mold
- To get enough metal into the mold cavity before the metal starts to solidify
- To avoid shrinkage
- Establish the best possible temperature gradient in the solidifying casting so that the shrinkage if occurs must be in the gating system not in the required cast part.
- Incorporates a system for trapping the non-metallic inclusions.

IES-1998

Which of the following are the requirements of an ideal gating system?

1. The molten metal should enter the mould cavity with as high a velocity as possible.
2. It should facilitate complete filling of the mould cavity.
3. It should be able to prevent the absorption of air or gases from the surroundings on the molten metal while flowing through it.

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1 and 2 (c) 2 and 3 (d) 1 and 3

IES-2009

Consider the following statements:

1. The actual entry point through which the molten metal enters the mould cavity is called ingate.
2. Bottom gate in case of a mould creates unfavourable temperature gradient.
3. Sprue in case of a mould is made tapered to avoid air inclusion.

Which of the above statements is/are correct?

- (a) 1 only (b) 1 and 2 (c) 2 and 3 (d) 1 and 3

Types of Gating Systems

The gating systems are of two types:

- Pressurized gating system
- Un-pressurized gating system

Pressurized Gating System

- The total cross sectional area decreases towards the mold cavity
- Back pressure is maintained by the restrictions in the metal flow
- Flow of liquid (volume) is almost equal from all gates
- Back pressure helps in reducing the aspiration as the sprue always runs full
- Because of the restrictions the metal flows at high velocity leading to more turbulence and chances of mold erosion.

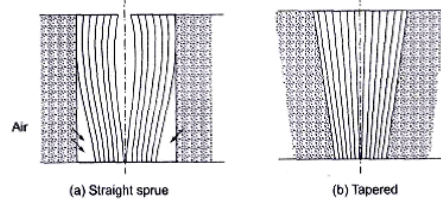
Un-Pressurized Gating System

- The total cross sectional area increases towards the mold cavity
- Restriction only at the bottom of sprue
- Flow of liquid (volume) is different from all gates
- Aspiration in the gating system as the system never runs full
- Less turbulence.

Sprue Design

- **Sprue:** Sprue is the channel through which the molten metal is brought into the parting plane where it enters the runners and gates to ultimately reach the mould cavity.
- The molten metal when moving from the top of the cope to the parting plane gains in velocity and some low-pressure area would be created around the metal in the sprue.
- Since the sand mould is permeable, atmospheric air would be breathed into this low-pressure area which would then be carried to the mould cavity.
- To eliminate this problem of air aspiration, the sprue is tapered to gradually reduce the cross section as it moves away from the top of the cope as shown in Figure below (b).

Contd...



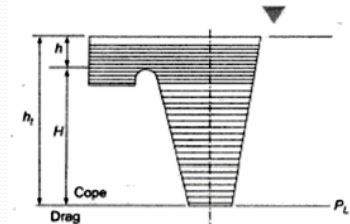
The exact tapering can be obtained by the equation of continuity. Denoting the top and choke sections of The sprue by the subscripts 't' and 'c' respectively, we get

$$A_t V_t = A_c V_c \Rightarrow A_t = A_c \frac{V_c}{V_t}$$

Contd...

Since the velocities are proportional to the square of the potential heads, as can be derived from Bernoulli's equation,

$$A_t = A_c \sqrt{\frac{h_c}{h_t}}$$



Where H = actual sprue height and $h_t = h + H$

GATE-2001

The height of the down-sprue is 175 mm and its cross-sectional area at the base is 200 mm². The cross-sectional area of the horizontal runner is also 200 mm². Assuming no losses, indicate the correct choice for the time (in seconds) required to fill a mould cavity of volume 10⁶ mm³. (Use $g = 10 \text{ m/s}^2$).

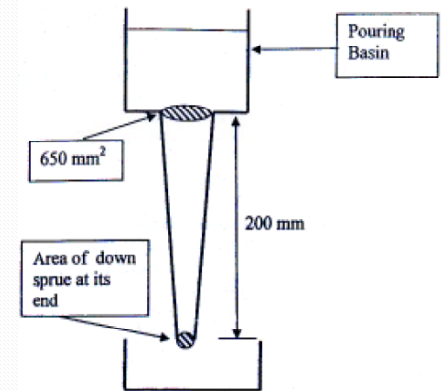
- (a) 2.67 (b) 8.45 (c) 26.72 (d) 84.50

GATE-2007

A 200 mm long down sprue has an area of cross section of 650 mm² where the pouring basin meets the down sprue (i.e. at the beginning of the down sprue). A constant head of molten metal is maintained by the pouring basin. The Molten metal flow rate is $6.5 \times 10^5 \text{ mm}^3/\text{s}$. Considering the end of down sprue to be open to atmosphere and an acceleration due to gravity of 10⁴ mm/s², the area of the down sprue in mm² at its end (avoiding aspiration effect) should be

- (a) 650.0 (b) 350.0 (c) 290.7 (d) 190.0

Contd...



Gating ratio

- Gating ratio is defined as: Sprue area: Runner area: Ingate area.
- For high quality steel castings, a gating ratio of 1: 2: 2 or 1: 2: 1.5 will produce castings nearly free from erosion, will minimize oxidation, and will produce uniform flow.
- A gating ratio of 1: 4: 4 might favour the formation of oxidation defects.

For 2015 (IES, GATE & PSUs)

IES-2003

A gating ratio of 1: 2: 4 is used to design the gating system for magnesium alloy casting. This gating ratio refers to the cross- section areas of the various gating elements as given below:

1. Down sprue 2. Runner bar 3. Ingates

The correct sequence of the above elements in the ratio 1: 2: 4 is

- (a) 1, 2 and 3
(b) 1, 3 and 2
(c) 2, 3 and 1
(d) 3, 1 and 2

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IES-2005

The gating ratio 2: 8: 1 for copper in gating system design refers to the ratio of areas of:

- (a) Sprue: Runner: Ingate
(b) Runner: Ingate: Sprue
(c) Runner: Sprue: Ingate
(d) Ingate: Runner: Sprue

Rev.0

GATE-2010

In a gating system, the ratio 1:2:4 represents

- (a) Sprue base area: runner area: ingate area
- (b) Pouring basin area : ingate area : runner area
- (c) Sprue base area : ingate area : casting area
- (d) Runner area : ingate area : casting area

IAS-1999

Assertion (A): The rate of flow of metal through sprue is NOT a function of the cross-sectional areas of sprue, runner and gate.

Reason (R): If respective cross-sectional areas of sprue, runner and gate are in the ratio of 1: 2: 2, the system is known as unpressurised gating system.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Risers and Riser Design

- Risers are added reservoirs designed to feed liquid metal to the solidifying casting as a means of compensating for solidification shrinkage.
- To perform this function, the risers must solidify after the casting.
- According to Chvorinov's rule, a good shape for a riser would be one that has a long freezing time (i.e., a small surface area per unit volume).
- **Live risers** (also known as hot risers) receive the last hot metal that enters the mold and generally do so at a time when the metal in the mold cavity has already begun to cool and **solidify**.

IES-1994

Assertion (A): In a mould, a riser is designed and placed so that the riser will solidify after the casting has solidified.

Reason (R): A riser is a reservoir of molten metal which will supply molten metal where a shrinkage cavity would have occurred.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Chvorinov's rule

- **Total solidification time** (t_s) = $B (V/A)^n$
where $n = 1.5$ to 2.0

[Where, B = mould constant and is a function of (mould material, casting material, and condition of casting)]

$$n = 2 \text{ and } t_{\text{riser}} = 1.25 t_{\text{casting}}$$

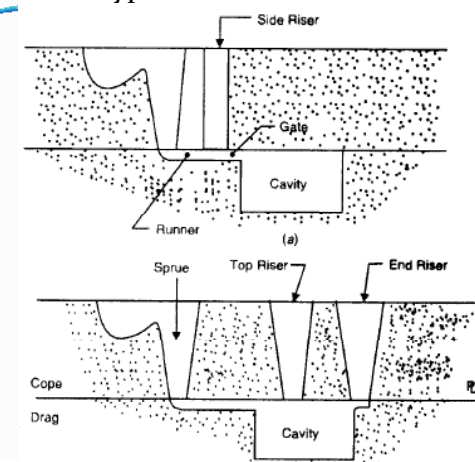
$$\text{OR} \quad \left(\frac{V}{A}\right)_{\text{riser}}^2 = 1.25 \left(\frac{V}{A}\right)_{\text{casting}}^2$$

For cylinder
of diameter D
and height H

$$V = \pi D^2 H / 4$$

$$A = \pi D H + 2 \left(\pi \frac{D^2}{4} \right)$$

Types of Risers



IES 2011

The relationship between total freezing time t , volume of the casting V and its surface area A , according to Chvorinov's rule is :

$$(a) t = k \left(\frac{V}{A} \right)$$

$$(b) t = k \left(\frac{A}{V} \right)$$

$$(c) t = k \left(\frac{A}{V} \right)^2$$

$$(d) t = k \left(\frac{V}{A} \right)^2$$

Where K is a constant

For-2015 (IES, GATE & PSUs)

IES-1998

A spherical drop of molten metal of radius 2 mm was found to solidify in 10 seconds. A similar drop of radius 4 mm would solidify in

- (a) 14.14 seconds
- (b) 20 seconds
- (c) 28.30 seconds
- (d) 40 seconds

GATE-2013 Same Question (PI)

A cube shaped casting solidifies in 5 min. The solidification time in min for a cube of the same material, which is 8 times heavier than the original casting, will be

- (a) 10 (b) 20 (c) 24 (d) 40

GATE-2014 (PI)

For a given volume of a riser, if the solidification time of the molten metal in riser needs to be quadrupled, the surface area of the riser should be made

- (a) one-fourth (b) half
(c) double (d) four times

GATE-2014

A cylindrical riser of 6 cm diameter and 6 cm height has to be designed for a sand casting mould for producing a steel rectangular plate casting of 7 cm × 10 cm × 2 cm dimensions having the total solidification time of 1.36 minute. The total solidification time (in minute) of the riser is

GATE-2003

With a solidification factor of $0.97 \times 10^6 \text{ s/m}^2$, the solidification time (in seconds) for a spherical casting of 200 mm diameter is

- (a) 539 (b) 1078 (c) 4311 (d) 3233

IES-2006

According to Chvorinov's equation, the solidification time of a casting is proportional to:

- (a) v^2
(b) v
(c) $1/v$
(d) $1/v^2$

Where, v = volume of casting

GATE – 2010 (PI)

Solidification time of a metallic alloy casting is

- (a) Directly proportional to its surface area
(b) Directly proportional to the specific heat of the cast material
(c) Directly proportional to the thermal diffusivity of the molten metal
(d) Inversely proportional to the pouring temperature.

GATE-2007

Volume of a cube of side 'l' and volume of a sphere of radius 'r' are equal. Both the cube and the sphere are solid and of same material. They are being cast. The ratio of the solidification time of the cube to the same of the sphere is:

- (a) $\left(\frac{4\pi}{6}\right)^3 \left(\frac{r}{l}\right)^6$ (b) $\left(\frac{4\pi}{6}\right) \left(\frac{r}{l}\right)^2$ (c) $\left(\frac{4\pi}{6}\right)^2 \left(\frac{r}{l}\right)^3$ (d) $\left(\frac{4\pi}{6}\right)^2 \left(\frac{r}{l}\right)^4$

GATE -2011 (PI)

In a sand casting process, a sphere and a cylinder of equal volumes are separately cast from the same molten metal under identical conditions. The height and diameter of the cylinder are equal. The ratio of the solidification time of the sphere to that of the cylinder is

- (a) 1.14 (b) 0.87
(c) 1.31 (d) 0.76

GATE-2009 (PI)

A solid cylinder of diameter D and height equal to D, and a solid cube of side L are being sand cast by using the same material. Assuming there is no superheat in both the cases, the ratio of solidification time of the cylinder to the solidification time of the cube is

- (a) $(L/D)^2$
(b) $(2L/D)^2$
(c) $(2D/L)^2$
(d) $(D/L)^2$

• Compare the solidification times for castings of three different shapes of same volume:

- (i) Cubic
(ii) Cylindrical (with height equal to its diameter)
(iii) Spherical

IES - 2012

The ratio of surface area of volume for a unit volume of riser is minimum in case of

- (a) Cylindrical riser
- (b) Spherical riser
- (c) Hemispherical riser
- (d) Cuboids riser

IES 2011 Conventional

- A round casting is 20 mm in diameter and 50 mm in length. Another casting of the same metal is elliptical in cross section, with a major to minor axis ratio of 2, and has the same length and cross-sectional area as the round casting. Both pieces are cast under the same conditions. What is the difference in the solidification times of the two castings ? [10 - Marks]

$$\text{Area of ellipse} = \pi ab$$

$$\begin{aligned} \text{Circumference} &= \pi \left[3(a+b) - \sqrt{(3a+b)(a+3b)} \right] \\ &= 2\pi \sqrt{(a^2 + b^2)/2} \quad (\text{approx.}) \end{aligned}$$

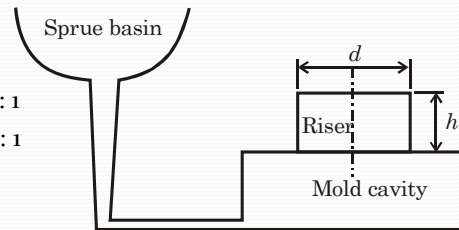
Conventional Question ESE 2003

Compare the solidification time of two optimum side – risers of the same volume with one has cylindrical shape and other is parallopiped. [30 Marks]

GATE-2014

A cylindrical blind riser with diameter d and height h , is placed on the top of the mold cavity of a closed type sand mold as shown in the figure. If the riser is of constant volume, then the rate of solidification in the riser is the least when the ratio $h : d$ is

- (a) 1 : 2 (b) 2 : 1
- (c) 1 : 4 (d) 4 : 1



Modulus Method

- It has been empirically established that if the modulus of the riser exceeds the modulus of the casting by a factor of 1.2, the feeding during solidification would be satisfactory.

$$M_R = 1.2 M_c$$

- Modulus = volume/Surface area
- In steel castings, it is generally preferable to choose a riser with a height-to-diameter ratio of 1.

Contd...

Long bar		$\frac{ab}{2(a+b)}$
Cube		$\frac{D}{6}$
Cylinder		$\frac{D}{6}$
Sphere		$\frac{D}{6}$

Conventional Question IES-2008

- Calculate the size of a cylindrical riser (height and diameter equal) necessary to feed a steel slab casting of dimensions 30 x 30 x 6 cm with a side riser, casting poured horizontally into the mould.

[Use Modulus Method]

[10 - Marks]

Caine's Method

Freezing ratio = ratio of cooling characteristics of casting to the riser.

$$X = \frac{\left(\frac{A}{V}\right)_{\text{Casting}}}{\left(\frac{A}{V}\right)_{\text{Riser}}}$$

The riser should solidify last so $X > 1$

$$\text{According to Caine} \quad X = \frac{a}{Y-b} + c$$

$$Y = \frac{V_{\text{riser}}}{V_{\text{casting}}} \quad \text{and } a, b, c \text{ are constant.}$$

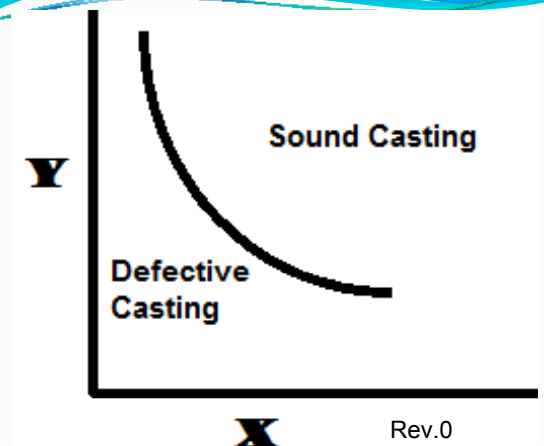


Table: Constants in Caine's Method

	<i>a</i>	<i>b</i>	<i>c</i>
Steel	0.10	0.03	1.00
Aluminium	0.10	0.06	1.08
Cast iron, brass	0.04	0.017	1.00
Grey cast iron	0.33	0.030	1.00
Aluminium bronze	0.24	0.017	1.00
Silicon bronze	0.24	0.017	1.00

Conventional Question IES-2007

- Calculate the size of a cylindrical riser (height and diameter equal) necessary to feed a steel slab casting of dimensions 25 x 25 x 5 cm with a side riser, casting poured horizontally into the mould.

[Use Caine's Method]

[For steel $a = 0.10$, $b = 0.03$ and $c = 1.00$]

Chills

- External chills** are masses of high-heat-capacity, high-thermal-conductivity material that are placed in the mould (adjacent to the casting) to accelerate the cooling of various regions. Chills can effectively promote **directional solidification** or increase the effective feeding distance of a riser. They can often be used to reduce the number of risers required for a casting.
- Internal chills** are pieces of metal that are placed within the mould cavity to absorb heat and promote more rapid solidification. Since some of this metal will melt during the operation, it will absorb not only the heat-capacity energy, but also some heat of fusion. Since they ultimately become part of the final casting, internal chills must be made from the same alloy as that being cast.

IES-1995

Directional solidification in castings can be improved by using

- Chills and chaplets
- Chills and padding
- Chaplets and padding
- Chills, chaplets and padding.

GATE-1998,2007, 2014(PI)

Chills are used in moulds to

- Achieve directional solidification
- Reduce the possibility of blowholes
- Reduce freezing time
- Smoothen metal flow for reducing splatter.

IAS 1994

Chills are used in casting moulds to

- Achieve directional solidification
- Reduce possibility of blow holes
- Reduce the freezing time
- Increase the smoothness of cast surface

Cupola

- Cupola has been the most widely used furnace for melting cast iron.
- In hot blast cupola, the flue gases are used to preheat the air blast to the cupola so that the temperature in the furnace is considerably higher than that in a conventional cupola. Coke is fuel and Lime stone (CaCO_3) is mostly used flux.
- Cost of melting low.
- Main disadvantages of cupola is that it is not possible to produce iron below 2.8% carbon.
- Steel can be also prepared in cupola by employing duplexing and triplexing operations.

IES-1997

Assertion (A): Steel can be melted in hot blast cupola.

Reason (R): In hot blast cupola, the flue gases are used to preheat the air blast to the cupola so that the temperature in the furnace is considerably higher than that in a conventional cupola.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

IES - 2012

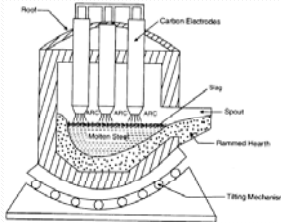
Statement (I): Cupola furnace is not employed for melting steel in foundry

Statement (II): The temperatures generated within a cupola are not adequate for melting Steel

- Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- Statement (I) is true but Statement (II) is false
- Statement (I) is false but Statement (II) is true

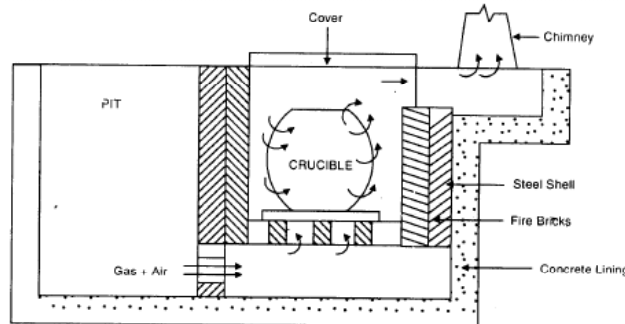
Electric Arc Furnace

- For heavy steel castings, the open-hearth type of furnaces with electric arc or oil fired would be generally suitable in view of the large heat required for melting.
- Electric arc furnaces are more suitable for ferrous materials and are larger in capacity.



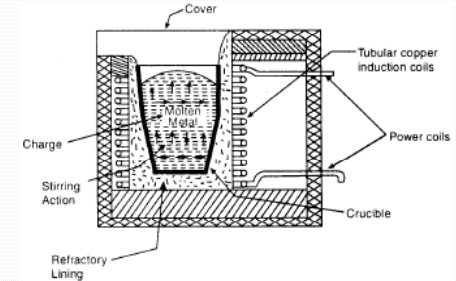
Crucible Furnace or Pot Furnace

- Smaller foundries generally prefer the crucible furnace.
- The crucible is generally heated by electric resistance or gas flame.



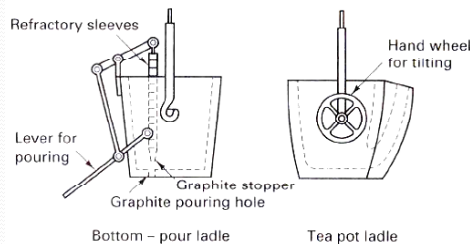
Induction Furnace

- The induction furnaces are used for all types of materials, the chief advantage being that the heat source is isolated from the charge and the slag and flux get the necessary heat directly from the charge instead of the heat source.



Ladles

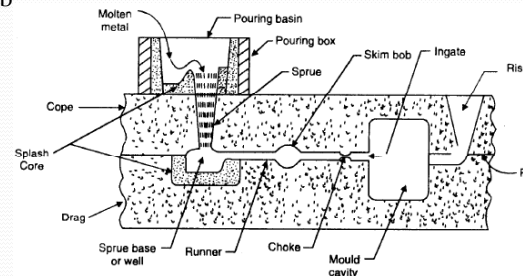
- Two types of ladles used in the pouring of castings.



Casting Cleaning (fettling)

Impurities in the molten metal are prevented from reaching the mould cavity by providing a

- Strainer
- Bottom well
- Skim bob



GATE-1996

Light impurities in the molten metal are prevented from reaching the mould cavity by providing a

- Strainer
- Bottom well
- Skim bob
- All of the above

Pouring time

Time taken to fill the mould with top gate

$$t_A = \frac{A \cdot H}{A_g \sqrt{2gh_m}} \quad \text{Where } \begin{array}{l} A = \text{Area of mould} \\ H = \text{Height of mould} \\ A_g = \text{Area of Gate} \\ H_m = \text{Gate height} \end{array}$$

Time taken to fill the mould with bottom gate

$$t_B = \frac{2A}{A_g \sqrt{2g}} (\sqrt{h_m} - \sqrt{h_m - H})$$

For-2015 (IES, GATE & PSUs)

GATE-2005

A mould has a downsprue whose length is 20 cm and the cross sectional area at the base of the downsprue is 1 cm². The downsprue feeds a horizontal runner leading into the mould cavity of volume 1000 cm³. The time required to fill the mould cavity will be

- 4.05 s
- 5.05 s
- 6.05 s
- 7.25 s

GATE-2006

In a sand casting operation, the total liquid head is maintained constant such that it is equal to the mould height. The time taken to fill the mould with a top gate is t_A . If the same mould is filled with a bottom gate, then the time taken is t_B . Ignore the time required to fill the runner and frictional effects. Assume atmospheric pressure at the top molten metal surfaces. The relation between t_A and t_B is

- $t_B = \sqrt{2} t_A$
- $t_B = 2 t_A$
- $t_B = \frac{t_A}{\sqrt{2}}$
- $t_B = 2\sqrt{2} t_A$

Rev.0

GATE – 2007 (PI) Linked S-1

In a sand casting process, a sprue of 10 mm base diameter and 250 mm height leads to a runner which fills a cubical mould cavity of 100 mm size

The volume flow rate (in mm³/s) is

- (a) 0.8×10^5 (b) 1.1×10^5
(c) 1.7×10^5 (d) 2.3×10^5

GATE – 2007 (PI) Linked S-2

In a sand casting process, a sprue of 10 mm base diameter and 250 mm height leads to a runner which fills a cubical mould cavity of 100 mm size

The mould filling time (in seconds) is

- (a) 2.8 (b) 5.78
(c) 7.54 (d) 8.41

Expression for choke area

$$CA = \frac{m}{c \rho t \sqrt{2gH}} \text{ mm}^2$$

Where m = mass of the casting, kg

ρ = Density of metal, kg / m³

t = pouring time

c = Efficiency factor and is the function of gate system used

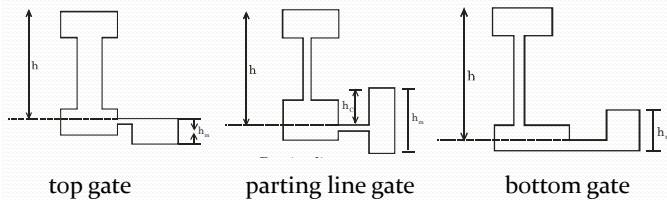
H = Effective head of liquid metal

= h for top gate

Contd...

$$H = h - \frac{h_m}{2} \text{ for bottom gate}$$

$$= h - \frac{h_c^2}{2h_m} \text{ for parting line gate}$$



IES 2009

• 2 marks

What is the shape of a runner for making a sand mould ? On what considerations is this shape selected ?

IAS-2011 Main

Sketch a mould for two hollow components to be cast. On the diagram, indicate runner, gate, riser, core, cope, sprue, pouring basin, sprue well, drag, parting line.

[10-Marks]

IES-2013

When an alloy solidifies over a range of temperature, the resulting casting structure is:

- (a) Wholly equi-axed
(b) Wholly columnar
(c) Partially columnar partially equi-axed
(d) Dendritic

For-2015 (IES, GATE & PSUs)

Casting Defects

The following are the major defects, which are likely to occur in sand castings:

- Gas defects
- Shrinkage cavities
- Molding material defects
- Pouring metal defects
- Mold shift.

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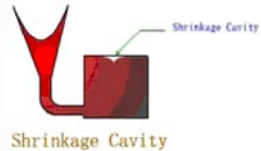
Gas Defects

- A condition existing in a casting caused by the trapping of gas in the molten metal or by mold gases evolved during the pouring of the casting.
- The defects in this category can be classified into blowholes and pinhole porosity.
- Blowholes are spherical or elongated cavities present in the casting on the surface or inside the casting.
- Pinhole porosity occurs due to the dissolution of hydrogen gas, which gets entrapped during heating of molten metal.

Rev.0

Shrinkage Cavities

- These are caused by liquid shrinkage occurring during the solidification of the casting.
- To compensate for this, proper feeding of liquid metal is required. For this reason risers are placed at the appropriate places in the mold.
- Sprues may be too thin, too long or not attached in the proper location, causing shrinkage cavities.
- It is recommended to use thick sprues to avoid shrinkage cavities.

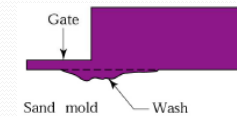


Molding Material Defects

- Cuts and washes,
- Scab
- Metal penetration,
- Fusion, and
- Swell

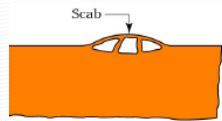
Cut and washes

- These appear as rough spots and areas of excess metal, and are caused by erosion of molding sand by the flowing metal.
- This is caused by the molding sand not having enough strength and the molten metal flowing at high velocity.
- The former can be taken care of by the proper choice of molding sand and the latter can be overcome by the proper design of the gating system.



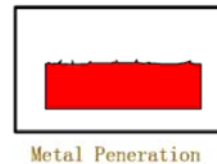
Scab

- This defect occurs when a portion of the face of a mould lifts or breaks down and the recess thus made is filled by metal.
- When the metal is poured into the cavity, gas may be disengaged with such violence as to break up the sand, which is then washed away and the resulting cavity filled with metal.
- The reasons can be: - too fine sand, low permeability of sand, high moisture content of sand and uneven mould ramming.



Metal penetration

- When molten metal enters into the gaps between sand grains, the result is a rough casting surface.
- This occurs because the sand is coarse or no mold wash was applied on the surface of the mold. The coarser the sand grains more the metal penetration.



Fusion

- This is caused by the fusion of the sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface.
- The main reason for this is that the clay or the sand particles are of lower refractoriness or that the pouring temperature is too high.

Swell

Under the influence of metallostatic forces, the mold wall may move back causing a swell in the dimension of the casting. A proper ramming of the mold will correct this defect.

Inclusions

Particles of slag, refractory materials sand or deoxidation products are trapped in the casting during pouring solidification. The provision of choke in the gating system and the pouring basin at the top of the mold can prevent this defect

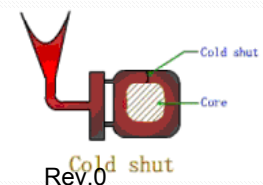
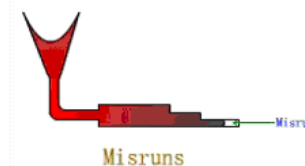
For-2015 (IES, GATE & PSUs)

Pouring Metal Defects

The likely defects in this category are

- Mis-runs and
- Cold shuts
- A **mis-run** is caused when the metal is unable to fill the mold cavity completely and thus leaves unfilled cavities.
- A **cold shut** is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting.

- The mis-run and cold shut defects are caused either by a lower fluidity of the mold or when the section thickness of the casting is very small. Fluidity can be improved by changing the composition of the metal and by increasing the pouring temperature of the metal.



GATE-2014

Match the casting defects (Group A) with the probable causes (Group B):

Group A	Group B
P: Hot tears	1: Improper fusion of two streams of liquid metal
Q: Shrinkage	2: Low permeability of the sand mould
R: Blow holes	3: Volumetric contraction both in liquid and solid stage
S: Cold Shut	4: Differential cooling rate

P	Q	R	S	P	Q	R	S
(a) 1	3	2	4	(b) 4	3	2	1
(c) 3	4	2	1	(d) 1	2	4	3

GATE-2004

Misrun is a casting defect which occurs due to

- (a) Very high pouring temperature of the metal
- (b) Insufficient fluidity of the molten metal
- (c) Absorption of gases by the liquid metal
- (d) Improper alignment of the mould flasks

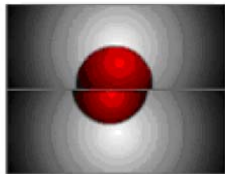
GATE-2009

Two streams of liquid metal which are not hot enough to fuse properly result into a casting defect known as

- (a) Cold shut
- (b) Swell
- (c) Sand wash
- (d) Scab

Mold Shift

The mold shift defect occurs when cope and drag or molding boxes have not been properly aligned.



Mismatch

Metallurgical defects

- **Hot tears or hot cracking**, cause of this defect is that stresses and strains built up during solidification are too high compared to the actual strength of the semisolid material. This type of defects occurs in the lower part of the solidification range, close to the solidus, when the alloy has a wide solidification temperature range and a small amount of liquid, when the solid fraction is more than 0.9, the hot tearing is easy to occur. Proper mould design prevents this type of defect.
- **Hot spots** are areas on the surface of casting that become very hard because they cooled more quickly than the surrounding material.

GATE-2014

The hot tearing in a metal casting is due to

- (a) high fluidity
- (b) high melt temperature
- (c) wide range of solidification temperature
- (d) low coefficient of thermal expansion

IES-2001

Scab is a

- (a) Sand casting defect
- (b) Machining defect
- (c) Welding defect
- (d) Forging defect

IAS-2004

Match List-I (Casting Defects) with List-II (Explanation) and select the correct answer using the codes given below the lists:

List-I (Casting Defects)	List-II (Explanation)
A. Metallic projections	1. Consist of rounded or rough internal or exposed cavities including blow holes and pin holes
B. Cavities	2. Formed during melting, solidification and moulding.
C. Inclusions	3. Includes single folds, laps, scars adhering sand layers and oxide scale
D. Discontinuities	4. Include cracks, cold or hot tearing and cold shuts
	5. Consist of fins, flash or massive projections and rough surfaces
Codes: A B C D	A B C D
(a) 1 5 3 2	(b) 1 5 2 4
(c) 5 1 2 4	(d) 5 1 3 2

GATE-2003

Hardness of green sand mould increases with

- (a) Increase in moisture content beyond 6 percent
- (b) Increase in permeability
- (c) Decrease in permeability
- (d) Increase in both moisture content and permeability

IES-1998

Assertion (A): Stiffening members, such as webs and ribs, used on a casting should be liberally provided.

Reason (R): They will provide additional strength to a cast member.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2005

In gating system design, which one of the following is the correct sequence in which choke area, pouring time, pouring basin and sprue sizes are calculated?

- (a) Choke area - Pouring time - Pouring basin - Sprue
- (b) Pouring basin - Sprue - Choke area - Pouring time
- (c) Choke area - Sprue - Pouring basin - Pouring time
- (d) Pouring basin - Pouring time - Choke area - Sprue

IES-1997

If the melting ratio of a cupola is 10: 1, then the coke requirement for one ton melt will be

- (a) 0.1 ton
- (b) 10 tons
- (c) 1 ton
- (d) 11 tons

IES-2009

In which one of the following furnaces most of the non-ferrous alloys are melted?

- (a) Reverberatory furnace
- (b) Induction furnace
- (c) Crucible furnace
- (d) Pot furnace

IAS-2001

Which of the following pattern-materials are used in Precision Casting?

- 1. Plaster of Paris
- 2. Plastics
- 3. Anodized Aluminium Alloy
- 4. Frozen Mercury

Select the correct answer using the codes given below:

- (a) 1 and 2 (b) 2 and 4 (c) 3 and 4 (d) 1 and 3

IAS-2004

Which one of the following gating systems is best suited to obtain directional solidification?

- (a) Top gating
- (b) Part-line gating
- (c) Bottom gating
- (d) Stepped gating

Cast Aluminium Code

- Four digit identification system
- First digit indicates alloy group
 - 1 – Aluminium, 99% or more
 - 2 – copper
 - 3 – Silicon, with copper and/or magnesium
 - 4 – silicon
 - 5 – magnesium
 - 6 – not used
 - 7 – zinc
 - 8 – tin
 - 9 – other elements

For 2015 (IES, GATE & PSUs)

Cast Aluminium Code

Contd..

- Second two digits identify the aluminium alloy or indicate the aluminium purity.
- The last digit is separating from the other three by a decimal point and indicates the product form; that is, castings or ingots
- A modification of the original alloy is indicated by a serial letter before the numerical designation.
- Alloy A514.0 indicates an aluminium alloy casting with magnesium as the principal alloy. One modification to the original alloy has made, as indicated by the letter A.

IES 2011

In the designation of Aluminium casting A514.0 indicates :

- (a) Aluminium purity
- (b) Aluminium content
- (c) Percentage of alloy element
- (d) Magnesium Content

Ans. (d)

Special Casting

By S K Mondal

Shell Moulding

- The sand is mixed with a thermosetting resin is allowed to come in contact with a heated metal pattern (200°C).
- A skin (shell) of about 3.5 mm of sand and plastic mixture adhere to the pattern.
- Then the shell is removed from the pattern.
- The cope and drag shells are kept in a flask with necessary backup material and the molten metal is poured into the mold.

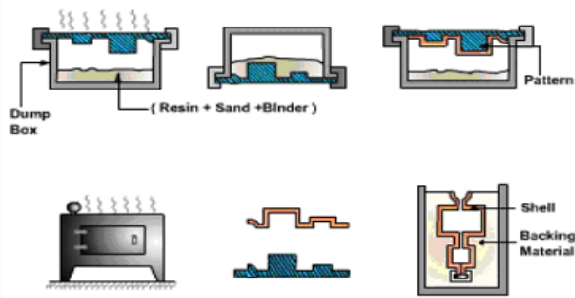
- Can produce complex parts.
- A good surface finish and good size tolerance reduce the need for machining.
- Materials can be cast: CI, Al and Cu alloys.

Molding Sand in Shell Molding

- The molding sand is a mixture of fine grained quartz sand and powdered bakelite.
- Cold coating and Hot coating methods are used for coating the sand grains with bakelite.
- **Cold coating:** quartz sand is poured into the mixer and then the solution of powdered bakelite in acetone and ethyl aldehyde are added. (mixture is 92% quartz sand, 5% bakelite, 3% ethylaldehyde)

Contd...

- **Hot coating:** the mixture is heated to 150°C– 180°C prior to loading the sand. In the course of sand mixing, the soluble phenol formaldehyde resin is added. The mixer is allowed to cool up to 80 – 90° C. Hot coting gives better properties to the mixtures than cold method.



Shell moulding process

Advantages

- Dimensional accuracy.
- Smoother surface finish. (Due to finer size grain used)
- Very thin sections can be cast.
- Very small amount of sand is needed.

Limitations

- Expensive pattern
- Small size casting only.
- Highly complicated shapes cannot be obtained.
- More sophisticated equipment is needed for handling the shell moldings.

Applications

- Cylinders and cylinder heads for air- cooled IC engines
- Automobile transmission parts.
- Piston rings

IES 2010

Consider the following advantages of shell mould casting:

1. Close dimensional tolerance.
2. Good surface finish.
3. Low cost.
4. Easier.

Which of these are correct?

- (a) 1, 2 and 3 only (b) 2, 3 and 4 only
(c) 1, 2 and 4 only (d) 1, 2, 3 and 4

IES-1996

Consider the following ingredients used in moulding:

1. Dry silica sand
2. Clay
3. Phenol formaldehyde
4. Sodium silicate

Those used for shell mould casting include

- (a) 1, 2 and 4 (b) 2, 3 and 4
(c) 1 and 3 (d) 1, 2, 3 and 4

IES-2005

In shell moulding, how can the shell thickness be accurately maintained?

- (a) By controlling the time during which the pattern is in contact with mould
(b) By controlling the time during which the pattern is heated
(c) By maintaining the temperature of the pattern in the range of $175^{\circ}\text{C} - 380^{\circ}\text{C}$
(d) By the type of binder used

IES-2006

Shell moulding can be used for:

- (a) Producing milling cutters
(b) Making gold ornaments
(c) Producing heavy and thick walled casting
(d) Producing thin casting

IES 2007

Which of the following are employed in shell moulding?

1. Resin binder 2. Metal pattern 3. Heating coils
Select the correct answer using the code given below:
(a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

IAS-2007

The mould in shell moulding process is made up of which of the following?

- (a) Gypsum + setting agents
(b) Green sand + clay
(c) Sodium silicate + dried sand
(d) Dried silica + phenolic resin

IAS-1999

Match List I (Moulding Process) with List II (Binding Agent) and select the correct answer using the codes given below the lists:

- | | |
|----------------------------|---------------------|
| List I | List II |
| A. Green sand | 1. Silicate |
| B. Core sand | 2. Organic |
| C. Shell moulding | 3. Clay |
| D. CO ₂ process | 4. Plaster of Paris |
| | 5. Plastic |

- | | | | | | | | | |
|---------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Codes: | A | B | C | D | A | B | C | D |
| (a) | 3 | 2 | 5 | 1 | (b) | 3 | 2 | 4 |
| (c) | 2 | 3 | 5 | 4 | (d) | 2 | 3 | 4 |

For-2015 (IES, GATE & PSUs)

Investment Casting

Investment casting process or lost wax process

Basic steps:

1. Produce expendable wax, plastic, or polystyrene patterns.
2. Assemble these patterns onto a gating system
3. Investing or covering the pattern assembly with refractory slurry
4. Melting the pattern assembly to remove the pattern material
5. Firing the mould to remove the last traces of the pattern material
6. Pouring molten metal
7. Knockout, cutoff and finishing.

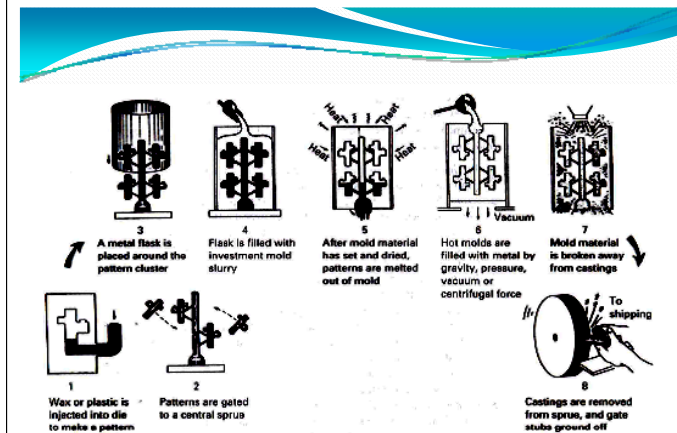
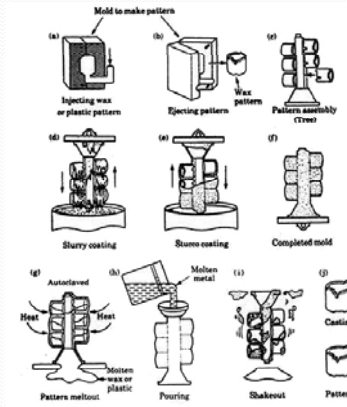


Fig. Investment flask-casting procedure

Ceramic Shell Investment Casting

- In ceramic shell investment casting a ceramic shell is built around a tree assembly by repeatedly dipping a pattern into a slurry (refractory material such as zircon with binder).
- After each dipping and stuccoing is completed, the assembly is allowed to thoroughly dry before the next coating is applied.



IES 2009

- 2 marks

In investment casting process two types of ceramic slurries are used. Why do we use them and in what sequence are they applied ?

Advantages

- Tight dimensional tolerances
- Excellent surface finish (1.2 to 3.0 μm)
- Machining can be reduced or completely eliminated
- High melting point alloy can be cast, almost any metal can be cast
- Almost unlimited intricacy

Limitations

- Costly patterns and moulds
- Labour costs can be high
- Limited size

Applications

- Aerospace and rocket components.
- Vanes and blades for gas turbines.
- Surgical instruments

IES 2011

The proper sequence of investment casting steps is :

- Slurry coating – pattern melt out-Shakeout – Stucco coating
- Stucco coating – Slurry coating – Shakeout – Pattern melt out
- Slurry coating – Stucco coating – Pattern melt out – Shakeout
- Stucco coating – Shakeout – Slurry coating – Pattern melt out

GATE-2006

An expendable pattern is used in

- Slush casting
- Squeeze casting
- Centrifugal casting
- Investment casting

GATE-2011 (PI)

Which of the following casting processes uses expendable pattern and expendable mould?

- Shell mould casting
- Investment casting
- Pressure die casting
- Centrifugal casting

ISRO-2010

Investment casting is used for

- (a) Shapes which are made by difficulty using complex patterns in sand casting
- (b) Mass production
- (c) Shapes which are very complex and intricate and can't be cast by any other method
- (d) There is nothing like investment casting

IES-1992

The most preferred process for casting gas turbine blades is:

- (a) Die moulding
- (b) Shell moulding
- (c) Investment moulding
- (d) Sand casting

JWM 2010

Consider the following materials :

- 1. Wax
- 2. Wood
- 3. Plastic

Which of these materials can be used as pattern in investment casting process ?

- (a) 1, 2 and 3
- (b) 1 and 2 only
- (c) 2 and 3 only
- (d) 1 and 3 only

IES 2010

Assertion (A): The investment casting is used for precision parts such as turbine plates, sewing machines etc.

Reason (R): The investment castings have a good surface finish and are exact reproductions of the master pattern.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES 2007

Consider the following statements in respect of investment castings:

- 1. The pattern or patterns is/are not joined to a stalk or sprue also of wax to form a tree of patterns.
- 2. The prepared moulds are placed in an oven and heated gently to dry off the invest and melt out the bulk of wax.
- 3. The moulds are usually poured by placing the moulds in a vacuum chamber. Which of the statements given above are correct?

- (a) 1 and 2 only
- (b) 1 and 3 only
- (c) 2 and 3 only
- (d) 1, 2 and 3

IES-2006

Which of the following materials are used for making patterns in investment casting method?

- 1. Wax 2. Rubber 3. Wood 4. Plastic

Select the correct answer using the codes given below:

- (a) Only 1 and 3
- (b) Only 2 and 3
- (c) Only 1, 2 and 4
- (d) Only 2, 3 and 4

IAS-1996

Light and intricate parts with close dimensional tolerances of the order of ± 0.005 mm are produced by

- (a) Investment casting
- (b) Die casting
- (c) Centrifugal casting
- (d) Shell mould casting

Permanent Mould Casting

- The process in which we use a die to make the castings is called permanent mold casting or gravity die casting, since the metal enters the mold under gravity.
- Some time in die-casting we inject the molten metal with a high pressure. When we apply pressure in injecting the metal it is called pressure die casting process.
- Grey cast iron is used for mould material.

Advantages

- Good surface finish and dimensional accuracy
- Metal mold gives rapid cooling and fine-grain structure
- Multiple-use molds.

Disadvantages

- High initial mold cost
- Shape, size, and complexity are limited
- Mold life is very limited with high-melting-point metals such as steel.
- Low melting point metals can be cast
 - Aluminum
 - Zinc
 - Magnesium alloys
 - Brass
 - Cast iron

Applications

- Pistons/cylinders/rods
- Gears
- Kitchenware

IES-2013

Statement (I): Mould walls of a permanent mould are kept thick.

Statement (II): The thicker mould walls retain maximum heat increasing flow of molten metal.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- (b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- (c) Statement (I) is true but Statement (II) is false
- (d) Statement (I) is false but Statement (II) is true

Die Casting

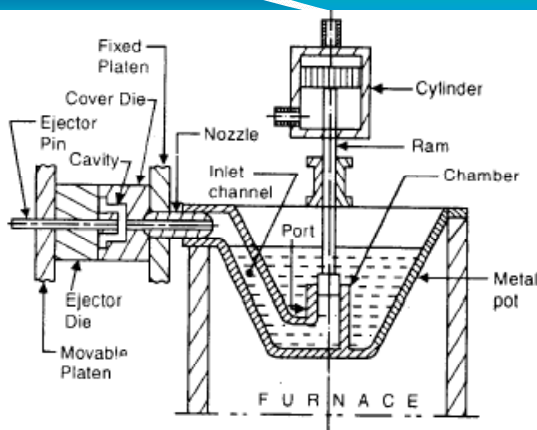
- Molten metal is injected into closed metal dies under pressures ranging from 100 to 150 MPa.
- Pressure is maintained during solidification
- After which the dies separate and the casting is ejected along with its attached sprues and runners.
- Cores must be simple and retractable and take the form of moving metal segments

Die casting machines can be

- Hot chamber
- Cold chamber

Hot chamber machines are

- Good for low temperature (approx. 400°C)
- Faster than cold chamber machines
- Cycle times must be short to minimize metal contamination
- Metal starts in a heated cylinder
- A piston forces metal into the die
- The piston retracts, and draws metal in
- **Metal: Lead, Tin, Zinc**

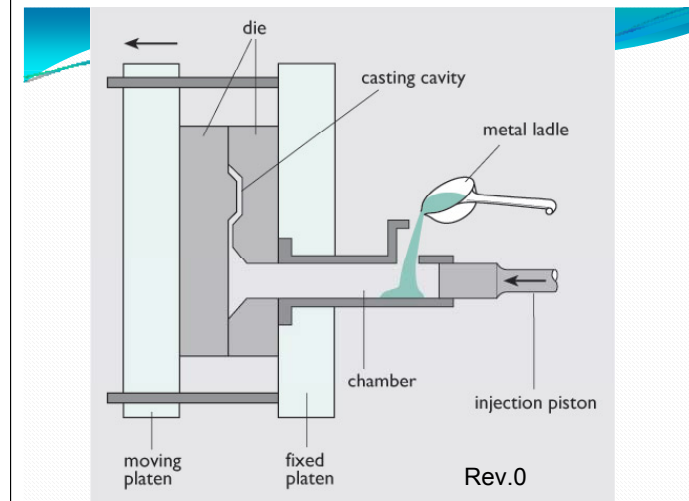


For-2015 (IES, GATE & PSUs)
Hot Chamber

Cold chamber machines

- Casts high melting point metals ($> 600^{\circ}\text{C}$)
- High pressures used
- Metal is heated in a separate crucible
- Metal is ladled into a cold chamber
- The metal is rapidly forced into the mold before it cools
- Copper, Brass and Aluminium can cast.

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Advantages

- Extremely smooth surfaces ($1\text{ }\mu\text{m}$)
- Excellent dimensional accuracy
- Rapid production rate
- Better mechanical properties compared to sand casting
- Intricate parts possible
- Minimum finishing operations
- Thin sections possible

Limitations

- High initial die cost
- Limited to high-fluidity nonferrous metals
- Part size is limited
- **Porosity may be a problem**
- Some scrap in sprues, runners, and flash, but this can be directly recycled

➤ Applications

- Carburettors
- Automotive parts
- Bathroom fixtures
- Toys

➤ Common metals

- Alloys of aluminum, zinc, magnesium, and lead
- Also possible with alloys of copper and tin

IES 2011

Consider the following advantages of die casting over sand casting :

1. Rapidity of the process
2. Smooth surface
3. Strong dense metal structure

Which of these advantages are correct ?

- (a) 1, 2 and 3
- (b) 1 and 2 only
- (c) 2 and 3 only
- (d) 1 and 3 only

IES-2009

Which of the following are the most suitable materials for die casting?

- (a) Zinc and its alloys
- (b) Copper and its alloys
- (c) Aluminium and its alloys
- (d) Lead and its alloys

JWM 2010

Assertion (A) : In die casting method, small thickness can be filled with liquid metal.

Reason (R) : The air in die cavity trapped inside the casting causes problems.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2005

Which one of the following processes produces a casting when pressure forces the molten metal into the mould cavity?

- (a) Shell moulding
- (b) Investment casting
- (c) Die casting
- (d) Continuous casting

IES-2006

In which of the following are metal moulds used?

- (a) Greensand mould
- (b) Dry sand mould
- (c) Die casting process
- (d) Loam moulding

IES-1995

Assertion (A): An aluminium alloy with 11 % silicon is used for making engine pistons by die casting technique.

Reason (R): Aluminium has low density and addition of silicon improves its fluidity and therefore its castability.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-1995

Match List I with List II and select the correct answer taking the help of codes given below the lists:

List I (Products)

- Automobile piston in aluminium alloy
- Engine crankshaft in spheroidal graphite iron
- Carburettor housing in aluminium alloy
- Cast titanium blades

List II

(Process of manufacture)

- Pressure die-casting
- Gravity die-casting
- Sand casting
- Precision investment casting
- Shell moulding

Code:	A	B	C	D		A	B	C	D
(a)	2	3	1	5	(b)	3	2	1	5
(c)	2	1	3	4	(d)	4	1	2	3

IAS-2007

Consider the following statements:

- Zinc die castings have low strength.
- In the die casting process, very thin sections or complex shapes can be obtained easily.

Which of the statements given above is/are correct?

- 1 only
- 2 only
- Both 1 and 2
- Neither 1 nor 2

IAS-1996

Assertion (A): Die casting yields a product of good accuracy and finish.

Reason (R): Low melting alloys used in die casting.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

IES 2011

Consider the following statements :

- Hot chamber machine is used for casting zinc, tin and other low melting alloys.
- Cold chamber machine is used for die casting of ferrous alloys
- Rapid cooling rate in die casting produces high strength and quality in many alloys.

Which of these statements are correct?

- 1, 2 and 3
- 1 and 2 only
- 2 and 3 only
- 1 and 3 only

GATE-2007

Which of the following engineering materials is the most suitable candidate for hot chamber die casting?

- Low carbon steel
- Titanium
- Copper
- Tin

IES-1995

Assertion (A): Aluminium alloys are cast in hot chamber die casting machine.

Reason (R): Aluminium alloys require high melting when compared to zinc alloys.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

GATE -2009 (PI)

Hot chamber die casting process is NOT suited for

- Lead and its alloy
- Zinc and its alloy
- Tin and its alloy
- Aluminum and its alloy

Centrifugal Casting

- Process:** Molten metal is introduced into a rotating sand, metal, or graphite mould, and held against the mould wall by centrifugal force until it is solidified
- A mold is set up and rotated along a vertical (rpm is reasonable), or horizontal (200-1000 rpm is reasonable) axis.
- The mold is coated with a refractory coating.
- During cooling lower density impurities will tend to rise towards the center of rotation.

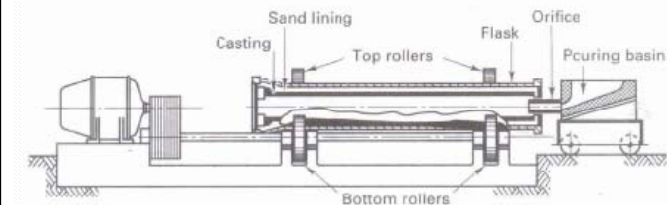


Fig. True centrifugal casting
Rev.0

Properties

- The mechanical properties of centrifugally cast jobs are better compared to other processes, because the inclusions such as slag and oxides get segregated towards the centre and can be easily removed by machining. Also, the pressure acting on the metal throughout the solidification causes the porosity to be eliminated giving rise to dense metal.
- No cores are required for making concentric holes in the case of true centrifugal casting.

Advantages

- Fine grained structure at the outer surface of the casting free of gas and shrinkage cavities and porosity
- Formation of hollow interiors in cylinders without cores
- Can produce a wide range of cylindrical parts, including ones of large size.
- Good dimensional accuracy, soundness, and cleanliness
- There is no need for gates and runners, which increases the casting yield, reaching almost 100 %.

Limitations

- More segregation of alloy component during pouring under the forces of rotation
- Contamination of internal surface of castings with non-metallic inclusions
- Inaccurate internal diameter
- Shape is limited.
- Spinning equipment can be expensive
- Poor machinability

Common metals

- Iron
- steel
- stainless steel
- alloys of aluminium, copper, and nickel

GATE-2002

In centrifugal casting, the impurities are

- (a) Uniformly distributed
- (b) Forced towards the outer surface
- (c) Trapped near the mean radius of the casting
- (d) Collected at the centre of the casting

GATE-1993

Centrifugally cast products have

- (a) Large grain structure with high porosity
- (b) Fine grain structure with high density
- (c) Fine grain structure with low density
- (d) Segregation of slug towards the outer skin of the casting

GATE -2008 (PI)

In hollow cylindrical parts, made by centrifugal casting, the density of the part is

- (a) maximum at the outer region
- (b) maximum at the inner region
- (c) maximum at the mid-point between outer and inner surfaces
- (d) uniform throughout

IES-2008

Which of the following casting processes does not /do not require central core for producing pipe?

1. Sand casting process
2. Die casting process
3. Centrifugal casting process

Select the correct answer using the code given below:

- (a) 1 and 2
- (b) 2 only
- (c) 2 and 3
- (d) 3 only

IES-2009

Which one of the following casting processes is best suited to make bigger size hollow symmetrical pipes?

- (a) Die casting
- (b) Investment casting
- (c) Shell moulding
- (d) Centrifugal casting

Rev.0

IES 2007

Which one of the following is the correct statement?

In a centrifugal casting method

- (a) No core is used
- (b) Core may be made of any metal
- (c) Core is made of sand
- (d) Core is made of ferrous metal

IES-1998

Poor machinability of centrifugally cast iron pipe is due to

- (a) Chilling
- (b) Segregation
- (c) Dense structure
- (d) High mould rotation speed

IES-2009

Which of the following are the most likely characteristics in centrifugal casting?

- (a) Fine grain size and high porosity
- (b) Coarse grain size and high porosity
- (c) Fine grain size and high density
- (d) Coarse grain size and high density

IES 2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I
(Casting Process)

- A. Die casting
- B. Investment casting
- C. Shell moulding
- D. Centrifugal casting

List II
(Principle)

- 1. The metal solidifies in a rotating mould
- 2. The pattern cluster is repeatedly dipped into a ceramic slurry and dusted with refractory
- 3. Molten metal is forced by pressure into a metallic mould
- 4. After cooling, the invest is removed from the Casting by pressure jetting or vibratory cleaning

Code:	A	B	C	D
(a)	2	1	3	4
(b)	3	4	2	1
(c)	2	4	3	1

IES-2000

Match List I (Process) with List II (Products/materials) and select the correct answer using the codes given below the Lists:

List I

- A. Die casting
- B. Shell molding
- C. CO₂ molding
- D. Centrifugal casting

List II

- 1. Phenol formaldehyde
- 2. C.I. pipes
- 3. Non-ferrous alloys
- 4. Sodium silicate

Codes:	A	B	C	D
(a)	1	3	4	2
(b)	3	1	4	2
(c)	3	1	2	4

IAS-2004

Match List-I (Name of the Process) with List-II (Advantage) and select the correct answer using the codes given below the lists:

List-I

(Name of the Process)

- A. Sand Casting
- B. Ceramic mold casting
- C. Die casting
- D. Centrifugal casting

List-II

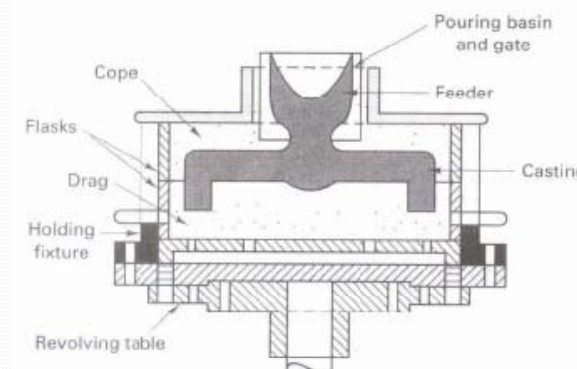
(Advantage)

- 1. Large cylindrical parts with good quality
- 2. Excellent dimensional accuracy and surface finish
- 3. Intricate shapes and close tolerance parts
- 4. Almost any metal is cast and there if no limit to size, shape and weight
- 5. Good dimensional accuracy, finish and low porosity

Codes:	A	B	C	D
(a)	2	3	5	1
(b)	4	1	2	3
(c)	2	1	5	3
(d)	4	3	2	1

Semi-centrifugal Casting

- Centrifugal force assists the flow of metal from a central reservoir to the extremities of a rotating symmetrical mold, which may be either expendable or multiple-use
- Rotational speeds are lower than for true centrifugal casting
- Cores can be used to increase the complexity of the product.



Page 30 of 240
Fig. Semi-centrifugal casting

IAS-2003

Assertion (A): Semi-centrifugal casting process is similar to true centrifugal casting except that the central core is used in it to form inner surface.

Reason (R): In semi-centrifugal casting process the axis of spin is always vertical

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2013

Statement (I): In semi centrifugal casting a particular shape of the casting is produced by mould, core and the centrifugal force of molten metal.

Statement (II): The centrifugal force aids to proper feeding to produce the casting free from porosity.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- (b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- (c) Statement (I) is true but Statement (II) is false
- (d) Statement (I) is false but Statement (II) is true

Centrifuging

- Uses centrifuging action to force the metal from a central pouring reservoir into separate mold cavities that are offset from the axis of rotation.
- Low speed
- May used to assist in the pouring of investment casting trees.

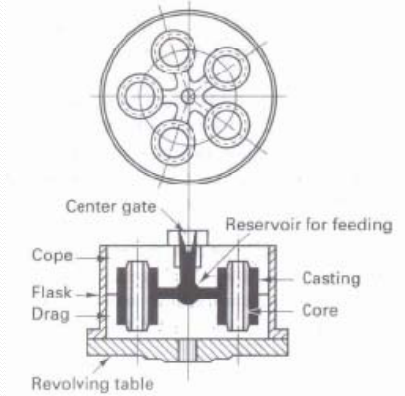


Fig. Method of casting by the centrifuging process

IES-2000

Match List I (Type of casting) with List II (Working principles) and select the correct answer using the codes given below the Lists:

List I

- A. Die casting
B. Centrifugal casting
C. Centrifuging
D. Continuous casting

List II

1. Molten metal is forced into the die under pressure
2. Axis of rotation does not coincide with axis of mould
3. Metal solidifies when mould is rotating
4. Continuously pouring molten metal into mould

Codes:	A	B	C	D	A	B	C	D
(a)	1	3	2	4	(b)	4	3	2
(c)	1	2	3	4	(d)	4	2	3

Dry Sand Molding

- To reduce gas forming materials air dried mould used.

Types:

- 1.Skin drying and
- 2.Complete mold drying

Slush Casting

- Slush casting is a variation of the permanent mold process in which the metal is permitted to remain in the mold only until a shell of the desired thickness has formed.
- The mold is then inverted and the remaining liquid is poured out.
- When the mold halves are separated, the resulting casting is a hollow shape with good surface detail but variable wall thickness.
- Frequently used to cast low-melting-temperature metals into ornamental objects such as candlesticks, lamp bases, and statuary.

IAS-2004

Which of the following are produced by slush casting?

- (a) Hollow castings with thick walls
(b) Hollow castings with thin walls
(c) Thin castings
(d) Thick castings

IES 2011

The method of casting for producing ornamental pieces are:

- (a) Slush and gravity casting
(b) Pressed and slush casting
(c) Gravity and semi permanent mould casting
(d) Semi permanent mould and pressed casting

IES - 2012

The process of making hollow castings of non-circular shape and desired thickness by permanent mould without the use of cores is known as

- (a) Die casting
(b) Slush casting
(c) Pressed casting
(d) Centrifugal casting

Squeeze Casting

Process:

1. Molten metal is poured into an open face die.
 2. A punch is advanced into the die, and to the metal.
 3. Pressure (less than forging) is applied to the punch and die while the part solidifies.
 4. The punch is retracted, and the part is knocked out with an ejector pin.
- Overcomes problems with feeding the die, and produces near net, highly detailed parts.

IAS-2002

Match List I (Casting Process) with List II (Applications) and select the correct answer using the codes given below the Lists:

List I

(Casting Process)

- A. Centrifugal casting
- B. Squeeze casting
- C. Die Casting

List II

(Applications)

1. Carburetor
2. Pipes
3. Wheels for automobiles
4. Gear housings

Codes: A B C

- (a) 2 3 1
(c) 2 1 3

A B C

- (b) 4 1 3
(d) 4 3 1

Single Crystal Casting

The process is effectively:

1. Prepare a mold so that one end is a heated oven, and the other end chilled. The part should be oriented so that the cooling happens over the longest distance.
2. Cast metal into the mold
3. Solidification will begin at the chill plate. These dendrites will grow towards the heated end of the part as long dendritic crystals. The part is slowly pulled out of the oven, past the chill plate.
4. Remove the solidified part.

- Creep and thermal shock resistance properties.

IES 2009

What is achieved by using a metallic single crystal casting ? Give one application of a single crystal casting made of wasp alloy.

2 marks

Plaster Casting

- **Process:** A slurry of plaster, water, and various additives is added to a pattern and allowed to set. The pattern is removed and the mould is baked to remove excess water. After pouring and solidification, the mould is broken and the casting is removed.
- **Advantage:** High dimensional accuracy and smooth surface finish, thin sections and intricate detail can produce.
- **Limitations:** Lower-temperature nonferrous metals only:
- **Common metals:** Primarily aluminium and copper

Pit Moulding

- This method is used for very large castings and is done on the foundry floor.

IES-1996

Which of the following pairs are correctly matched?

1. Pit mouldingFor large jobs.
2. Investment moulding ... Lost wax process.
3. Plaster moulding Mould prepared in gypsum.

- (a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

Loam Moulding

- Moulding loam is generally artificially composed of common brick-clay, and sharp sand.
- Loam means mud.
- Loam Moulding is restricted to forms which cannot be cast conveniently in any other process.
- It is costly.

IES-1997

Which one of the following pairs is not correctly matched?

- (a) Aluminium alloy pistonPressure die casting
- (b) Jewellery..... Lost wax process
- (c) Large pipesCentrifugal casting
- (d) Large bellsLoam moulding

GATE-1998

List I

- (A) Sand casting circular shapes only
- (B) Plaster mould casting skins and soft interior
- (C) Shell mould casting processing
- (D) Investment casting

List II

- (1) Symmetrical and
- (2) Parts have hardened
- (3) Minimum post-
- (4) Parts have a tendency to warp
- (5) Parts have soft skin and hard interior
- (6) Suitable only for non-ferrous metals

GATE-1992

Match the following moulding/casting processes with the product:

Moulding/Casting processes

- (A) Slush casting
- (B) Shell moulding
- (C) Dry sand moulding
- (D) Centrifugal casting

Product

- (P) Turbine blade
- (Q) Machine tool bed
- (R) Cylinder block
- (S) Hollow castings like lamp shades
- (T) Rain water pipe
- (U) Cast iron shoe brake

GATE-1996

List I

- (A) Rivets for aircraft body
- (B) Carburettor body
- (C) Crankshafts
- (D) Nails

List II

- 1. Forging
- 2. Cold heading
- 3. Aluminium-based alloy
- 4. Pressure die casting
- 5. Investment casting

IES-2003

Match List I (Products) with List II (Casting Process) and select the correct answer using the codes given below the Lists:

List I (Products)

- A. Hollow statues
- B. Dentures
- C. Aluminium alloy pistons
- D. Rocker arms

List II (Casting Process)

- 1. Centrifugal Casting
- 2. Investment Casting
- 3. Slush Casting
- 4. Shell Moulding
- 5. Gravity Die Casting

Codes: A	B	C	D	A	B	C	D
(a) 3	2	4	5	(b) 1	3	4	5
(c) 1	2	3	4	(d) 3	2	5	4

IES-1993

Match the items of List I (Equipment) with the items of List II (Process) and select the correct answer using the given codes.

List I (Equipment)

- P - Hot Chamber Machine
- Q - Muller
- R - Dielectric Baker
- S - Sand Blaster

List II (Process)

- 1. Cleaning
- 2. Core making
- 3. Die casting
- 4. Annealing
- 5. Sand mixing
- (b) P-4, Q-2, R-3, S-5
- (d) P-3, Q-5, R-2, S-1

- (a) P-2, Q-1, R-4, S-5
- (c) P-4, Q-5, R-1, S-2

IAS-2004

Match List-I (Name of the Casting Process) with List-II (Process Definition) and select the correct answer using the codes given below the lists:

List-I (Name of the Casting Process)

- A. Die casting
- B. Electroslog casting
- C. Centrifugal casting
- D. Precision casting

List-II (Process Definition)

- 1. This process involves use of a mould made of Dried silica sand and phenolic resin mixture
- 2. In this process, molten metal is forced by Pressure into a metal mould
- 3. This process employs a consumable electrode
- 4. This process involves rotating a mould while the metal solidifies
- 5. This process produces very smooth, highly Accurate castings from both ferrous and non ferrous alloys

Codes: A	B	C	D	A	B	C	D
(a) 5	4	1	2	(b) 2	3	4	5
(c) 5	3	For-2015 (IES, GATE & PSUs)	1				5

GATE – 2007 (PI)

Match the lists

Group-1	Group-2
P. Sand Casting	1. Turbine blades
Q. Centrifugal Casting	2. IC Engine Pistons
R. Investment Casting	3. Large bells
S. Die Casting	4. Pulleys

- (a) P - 4, Q - 1, R - 3, S - 2
- (b) P - 2, Q - 4, R - 3, S - 1
- (c) P - 3, Q - 4, R - 1, S - 2
- (d) P - 3, Q - 2, R - 1, S - 4



Welding Definition

- Welding is a process by which two materials, usually metals, are permanently joined together by coalescence, which is induced by a combination of temperature, pressure, and metallurgical conditions.
- The particular combination of these variables can range from high temperature with no pressure to high pressure with no increase in temperature.
- Welding (positive process)
- Machining (negative process)
- Forming, casting (zero process)

Requirement for a high quality welding

1. A source of satisfactory heat and/or pressure,
2. A means of protecting or cleaning the metal, and
3. Caution to avoid, or compensate for, harmful metallurgical effects.

Classification of welding processes

- Oxy fuel gas welding (OFW)
- Arc welding (Aw)
- Resistance welding
- Solid state welding (friction welding, ultrasonic welding, forge welding etc.)
- Unique process
 - Thermit welding
 - Laser beam welding
 - Electroslag welding
 - Flash welding
 - Induction welding
 - Electron beam welding

IES - 2012

The advantage of the welding process is

- (a) It relieves the joint from residual stresses
- (b) It helps in checking of distortion of work piece
- (c) Large number of metals and alloys, both similar and/or dissimilar can be joined.
- (d) Heat produced during the welding does not produce metallurgical changes.

Weldability / Fabrication Processes

- The weldability of a material will depend on the specific welding or joining process being considered.
- For resistance welding of consistent quality, it is usually necessary to remove the oxide immediately before welding.
- Fabrication weldability test is used to determine mechanical properties required for satisfactory performance of welded joint.
- The correct sequence of the given materials in ascending order of their weldability is

Aluminum < copper < cast iron < MS

Contd...

Case of Aluminium

- The oxide coating on aluminum alloys causes some difficulty in relation to its weldability.
- It also has high thermal conductivity and a very short temperature range between liquidus and solidus and when liquid its viscosity is very low.
- Aluminium is poor absorber of laser light.
- During fusion welding, the aluminum would oxidize so readily that special fluxes or protective inert-gas atmospheres must be employed.
- Friction welding and TIG welding is good for aluminium.
- For aluminium AC current plus high frequency is must.

Case of Cast Iron

- Cast iron is more difficult to weld because of its high carbon content and brittleness (poor ductility)
- Massive carbon deposits have a tendency to form in the areas adjacent to the weld, and high-carbon martensite tends to form in the heat-affected zones. These microstructures are very brittle and may crack spontaneously while welding is in progress or later when load is applied to the workpiece.
- Cast iron can be joined by the oxyacetylene brazing process and shielded metal-arc welding (stick) process.
- Some cases preheating and/or post heating is required.

For 2015 (IES, GATE & PSUs)

Case of Stainless Steel

- Stainless steel is a difficult metal to weld because it contains both nickel and chromium.
- The best method for welding stainless steel is TIG welding.
- The electric arc is also preferred for welding stainless steels. A heavily coated welding rod, which produce a shielded arc, is employed.
- You must do a better job of pre-cleaning.
- Using a low arc current setting with faster travel speeds is important when welding stainless steel, because some stainless steels are subject to carbide precipitation.

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Contd.....

Case of Stainless Steel

- The ferritic stainless steels are generally less weldable than the austenitic stainless steel and require both preheating and postweld heat treatments.
- Welds of ferritic stainless steel can be by
 - (i) autogenously (i.e. without the addition of filler metal)
 - (ii) with an austenitic stainless steel
 - (iii) using a high nickel filler alloy.
 - (iv) Type 405 filler (low 11% Cr, low carbon and small 0.2% Al)
- Welding process: TIG, MIG, Shielded-metal arc welding and Plasma arc welding

Rev.0

IES 2010

Assertion (A): It is generally difficult to weld Aluminum parts by normal arc welding process.

Reason (R): Hard and brittle Aluminum-oxide film is formed at the welded joints.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2006

Assertion (A): Aluminium has poor weldability.

Reason (R): Aluminium has high thermal conductivity and high affinity to oxygen.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

GATE-2014

The major difficulty during welding of aluminium is due to its

- (a) high tendency of oxidation
- (b) high thermal conductivity
- (c) low melting point
- (d) low density

IES 2011

During plasma arc welding of aluminium, improved removal of the surface oxide from the base metal is obtained with typical polarity of :

- (a) DC Straight
- (b) DC reverse
- (c) AC potential
- (d) Reverse polarity of phase of AC potential

IES 2011

Consider the following statements.

Cast iron is difficult to weld, because of

- 1. Low ductility
- 2. Poor fusion
- 3. Tendency to crack on cooling

Which of these statements are correct ?

- (a) 1, 2 and 3
- (b) 1 and 2 only
- (c) 2 and 3 only
- (d) 1 and 3 only

IES-2006

Fabrication weldability test is used to determine

- (a) Mechanical properties required for satisfactory performance of welded joint
- (b) Susceptibility of welded joint for cracking
- (c) Suitability for joint design
- (d) Appropriate machining process

IES-1999

The correct sequence of the given materials in ascending order of their weldability is

- (a) MS, copper, cast iron, aluminium
- (b) Cast iron, MS, aluminium copper
- (c) Copper, cast iron, MS, aluminium
- (d) Aluminium, copper, cast iron, MS

IES 2010

Weldability of ferritic stainless steel used in automotive exhaust system is improved by selecting stainless steel electrode having low content of

- (a) Carbon
- (b) Nitrogen
- (c) Chromium
- (d) Carbon and Nitrogen

IES 2010

Consider the following statements regarding welded joints:

- 1. It is a permanent type of joint.
- 2. It is reliable and economical for pressure vessel construction.
- 3. It is free from fabrication residual stresses.
- 4. Such joints are suitable for static loading only.
- 5. Welding is a versatile and flexible metal joining process.

Which of the above statements are correct?

- (a) 1, 2 and 3 only
- (b) 2, 3 and 4 only
- (c) 1, 2, 3, 4 and 5
- (d) 1, 2 and 5 only

IES - 2012

Which of the following factors improve weld ability of steel?

1. Low carbon content
2. High carbon content
3. Good affinity content
4. Poor affinity to oxygen

- (a) 1 and 3 (b) 2 and 3
(c) 1 and 4 (d) 2 and 4

IES-2013

Weldability depends on

1. Thermal conductivity
2. Surface condition
3. Change in microstructure

- (a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

Gas Flame Processes:

Welding, Cutting and Straightening

- **Oxy-fuel gas Welding (OFW):** Heat source is the flame produced by the combustion of a fuel gas and oxygen.
- OFW has largely been replaced by other processes but it is still popular because of its portability and the low capital investment.
- Acetylene is the principal fuel gas employed.

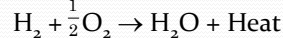
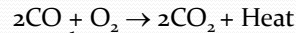
- Combustion of oxygen and acetylene (C_2H_2) in a welding torch produces a temp. in a two stage reaction.

- In the first stage

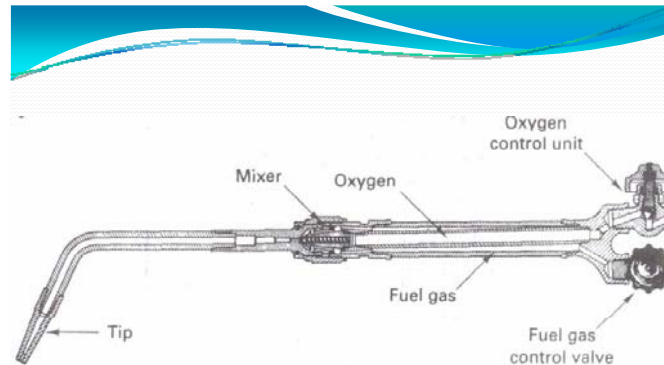


This reaction occurs near the tip of the torch.

- In the second stage combustion of the CO and H_2 and occurs just beyond the first combustion zone.



Oxygen for secondary reactions is obtained from the atmosphere.



Three types of flames can be obtained by varying the oxygen/acetylene (or oxygen/fuel gas) ratio.

- If the ratio is about 1 : 1 to 1.15 : 1, all reactions are carried to completion and a neutral flame is produced.
- Most welding is done with a neutral flame. It is chemically neutral and neither oxidizes or carburizes the metal being welded.



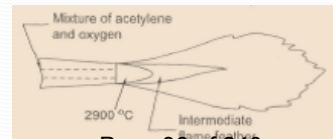
Oxy-acetylene gas welding neutral flame

- A higher ratio, such as 1.5 : 1, produces an oxidizing flame, hotter than the neutral flame (about 3300°C) but similar in appearance.
- Used when welding copper and copper alloys but harmful when welding steel because the excess oxygen reacts with the carbon, decarburizing the region around the weld.



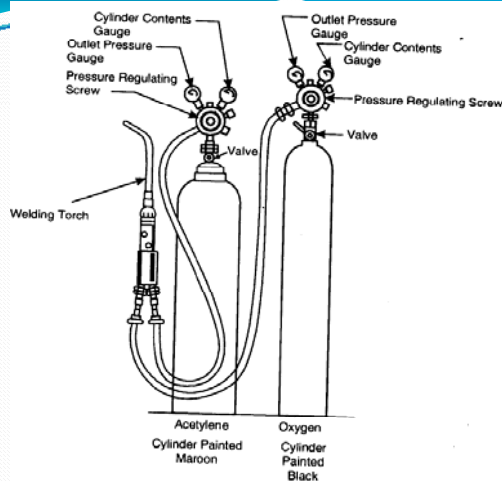
Fig. 9.7. Different types of gas welding

- Excess fuel, on the other hand, produces a carburizing flame. Carburizing flame can carburize metal also.
- The excess fuel decomposes to carbon and hydrogen, and the flame temperature is not as great (about 3000°C).
- Flames of this type are used in welding Monel (a nickel-copper alloy), high-carbon steels, and some alloy steels, and for applying some types of hard-facing material.



Oxy-acetylene gas welding Carburizing flame

Metal	Flame
M S	N
High carbon steel	R
Grey cast iron	N, slightly oxidizing
Alloy steel	N
Aluminium	Slightly carburizing
Brass	Slightly oxidizing
Copper, Bronze	N, slightly oxidizing
Nickel alloys	Slightly carburizing
Lead	N



Uses, Advantages, and Limitations

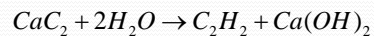
- OFW is **fusion welding**.
- **No pressure is involved**.
- Filler metal can be added in the form of a wire or rod.
- Fluxes may be used to clean the surfaces and remove contaminating oxide. The gaseous shield produced by vaporizing flux can prevent oxidation during welding, and the slag produced by solidifying flux can protect the weld pool. Flux can be added as a powder, the welding rod can be dipped in a flux paste, or the rods can be pre-coated.

Contd...

- Exposer of the heated and molten metal to the various gases in the flame and atmosphere makes it difficult to prevent contamination.
- Heat source is not concentrated, a large area of the metal is heated and distortion is likely to occur.
- Flame welding is still quite common in field work, in maintenance and repairs, and in fabricating small quantities of specialized products.

Oxy acetylene welding equipment

- Oxygen is stored in a cylinder at a pressure ranging from 13.8 MPa to 18.2 MPa .
- Due to high explosiveness of free acetylene it is stored in a cylinder with 80-85% porous calcium silicate and then filled with acetone which absorb upto 420 times by its volume at a pressure 1.75 MPa .
- At the time of acetylene release if acetone comes with acetylene the flame would give a purple colour.
- Another option is acetylene generator.



Pressure Gas Welding

- Pressure gas welding (PGW) or Oxyacetylene Pressure Welding is a process used to make butt joints between the ends of objects such as pipe and-railroad rail.
- The ends are heated with a gas flame to a temperature below the melting point, and the soft metal is then forced together under considerable pressure.
- This process, therefore, is actually a 'form of solid-state welding.

IES 2010

The ratio between Oxygen and Acetylene gases for neutral flame in gas welding is

- (a) 2 : 1 (b) 1 : 2
(c) 1 : 1 (d) 4 : 1

GATE-1994

The ratio of acetylene to oxygen is approximately..... for a neutral flames used in gas welding.

- (a) 1 : 1
(b) 1 : 2
(c) 1 : 3
(d) 1.5 : 1

GATE-2003

In Oxyacetylene gas welding, temperature at the inner cone of the flame is around

- (a) 3500°C
(b) 3200°C
(c) 2900°C
(d) 2550°C

IES 2010

Assertion (A): Oxidizing flame is used in gas welding to join medium carbon steels having high melting point.

Reason (R): In gas welding, oxidizing flame produces the maximum temperature compared to neutral and reducing flame.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

GATE-2002

The temperature of a carburising flame in gas welding is that of a neutral or an oxidising flame.

- (a) Lower than
- (b) Higher than
- (c) Equal to
- (d) Unrelated to

IES-2009

By which one of the following methods gray cast iron is usually welded?

- (a) TIG welding
- (b) MIG welding
- (c) Gas welding
- (d) Arc welding

IES-1998

In oxy-acetylene gas welding, for complete combustion, the volume of oxygen required per unit of acetylene is

- (a) 1
- (b) 1.5
- (c) 2
- (d) 2.5

IAS 1994

In gas welding of mild steel using an oxy-acetylene flame, the total amount of acetylene consumed was 10 litre. The oxygen consumption from the cylinder is

- (a) 5 litre
- (b) 10 litre
- (c) 15 litre
- (d) 20 litre

IAS-1995

Assertion (A): If neutral flame is used in oxy-acetylene welding, both oxygen and acetylene cylinders of same capacity will be emptied at the same time.

Reason (R): Neutral flame uses equal amounts of oxygen and acetylene.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2012

Statement (I): In gas welding the metal to be joined gets oxidized or carburized

Statement (II): The neutral flame affects no chemical change on the molten metal.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- (b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- (c) Statement (I) is true but Statement (II) is false
- (d) Statement (I) is false but Statement (II) is true

Oxygen Torch Cutting (Gas Cutting)

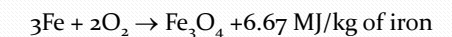
- Iron and steel oxidize (burn) when heated to a temperature between 800°C to 1000°C.
- High-pressure oxygen jet (300 KPa) is directed against a heated steel plate, the oxygen jet burns the metal and blows it away causing the cut (kerf).
- For cutting metallic plates shears are used. These are useful for straight-line cuts and also for cuts up to 40 mm thickness.

- For thicker plates with specified contour, shearing cannot be used and oxy-fuel gas cutting (OFC) is useful.
- Gas-cutting is similar to gas welding except torch tip.

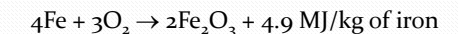
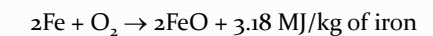


Fig- differences in torch tips for gas welding and gas cutting

- Larger size orifice produces kerf width wider and larger oxygen consumed.
- At kindling temperature (about 870°C), iron forms iron oxide.
- Reaction:



The other reactions:



- All exothermic reactions preheat the steel.

- For complete oxidation 0.287 m³ oxygen/kg of iron is required
- Due to unoxidized metal blown away the actual requirement is much less.
- Torch tip held vertically or slightly inclined in the direction of travel.
- Torch position is about 1.5 to 3 mm vertical from plate.

Contd...

- The drag lines shows the characteristics of the movement of the oxygen stream.

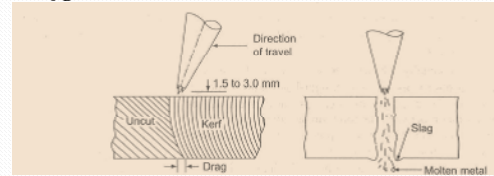


Fig- positioning of cutting torch in oxy- fuel gas cutting

- Drag is the amount by which the lower edge of the drag line trails from the top edge.
- Good cut means negligible drag.

Contd...

- If torch moved **too rapidly**, the bottom does not get sufficient heat and produces large drag so very rough and irregular-shaped-cut edges.
- If torch **moved slowly** a large amount of slag is generated and produces irregular cut.

Contd...

- Gas cutting is more useful with thick plates.

- For thin sheets (less than 3 mm thick) tip size should be small. If small tips are not available then the tip is inclined at an angle of 15 to 20 degrees.

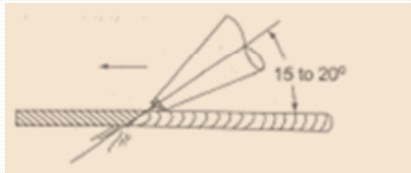


Fig. Recommended torch position for cutting thin steel

IAS-2011 Main

Draw a self explanatory sketch of oxy-acetylene gas cutting torch. Briefly explain how cutting is effected.

[20-Marks]

Application

- Useful only for materials which readily get oxidized and the oxides have lower melting points than the metals.
- Widely used for ferrous materials.
- Cannot be used for aluminum, bronze, stainless steel and like metals since they resist oxidation.

Difficulties

- Metal temperature goes beyond lower critical temperature and structural transformations occur.
- Final microstructure depends on cooling rate.
- Steels with less than 0.3 % carbon cause no problem.

Contd...

- For high carbon steel material around the cut should be preheated (about 250 to 300°C) and may post heat also necessary.
- Cutting CI is difficult, since its melting temp. is lower than iron oxide.
- If chromium and nickel etc are present in ferrous alloys oxidation and cutting is difficult.

IES-1992

The edge of a steel plate cut by oxygen cutting will get hardened when the carbon content is

- Less than 0.1 percent
- Less than 0.3 percent
- More than 0.3 percent
- Anywhere between 0.1 to 1.0 percent

IES 2007

Consider the following statements in respect of oxy-acetylene welding:

1. The joint is not heated to a state of fusion.
2. No pressure is used.
3. Oxygen is stored in steel cylinder at a pressure of 14 MPa.
4. When there is an excess of acetylene used, there is a decided change in the appearance of flame.

Which of the statements given above are correct?

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

IES-2001

Oxyacetylene reducing flame is used while carrying out the welding on

- (a) Mild steel (b) High carbon steel
(c) Grey cast iron (d) Alloy steels

IES-1992

Thick steel plate cut with oxygen normally shows signs of cracking. This tendency for cracking can be minimised by

- (a) Slow speed cutting
(b) Cutting in two or more stages
(c) Preheating the plate
(d) Using oxy-acetylene flame

IES-2005

Consider the following statements:

1. In gas welding, the torch should be held at an angle of 30° to 45° from the horizontal plane.
2. In gas welding, the size of the torch depends upon the thickness of metal to be formed.
3. Drag in gas cutting is the time difference between heating of the plate and starting the oxygen gas for cutting.

Which of the statements given above are correct?

- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

Powder Cutting

- Cast iron, stainless steel, and others high alloy steels are difficult to cut by oxy-fuel cutting and we can use powder cutting.
- By injecting a finely divided 200-mesh iron powder into the flame, a lower melting point eutectic oxide is formed at the cutting interface, where additional iron-oxygen reaction is generated and cutting proceeds in a similar way of oxy-fuel cutting.
- The heat and the fluxing action of the burning iron powder enable the cutting oxygen stream to oxidize the base metal continuously, just as in cutting carbon steel.

GATE-2009 (PI)

Which of the following powders should be fed for effective oxy-fuel cutting of stainless steel?

- (a) Steel
(b) Aluminum
(c) Copper
(d) Ceramic

Plasma Cutting

- Uses ionized gas jet (plasma) to cut materials resistant to oxy-fuel cutting.
- High velocity electrons generated by the arc impact gas molecules, and ionize them.
- The ionized gas is forced through nozzle (upto 500 m/s), and the jet heats the metal, and blasts the molten metal away.
- More economical, more versatile and much faster (5 to 8 times) than oxyfuel cutting, produces narrow kerfs and smooth surfaces.
- HAZ is $1/3$ to $1/4$ th than oxyfuel cutting.
- Maximum plate thickness = 200 mm

For-2015 (IES, GATE & PSUs)



Electric Arc Welding

Electric Arc Welding

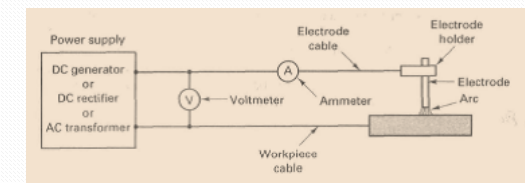


Fig. Basic circuit for arc welding

Rev.0

Principle of Arc

- An arc is generated between cathode and anode when they are touched to establish the flow of current and then separated by a small distance.
- 65% to 75% heat is generated at the anode.
- If DC is used and the work is positive (the anode of the circuit), the condition is known as **straight polarity** (SPDC).

Contd...

- Work is negative and electrode is positive is reverse polarity (RPDC).
- SPDC conditions are preferred.
- DC arc-welding maintain a stable arc and preferred for difficult tasks such as overhead welding.
- For a stable arc, the gap should be maintained.

Contd...

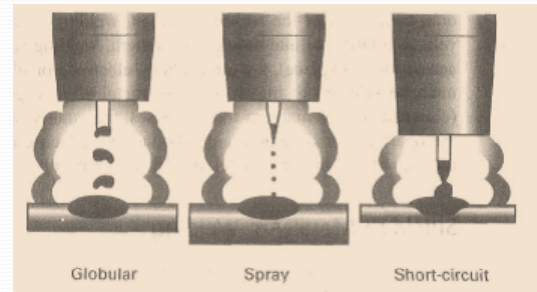
ISRO-2011

In arc welding, penetration is minimum for

- DCSP
- DCRP
- AC
- DCEN

- Manual arc welding is done with shielded (covered) electrodes
- Bare-metal wire used in automatic or semiautomatic machines.
- Non consumable electrodes (e.g tungsten) is not consumed by the arc and a separate metal wire is used as filler.
- There are three modes of metal transfer (globular, spray and short-circuit).

Three modes of metal transfer during arc welding



Major Forces take part in Metal Transfer

- gravity force
- Surface tension
- electromagnetic interaction
- hydrodynamic action of plasma

JWM 2010

Assertion (A) : Bead is the metal added during single pass of welding.

Reason (R) : Bead material is same as base metal.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is NOT the correct explanation of A
- A is true but R is false
- A is false but R is true

For-2015 (IES, GATE & PSUs)

GATE-1993

In d.c. welding, the straight polarity (electrode negative) results in

- Lower penetration
- Lower deposition rate
- Less heating of work piece
- Smaller weld pool

Arc welding equipments

- Droopers: Constant current welding machines
 - Good for manual welding
- Constant voltage machines
 - Good for automatic welding

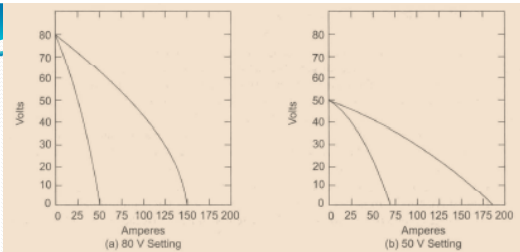


Fig. Machine with different settings

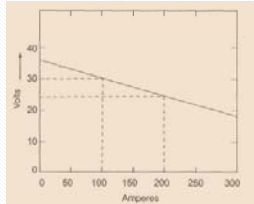
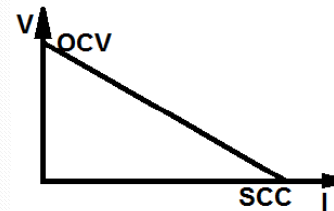


Fig. Characteristic curve of a constant voltage arc-welding machine

Formula



$$\frac{V}{OCV} + \frac{I}{SCC} = 1$$

- Requires a large current (150 to 1000 A), voltage is between 30 and 40 V, actual voltage across the arc varying from 12 to 30 V.
- To initiate a weld, the operator strike the electrode and start arc.

IES 2010

In arc welding, the arc length should be equal to

- 4.5 times the rod diameter
- 3 times the rod diameter
- 1.5 times the rod diameter
- Rod diameter

IES-2005

Consider the following statements:

- In arc welding, 65% to 75% heat is generated at the anode.
- Duty cycle in case of arc welding is the cycle of complete welding of work piece from the beginning.
- Arc blow is more common with DC welding.

Which of the statements given above are correct?

- 1, 2 and 3
- 1 and 2
- 2 and 3
- 1 and 3

IES-2001

In manual arc welding, the equipment should have drooping characteristics in order to maintain

- Voltage constant when arc length changes
- Current constant when arc length changes
- Temperature in the arc constant
- Weld pool red-hot

IES-2001

In arc welding, d.c. reverse polarity is used to bear greater advantage in

- Overhead welding
- Flat welding of lap joints
- Edge welding
- Flat welding of butt joints

IES-1998

The voltage-current characteristics of a dc generator for arc welding is a straight line between an open-circuit voltage of 80 V and short-circuit current of 300 A. The generator settings for maximum arc power will be

- 0 V and 150 A
- 40 V and 300 A
- 40 V and 150 A
- 80 V and 300 A

IAS-1999

Open-circuit voltage of 60 V and current of 160 A were the welding conditions for arc welding of a certain class of steel strip of thickness 10 mm. For arc welding of 5 mm thick strip of the same steel, the welding voltage and current would be

- 60 V and 80 A
- 120 V and 160 A
- 60 V and 40 A
- 120 V and 40 A

IAS-1998

Assuming a straight line V-I characteristics for a dc welding generator, short circuit current as 400A and open circuit voltage as 400 which one of the following is the correct voltage and current setting for maximum arc power?

- (a) 400 A and 100 V (b) 200 A and 200 V
(c) 400 A and 50 V (d) 200 A and 50 V

GATE -2012 Same Q in GATE -2012 (PI)

In a DC arc welding operation, the voltage-arc length characteristic was obtained as $V_{\text{arc}} = 20 + 5L$ where the arc length L was varied between 5 mm and 7 mm. Here V_{arc} denotes the arc voltage in Volts. The arc current was varied from 400 A to 500 A. Assuming linear power source characteristic, the open circuit voltage and the short circuit current for the welding operation are

- (a) 45 V, 450 A (b) 75 V, 750 A
(c) 95 V, 950 A (d) 150 V, 1500 A

GATE – 2007 (PI)

The DC power source for arc welding has the characteristic $3V + I = 240$, where V = Voltage and I = Current in amp. For maximum arc power at the electrode, voltage should be set at

- (a) 20 V (b) 40 V (c) 60 V (d) 80 V

GATE-1992

A low carbon steel plate is to be welded by the manual metal arc welding process using a linear $V - I$ characteristic DC Power source. The following data are available :

OCV of Power source = 62 V

Short circuit current = 130 A

Arc length, $L = 4$ mm

Traverse speed of welding = 15 cm/s

Efficiency of heat input = 85%

Voltage is given as $V = 20 + 1.5 L$

Calculate the heat input into the workpiece

GATE-2014 (PI)

In an arc welding operation, carried out with a power source maintained at 40 volts and 400 amperes, the consumable electrode melts and just fills the gap between the metal plates to be butt-welded. The heat transfer efficiency for the process is 0.8, melting efficiency is 0.3 and the heat required to melt the electrode is 20 J/mm³. If the travel speed of the electrode is 4 mm/s, the cross-sectional area, in mm², of the weld joint is _____

Duty Cycle

- The percentage of time in a 5 min period that a welding machine can be used at its rated output without overloading.
- Time is spent in setting up, metal chipping, cleaning and inspection.
- For manual welding a 60% duty cycle is suggested and for automatic welding 100% duty cycle.

Contd...

IFS-2011

What is the maximum output current that can be drawn at 100% duty cycle from a welding power source rated at 600A at 60% duty cycle.

[3-Marks]

$$\text{Required duty cycle, } T_a = \left(\frac{I}{I_a} \right)^2 T$$

Where, T = rated duty cycle

I = rated current at the rated duty cycle

I_o = Maximum current at the rated duty cycle

Electrode

1. Non-consumable Electrodes
2. Consumable Electrodes

Non-consumable Electrodes

- Made of carbon, Graphite or Tungsten.
- Carbon and Graphite are used for D.C.
- Electrode is not consumed, the arc length remains constant, arc is stable and easy to maintain.

Consumable Electrodes

- Provides filler materials.
- Same composition.
- This requires that the electrode be moved toward or away from the work to maintain the arc and satisfactory welding conditions.

Contd...

Consumable electrodes are three kinds:

- (a) Bare
- (b) Fluxed or lightly coated
- (c) Coated or extruded / shielded
- For automatic welding, bare electrode is in the form of continuous wire (coil).

Electrode coating characteristic

1. Provide a protective atmosphere.
2. Stabilize the arc.
3. Provide a protective slag coating to accumulate impurities, prevent oxidation, and slow the cooling of the weld metal.
4. Reduce spatter.
5. Add alloying elements.
6. Affect arc penetration
7. Influence the shape of the weld bead.
8. Add additional filler metal.

GATE-1994

The electrodes used in arc welding are coated. This coating is not expected to

- (a) Provide protective atmosphere to weld
- (b) Stabilize the arc
- (c) Add alloying elements
- (d) Prevents electrode from contamination

Electrode coatings

1. **Slag Forming Ingredients.** asbestos, mica, silica, fluorspar, titanium dioxide, Iron oxide, magnesium carbonate, Calcium carbonate and aluminium oxide.
2. **Arc Stabilizing Ingredients.** or ionizing agents: potassium silicate, $\text{TiO}_2 + \text{ZrO}_2$ (Rutile), Mica, Calcium oxide, sodium oxide, magnesium oxide, feldspar (KAlSi_3O_8)

Contd...

3. **Deoxidizing Ingredients.** Cellulose, Calcium carbonate, dolo- mite, starch, dextrin, wood flour, graphite, aluminium, ferromanganese.

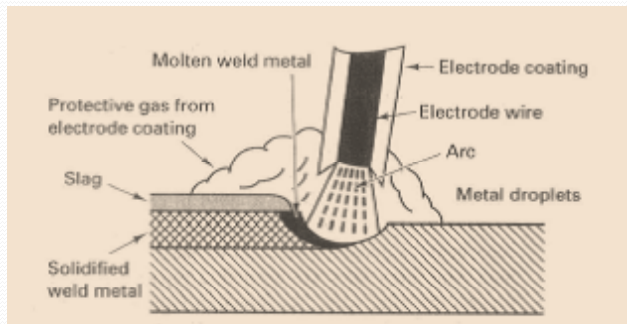
4. **Binding Materials** Sodium silicate, potassium silicate, asbestos.

5. **Alloying Constituents to Improve Strength of Weld**

6. TiO_2 and potassium compounds increase the melting rate of the base metal for better penetration.

7. Iron powder provides higher deposition rate.

Contd...



Contd...

Binders

- AC arc welding used potassium silicate binders.
- DC arc welding used sodium silicate binders.
- Potassium has a lower ionization potential as compared with sodium.

IES 2007

The coating material of an arc welding electrode contains which of the following?

1. Deoxidising agent
2. Arc stabilizing agent
3. Slag forming agent

Select the correct answer using the code given below:

- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

IES-1997

Assertion (A): The electrodes of ac arc welding are coated with sodium silicate, whereas electrodes used for dc arc welding are coated with potassium silicate binders.

Reason (R): Potassium has a lower ionization potential than sodium.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-2002

Match List I with List II and select the correct answer:

List I (Ingredients)

List II (Welding functions)

- | | |
|----------------------|-------------------------|
| A. Silica | 1. Arc stabilizer |
| B. Potassium oxalate | 2. De-oxidizer |
| C. Ferro silicon | 3. Fluxing agent |
| D. Cellulose | 4. Gas forming material |

Codes:	A	B	C	D		A	B	C	D
(a)	3	4	2	1	(b)	2	1	3	4
(c)	3	1	2	4	(d)	2	4	3	1

Welding Flux

Available in three forms

- Granular
- Electrode wire coating
- Electrode core

Low Hydrogen Electrode

- The basic coatings contain large amount of calcium carbonate (limestone) and calcium fluoride (fluorspar) and produce low hydrogen.
- But it can absorb moisture therefore coated low hydrogen electrodes are baked before use to a temperature of 200°C to 300°C and stored in an oven at 110°C to 150°C
- Other types of electrode release large amount of hydrogen, which can dissolve in the weld metal and lead to embrittlement or cracking.

IFS-2011

What is meant by low -hydrogen electrode ?

[2-marks]

Welding Positions

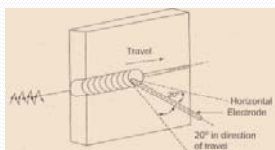
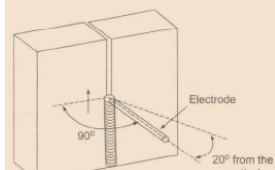


Fig. The position of electrode for horizontal welding



For-2015 (IES, GATE & PSUs)
Fig. Positioning of electrode for welding in vertically upward position

Welding Current

- Welding current depends upon: the thickness of the welded metal, type of joint, welding speed, position of the weld, the thickness and type of the coating on the electrode and its working length.
- Welding current, $I = k \cdot d$, amperes; d is dia. (mm)

Welding Voltage

- The arc voltage depends only upon the arc length

$$V = k_1 + k_2 l \quad \text{Volts}$$

Where l is the arc length in mm and k_1 and k_2 are constants,

$k_1 = 10$ to 12 ; and $k_2 = 2$ to 3

The minimum Arc voltage is given by

$$V_{\min} = (20 + 0.04 l) \text{ Volt} \quad \text{Rev.0}$$

Arc Length

- For good welds, a short arc length is necessary, because:
 - Heat is concentrated.
 - More stable
 - More protective atmosphere.

Contd...

A long arc results in

- Large heat loss into atmosphere.
- Unstable arc.
- Weld pool is not protected.
- Weld has low strength, less ductility, poor fusion and excessive spatter.

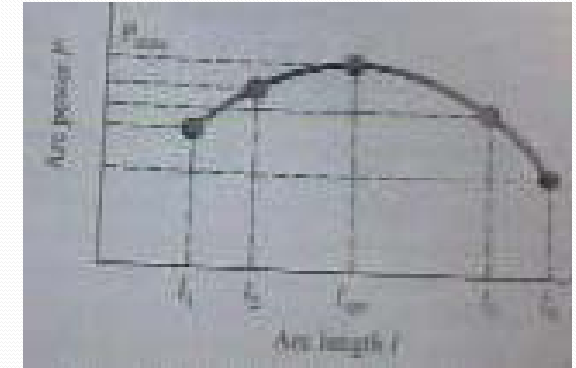
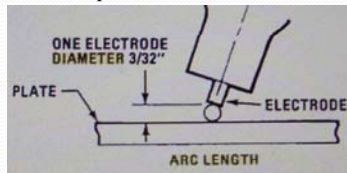
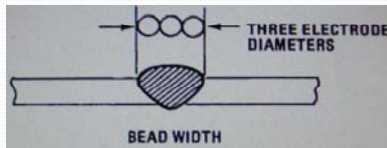


Fig. Arc Power Vs Arc Length

Arc length should be equal to the diameter of the electrode size



Bead width should be equal to three diameter of the electrode size



GATE-2002, Conventional

The arc length-voltage characteristic of a DC arc is given by the equation: $V = 24 + 4L$, where V is voltage in volts and L is arc length in mm. The static volt-ampere characteristic of the power source is approximated by a straight line with a no load voltage of 80 V and a short circuit current of 600 A. Determine the optimum arc length for maximum power.

GATE-2010 (PI)

During a steady gas metal arc welding with direct current electrode positive polarity, the welding current, voltage and weld speed are 150 A, 30 V and 6 m/min, respectively. A metallic wire electrode of diameter 1.2 mm is being fed at a constant rate of 12 m/min. The density, specific heat and melting temperature of the wire electrode are 7000 kg/m³, 500 J/kg°C and 1530°C, respectively. Assume the ambient temperature to be 30°C and neglect the latent heat of melting. Further, consider that two-third of the total electrical power is available for melting of the wire electrode. The melting efficiency (in percentage) of the wire electrode is

- (a) 39.58 (b) 45.25 (c) 49.38 (d) 54.98

GATE-2008

In arc welding of a butt joint, the welding speed is to be selected such that highest cooling rate is achieved. Melting efficiency and heat transfer efficiency are 0.5 and 0.7, respectively. The area of the weld cross section is 5 mm² and the unit energy required to melt the metal is 10 J/mm³. If the welding power is 2 kW, the welding speed in mm/s is closest to

- (a) 4 (b) 14 (c) 24 (d) 34

GATE-2006

In an arc welding process, the voltage and current are 25 V and 300 A respectively. The arc heat transfer efficiency is 0.85 and welding speed is 8 mm/sec. The net heat input (in J/mm) is

- (a) 64
(b) 797
(c) 1103
(d) 79700

GATE-2009 (PI)

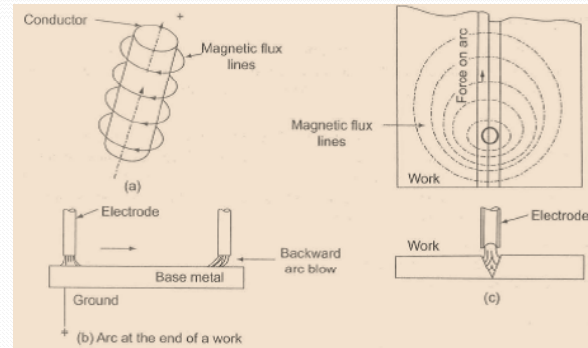
Autogenous gas tungsten arc welding of a steel plate is carried out with welding current of 500 A, voltage of 20 V, and weld speed of 20 mm/sec. Consider the heat transfer efficiency from the arc to the weld pool as 90%. The heat input per unit length (in KJ/mm) is

- (a) 0.25 (b) 0.35 (c) 0.45 (d) 0.55

Example

Calculate the melting efficiency in the case of arc-welding of steel with a potential of 20 V and a current of 200 A. The travel speed is 5 mm/s and the cross-sectional area of the joint is 20 mm². Heat required to melt steel may be taken as 10 J/mm³ and the heat transfer efficiency as 0.85.

Arc blow in DC arc welding



Contd...

- Arc blow occurs during the welding of magnetic materials with DC.
- The effect of arc blow is maximum when welding corners where magnetic field concentration is maximum.
- The effect is particularly noticeable when welding with bare electrodes or when using currents below or above
- Again the problem of arc blow gets magnified when welding highly magnetic materials such as Ni alloys, because of the strong magnetic fields set up by these metals.
- Cause: Unbalanced magnetic forces.

Contd...

Effect of arc blow

- Low heat penetration.
- Excessive weld spatter.
- Pinch effect in welding is the result of electromagnetic forces
- Weld spatter occurs due to
 - High welding current
 - Too small an electrode arc

Contd...

The effects of arc blow can be minimized with D.C. welding by

- Shortening the arc.
- Reduce current
- Reducing weld speed.
- Balance magnetic field by placing one ground lead at each end of the work piece.
- Wrapping the electrode cable a few turns around the work piece.

IES-2001

Arc blow is more common in

- A.C. welding
- D.C. welding with straight polarity
- D.C. welding with bare electrodes
- A.C. welding with bare electrodes

IES-2013

Statement (I): The deflection of Arc from its intended path is called 'Arc blow'.

Statement (II): The chances of Arc blow is common in A.C. Arc welding.

- Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
- Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
- Statement (I) is true but Statement (II) is false
- Statement (I) is false but Statement (II) is true

IES-2001

Pinch effect in welding is the result of

- Expansion of gases in the arc
- Electromagnetic forces
- Electric force
- Surface tension of the molten metal

ISRO-2006

- Too high welding current in arc welding would result in
- Excessive spatter, under cutting along edges, irregular deposits, wasted electrodes
 - Excessive piling up of weld metal, poor penetration, wasted electrodes
 - Too small bead, weak weld and wasted electrodes
 - Excessive piling up of weld metal, overlapping without penetration of edges, wasted electrodes

Gas shields

- An inert gas is blown into the weld zone to drive away other atmospheric gases.
- Gases are argon, helium, nitrogen, carbon dioxide and a mixture of the above gases.
- Argon ionizes easily requiring smaller arc voltages. It is good for welding thin sheets.

Contd...

- Helium, most expensive, has a better thermal conductivity, is useful for thicker sheets, copper and aluminium welding, higher deposition rate.
- The arc in carbon dioxide shielding gas is unstable, least expensive, deoxidizers needed.
- It is a heavy gas and therefore covers the weld zone very well.

Carbon Arc welding

- Arc is produced between a carbon electrode and the work.
- Shielding is not used.
- No pressure
- With or without filler metal
- May be used in "twin arc method", that is, between two carbon (graphite) electrodes.

IES 2010

Assertion (A): Straight polarity is always recommended for Carbon-electrode welding.

Reason (R): Carbon arc is stable in straight polarity.

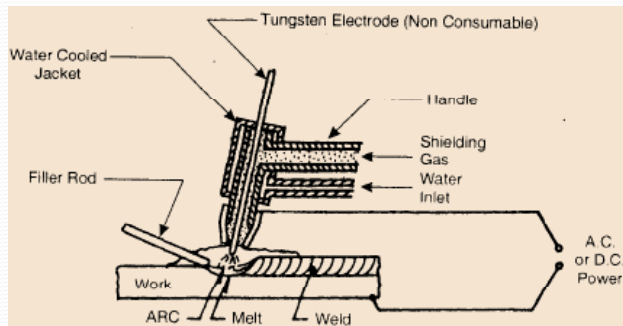
- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is NOT the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

Tungsten Inert Gas welding (TIG)

- Arc is established between a non-consumable tungsten electrode and the workpiece.
- Tungsten is alloyed with thorium or zirconium for better current-carrying and electron-emission characteristics.
- Arc length is constant, arc is stable and easy to maintain.
- With or without filler.

Contd...

- Very clean welds.
- All metals and alloys can be welded. (Al, Mg also)
- Straight polarity is used.
- Weld voltage 20 to 40 V and weld current 125 A for RPDC to 1000 A for SPDC.
- Shielded Gas: Argon
- Torch is water or air cooled.



For-2015 (IES, GATE & PSUs)

GATE 2011

Which one among the following welding processes used non – consumable electrode?

- (a) Gas metal arc welding
 (b) Submerged arc welding
 (c) Gas tungsten arc welding
 (d) Flux coated arc welding

IES 2010

In an inert gas welding process, the commonly used gas is

- (a) Hydrogen
 (b) Oxygen
 (c) Helium or Argon
 (d) Krypton

ISRO-2009

Following gases are used in tungsten inert gas welding

- (a) CO_2 and H_2
- (b) Argon and neon
- (c) Argon and helium
- (d) Helium and neon

GATE-2002

Which of the following arc welding processes does not use consumable electrodes?

- (a) GMAW
- (b) GTAW
- (c) Submerged Arc Welding
- (d) None of these

IES-1994

Which one of the following welding processes uses non-consumable electrodes?

- (a) TIG welding
- (b) MIG welding
- (c) Manual arc welding
- (d) Submerged arc welding.

IES-2000

Which one of the following statements is correct?

- (a) No flux is used in gas welding of mild steel
- (b) Borax is the commonly used flux coating on welding electrodes
- (c) Laser beam welding employs a vacuum chamber and thus avoids use of a shielding method
- (d) AC can be used for GTAW process

IES-2013

Statement (I): Non consumable electrodes, used in arc welding are made of high melting point temperature materials, even then the length of electrode goes on decreasing with passage of time.

Statement (II): The electrode material gets oxidized and melts on the weld material to form a strong flux.

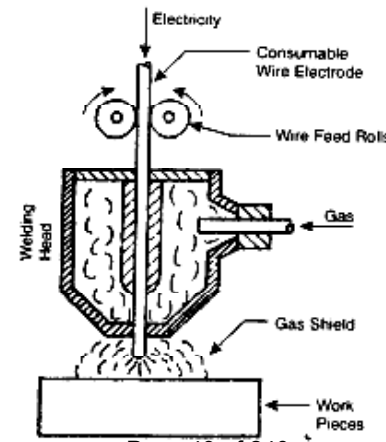
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- (c) Statement (I) is true but Statement (II) is false
- (d) Statement (I) is false but Statement (II) is true

Gas Metal Arc Welding (GMAW) or MIG

- A **consumable electrode** in a gas shield.
- Arc is between workpiece and an automatically fed bare-wire electrode.
- Argon, helium, and mixtures of the two can be used.
- Any metal can be welded but are used primarily with the non-ferrous metals.
- When welding steel, some O_2 or CO_2 is usually added to improve the arc stability and reduce weld spatter.

Contd...

- Fast and economical.
- A reverse-polarity dc arc is generally used because of its deep penetration, spray transfer, and ability to produce smooth welds with good profile.



Page 49 of 240
Fig. MIG

IES 2007

In MIG welding, the metal is transferred into the form of which one of the following?

- (a) A fine spray of metal
- (b) Molten drops
- (c) Weld pool
- (d) Molecules

IES-1997

Consider the following statements:

MIG welding process uses

1. Consumable electrode
2. non-consumable electrode
3. D.C. power supply
4. A.C. power supply

Of these statements

- (a) 2 and 4 are correct
- (b) 2 and 3 are correct
- (c) 1 and 4 are correct
- (d) 1 and 3 are correct

IES-2013

Consider the following statements:

In metal arc welding

1. Utilizes a consumable electrode
2. A welding torch used is connected to acetylene gas supply
3. The electrode and work-piece are connected to the welding power supply

Which of these statements are correct?

- (a) 1, 2 and 3
- (b) 1 and 2 only
- (c) 1 and 3 only
- (d) 2 and 3 only

IES 2010

Assertion (A): Inert gas and bare electrode instead of flux coated electrode is used in the case of automatic TIG and MIG welding processes.

Reason (R): Better protection is provided by a cloud of inert gas than the cover created by the flux.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2012

Statement (I): DC with reverse polarity is used in MIG welding

Statement (II): Use of DC with reverse polarity enables deeper penetration and a clean surface

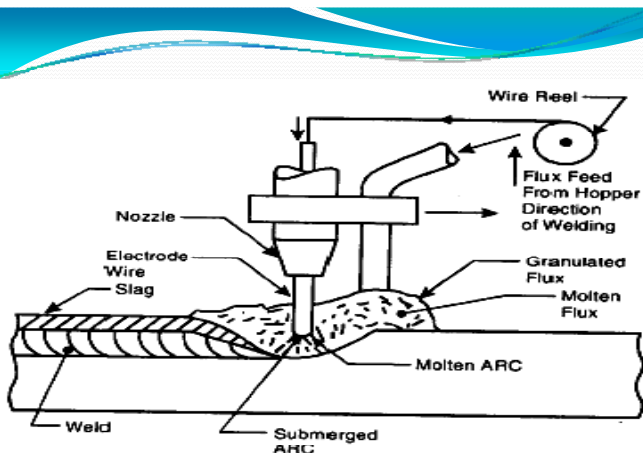
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Submerged Arc welding (SAW)

- A thick layer of granular flux is deposited just ahead of a bare wire consumable electrode, and an arc is maintained beneath the blanket of flux with only a few small flames being visible.
- A portion of the flux melts. Molten flux and flux provides thermal insulation, slows cooling rate and produce soft, ductile welds.

Contd...

- Most suitable for flat butt or fillet welds in low carbon steel (< 0.3% carbon).
- The process is not recommended for high-carbon steels, tool steels, aluminum, magnesium, titanium, lead, or zinc.



For-2015 (IES, GATE & PSUs)

Characteristic of submerged arc welding

- High speeds,
- High deposition rates,
- Deep penetration,
- High cleanliness (due to the flux action).

Advantages

- Wire electrodes are inexpensive.
- No weld spatter.
- Nearly 100% deposition efficiency.
- Lesser electrode consumption.

Limitations

- Extensive flux handling,
- Contamination of the flux by moisture.
- Large-grain-size structures.
- Welding is restricted to the horizontal position.
- Chemical control is important

IES 2011

The welding process in which bare wire is used as electrode, granular flux is used and the process is characterized by its high speed welding, is known as:

- Shielded arc welding
- Plasma arc welding
- Submerged arc welding
- Gas metal arc welding

IES-2006

In which of the following welding processes, flux is used in the form of granules?

- AC arc welding
- Submerged arc welding
- Argon arc welding
- DC arc welding

IES-2005

Which of the following are the major characteristics of submerged arc welding?

- High welding speeds.
- High deposition rates.
- Low penetration.
- Low cleanliness.

Select the correct answer using the code given below:

- 2 and 3
- 1, 2 and 3
- 3 and 4
- 1 and 2

IES-2008

Assertion (A): Submerged arc welding is not recommended for high carbon steels, tool steels, aluminium, magnesium etc.

Reason (R): This is because of unavailability of suitable fluxes, reactivity at high temperatures and low sublimation temperatures.

- Both A and R are true and R is the correct explanation of A
- Both A and R are true but R is NOT the correct explanation of A
- A is true but R is false
- A is false but R is true

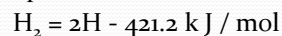
GATE-1999

For butt -welding 40 mm thick steel plates, when the expected quantity of such jobs is 5000 per month over a period of 10 year, choose the best suitable welding process out of the following available alternatives.

- Submerged arc welding
- Oxy-acetylene welding
- Electron beam welding
- MIG welding

Atomic Hydrogen welding (AHW)

- An a.c. arc is formed between two tungsten electrodes along which streams of hydrogen are fed to the welding zone. The molecules of hydrogen are dissociated by the high heat of the arc in the gap between the electrodes. The formation of atomic hydrogen proceeds with the absorption of heat:



- This atomic hydrogen recombines to form molecular hydrogen outside the arc, particularly on the relatively cold surface of the work being welded, releasing the heat gained previously:



For 2015 (IES, GATE & PSUs)

Contd...

- Temperature of about 3700°C.
- Hydrogen acts as shielding also.
- Used for very thin sheets or small diameter wires.
- Lower thermal efficiency than Arc welding.
- Ceramics may be arc welded.
- AC used.

IES-2005

In atomic hydrogen welding, hydrogen acts as

- A heating agent
- One of the gases to generate the flame
- An effective shielding gas protecting the weld
- A lubricant to increase the flow characteristics of weld metal

Resistance Welding

By S K Mondal

Resistance Welding

Principle

- Both heat and pressure are used.
- Heat is generated by the electrical resistance of the work pieces and the interface between them.
- Pressure is supplied externally and is varied throughout the weld cycle.
- Due to pressure, a lower temperature needed than oxy-fuel or arc welding.

Contd...

- They are not officially classified as solid-state welding by the American Welding Society.
- Very rapid and economical.
- Extremely well suited to automated manufacturing.
- No filler metal, no flux, no shielding gases.

Contd...

- Overall resistance very low.
- **Very high-current (up to 100,000 A)**
- **Very low-voltage (0.5 to 10 V) is used.**

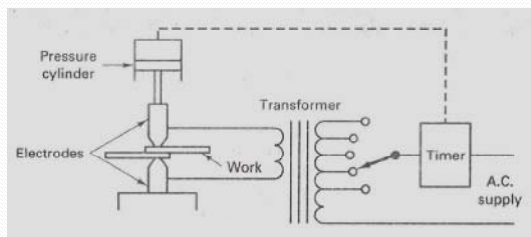


FIG. The fundamental resistance-welding circuit

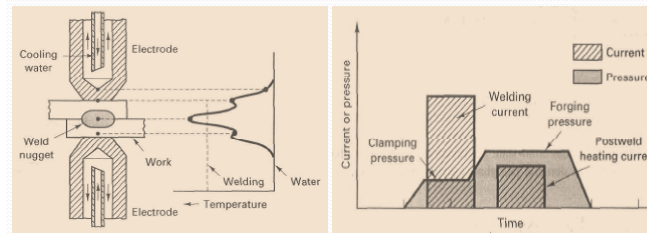


Fig. The desired temperature distribution across the electrodes and the work pieces in lap resistance welding.

Fig. Typical current and pressure cycle for resistance welding. The cycle includes forging and post heating operations.

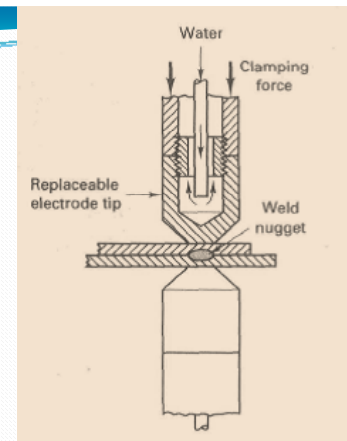


Fig. The arrangement of the electrodes and the work in spot welding, showing design for replaceable electrode tips.

IES 2007

What is the principle of resistance welding?
Indicate where the resistance is maximum in spot welding operation.

[2 marks]

Advantages

1. Very rapid.
2. Fully automation possible.
3. Conserve material; no filler metal, shielding gases, or flux is required.
4. Skilled operators are not required.
5. Dissimilar metals can be easily joined.
6. High reliability and High reproducibility.

Limitations

1. High initial cost.
2. Limitations to the type of joints (mostly lap joints).
3. Skilled maintenance personnel are required:
4. special surface treatment needed.

Application

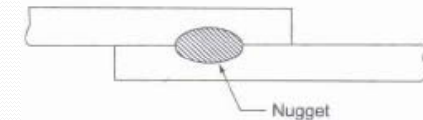
- The resistance welding processes are among the most common technique for high volume joining.

Different types

- Resistance spot welding
- Resistance seam welding
- Projection welding
- Upset welding
- Flash welding
- Percussion welding

Resistance spot welding

- The process description given so far is called resistance spot welding (RSW) or simply spot welding.
- This is essentially done to join two sheet-metal jobs in a lap joint, forming a small nugget at the interface of the two plates.



Heat input and Efficiency Calculations

Electric Arc Welding

We know that the power input by the heat source is given as,

$P = V \times I$, watts, where

V = potential of the power source, volts

I = Current, amperes.

Heat input into the work piece =

$P \times \text{efficiency of heat input/transfer}$

$\therefore H_i = P \times \eta_i$, watts (J/s)

Now heat needed for melting of the work piece,

H_m = Heat needed to melt a unit volume of work piece \times volume of work piece melted per unit time.

\therefore Melting efficiency, $\eta_m = \frac{H_m}{H_i}$

H = Heat energy input (J/mm) = P/v ,

where v = velocity of heat source (mm/s)

Contd...

Electric Resistance Welding

Joule's law applicable

$$Q = I^2 R t, \text{ Joules}$$

IES-2003

In resistance welding, heat is generated due to the resistance between

- Electrode and workpiece
- Asperities between touching plates
- Two dissimilar metals being in contact
- Inter atomic forces

IES-2001

The maximum heat in resistance welding is at the

- Tip of the positive electrode
- Tip of the negative electrode
- Top surface of the plate at the time of electric contact with the electrode
- Interface between the two plates being Joined

GATE-2007

Two metallic sheets, each of 2.0 mm thickness, are welded in a lap joint configuration by resistance spot welding at a welding current of 10 kA and welding time of 10 millisecond. A spherical fusion zone extending up to the full thickness of each sheet is formed. The properties of the metallic sheets are given as:

ambient temperature = 293 K

melting temperature = 1793 K

latent heat of fusion = 300 kJ/kg

density = 7000 kg/m³

specific heat = 800 J/kg K

Assume:

- Contact resistance along sheet-sheet interface is 500 micro-ohm and along electrode-sheet interface is zero;
- No conductive heat loss through the bulk sheet materials; and
- The complete weld fusion zone is at the melting temperature.

The melting efficiency (in %) of the process is

- (a) 50.37 (b) 60.37 (c) 70.37 (d) 80.37

GATE-2009 (PI) Linked S-1

Resistance spot welding of two steel sheets is carried out in lap joint configuration by using a welding current of 3 kA and a weld time of 0.2 S. A molten weld nugget of volume 20 mm³ is obtained. The effective contact resistance is 200 $\mu\Omega$ (micro-ohms). The material properties of steel are given as: (i) latent heat of melting: 1400 kJ/kg, (ii) density: 8000 kg/m³, (iii) melting temperature: 1520°C, (iv) specific heat: 0.5 kJ/kg°C. The ambient temperature is 20°C.

Heat (in Joules) used for producing weld nugget will be (assuming 100% heat transfer efficiency)

- (a) 324 (b) 334 (c) 344 (d) 354

GATE-2009 (PI) Linked S-2

Resistance spot welding of two steel sheets is carried out in lap joint configuration by using a welding current of 3 kA and a weld time of 0.2 S. A molten weld nugget of volume 20 mm³ is obtained. The effective contact resistance is 200 $\mu\Omega$ (micro-ohms). The material properties of steel are given as: (i) latent heat of melting: 1400 kJ/kg, (ii) density: 8000 kg/m³, (iii) melting temperature: 1520°C, (iv) specific heat: 0.5 kJ/kg°C. The ambient temperature is 20°C.

Heat (in Joules) dissipated to the base metal will be (neglecting all other heat losses)

- (a) 10 (b) 16 (c) 22 (d) 32

GATE-2005

Spot welding of two 1 mm thick sheets of steel (density = 8000 kg/m³) is carried out successfully by passing a certain amount of current for 0.1 second through the electrodes. The resultant weld nugget formed is 5 mm in diameter and 1.5 mm thick. If the latent heat of fusion of steel is 1400 kJ/kg and the effective resistance in the welding operation is 200 $\mu\Omega$, the current passing through the electrodes is approximately

- (a) 1480 A (b) 3300 A
(c) 4060 A (d) 9400 A

GATE-2001

Resistance spot welding is performed on two plates of 1.5 mm thickness with 6 mm diameter electrode, using 15000 A current for a time duration of 0.25 seconds. Assuming the interface resistance to be 0.0001 Ω , the heat generated to form the weld is

- (a) 5625 W-sec (b) 8437 W-sec
(c) 22500 W-sec (d) 33750 W-sec

GATE-2004

Two 1 mm thick steel sheets are to be spot welded at a current of 5000 A. Assuming effective resistance to be 200 micro-ohms and current flow time of 0.2 second, heat generated during the process will be

- (a) 0.2 Joule (b) 1 Joule
(c) 5 Joule (d) 1000 Joules

GATE-1992

For resistance spot welding of 1.5 mm thick steel sheets, the current required is of the order of

- (a) 10 A
(b) 100 A
(c) 1000 A
(d) 10,000 A

GATE-2010

Two pipes of inner diameter 100 mm and outer diameter 110 mm each joined by flash butt welding using 30 V power supply. At the interface, 1 mm of material melts from each pipe which has a resistance of 42.4 Ω . If the unit melt energy is 64.4 MJm⁻³, then time required for welding in seconds is

- (a) 1 (b) 5 (c) 10 (d) 20

GATE-2014

For spot welding of two steel sheets (base metal) each of 3 mm thickness, welding current of 10000 A is applied for 0.2 s. The heat dissipated to the base metal is 1000 J. Assuming that the heat required for melting 1 mm³ volume of steel is 20 J and interfacial contact resistance between sheets is 0.0002 Ω , the volume (in mm³) of weld nugget is

IES 2007 Conventional

Two steel sheets of thickness one mm are welded by resistance projection welding technique. A current of 30,000 A for 0.005 second is made to flow. The effective resistance of joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of diameter 5 mm and height 1.5 mm. The density of steel is 0.00786 gm/mm³. The heat needed for welding steel is 10 J/mm³. Calculate the efficiency of welding. [20]

GATE – 2008 (PI)

Aluminum strips of 2 mm thickness are joined together by resistance spot welding process by applying an electric current of 6000 A for 0.15 sec. The heat required for melting aluminum is 2.9 J/mm³. The diameter and the thickness of weld nugget are found to be 5 mm and 2.5 mm, respectively. Assuming the electrical resistance to be 75 $\mu\Omega$ (micro - ohms), the percentage of total energy utilized in forming the weld nugget is

- (a) 28 (b) 35 (c) 65 (d) 72

IAS-2003

Assertion (A): Spot welding is adopted to weld two overlapped metal pieces between two electrode points.

Reason (R): In this process when current is switched on, the lapped pieces of metal are heated in a restricted area.

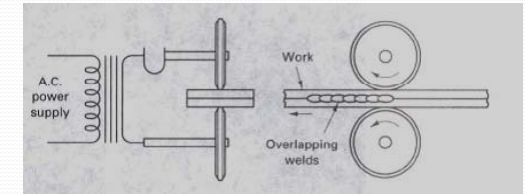
- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Resistance seam welding

- Weld is made between overlapping sheets of metal. The seam is a series of overlapping spot welds.
- The basic equipment is the same as for spot welding, except that the electrodes are now in the form of rotating disks.
- Timed pulses of current pass to form the overlapping welds.

Contd...

- Welding current is a bit higher than spot welding, to compensate short circuit of the adjacent weld.
- In other process a continuous seam is produced by passing a continuous current through the rotating electrodes with a speed of 1.5 m/min for thin sheet.



Contd...

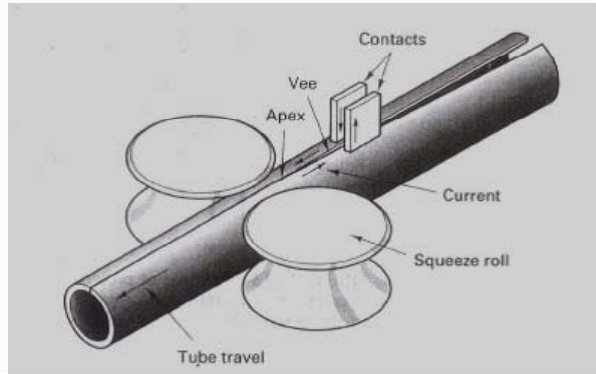


Fig. Resistance seam welding

GATE – 2012 (PI)

In resistance seam welding, the electrode is in the form of a

- (a) cylinder
- (b) flat plate
- (c) coil of wire
- (d) circular disc

Projection welding

- Limitations of spot welding.
 1. Electrode condition must be maintained continually, and only one spot weld at a time.
 2. For additional strength multiple welds needed.
- Projection welding (RPW) overcomes above limitations.

Contd...

- Dimples are embossed on work pieces at the weld locations and then placed between large-area electrodes, and pressure and current applied like spot welding.
- Current flows through the dimples and heats them and pressure causes the dimples to flatten and form a weld.

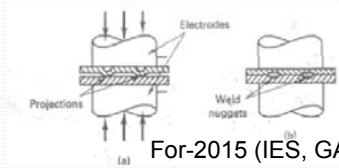


Fig. Principle of projection welding.
(a) prior to application of current and pressure
(b) and after formation of

For-2015 (IES, GATE & PSUs)

Contd...

- Projections are press-formed in any shape.
- Multiple welds at a time.
- No indentation mark on the surface.
- Bolts and nuts can be attached to other metal parts.

Upset welding

- Made butt joint compared to lap joint.
- Pieces are held tightly and current is applied.
- Due to pressure joints get slightly upset and hence its name.
- Useful for joining rods or similar pieces.

Contd...

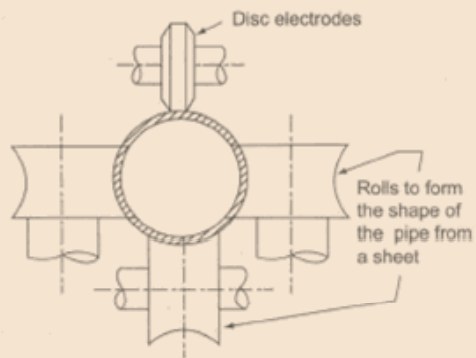


Fig. Forming and welding a pipe from a sheet by means of upset butt-welding process

Contd...

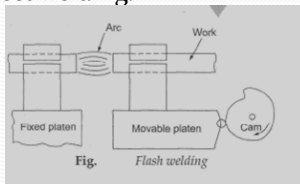
- This is the process used for making electric resistance-welded (ERW) pipes starting from a metal plate of suitable thickness.
- The plate is first formed into the shape of the pipe with the help of the three roll set as shown in Fig. above. The ends of the plate would then be forming the butt joint.
- The two rotating copper disc electrodes are made to contact the two ends of the plate through which the current is passed. The ends get heated and then forge-welded under the pressure of the rolls.
- The ends of the pieces to be upset welded must be perfectly parallel. Any high spots if present on the ends would get melted first before the two ends are completely joined.

Flash Welding

- It is similar to upset welding except the arc rather than resistance heating.
- One piece is clamped with cam controlled movable platen and other with is fixed platen.

Contd...

- Two pieces are brought together and the power supply is switched on. Momentarily the two pieces are separated to create the arc to melt the ends of the two pieces. Then again the pieces are brought together and the power switched off while the two ends are fused under force. Most of the metal melted would flash out through the joint and forms like a fin around the joint.
- Faster than upset welding.



Percussion Welding

- Similar to flash welding except arc power by a rapid discharge of stored electrical energy.
- The arc duration is only 1 to 10 ms, heat is intense and highly concentrated.
- Small weld metal is produced, little or no upsetting, and low HAZ.
- Application: Butt welding of bar or tube where heat damage is a major concern.

Contd...

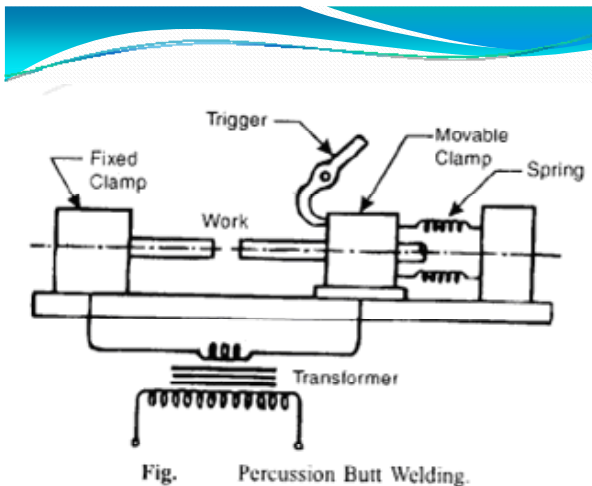


Fig. Percussion Butt Welding.

Thermit Welding

- Heating and coalescence is by superheated molten metal obtained from a chemical reaction between a metal oxide and a metallic reducing agent.
- Used mixture one part aluminum and three parts iron oxide and ignited by a magnesium fuse. (1150°C).



- Temp. 2750°C produced in 30 seconds, superheating the molten iron which provide both heat and filler metal.
- Runners and risers are provided like casting.
- Copper, brass, and bronze can be welded using a different starting mixture.
- Used to joint thick sections, in remote locations.

Contd...

Other Welding Technique

IES-2000

Consider the following processes:

1. Gas welding
2. Thermit welding
3. Arc welding
4. Resistance welding

The correct sequence of these processes in increasing order of their welding temperatures is

- (a) 1, 3, 4, 2 (b) 1, 2, 3, 4
(c) 4, 3, 1, 2 (d) 4, 1, 3, 2

Contd...

Electro Slag Welding

- Very effective for welding **thick sections**.
- Heat is derived from the passage of electrical current through a liquid slag and temp. 1760°C

Contd...

- A 65-mm deep layer of molten slag, protect and cleanse the molten metal.
- Water-cooled copper molding plates confined the liquid and moved upward.
- Multiple electrodes are used to provide an adequate supply of filler.

- **Applications:** Shipbuilding, machine manufacture, heavy pressure vessels, and the joining of large castings and forgings.

- Slow cooling produces a coarse grain structure.
- Large HAZ.

Contd...

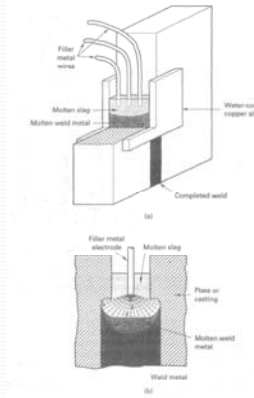


FIGURE 1.1 (a) Top arrangement of equipment and workpiece for making a vertical weld by the electroslag process. (b) Cross section of an electroslag weld, looking through the water-cooled copper side.

IAS-2003

Which one of the following is not an electric resistance method of welding?

- (a) Electro slag welding
(b) Percussion welding
(c) Seam welding
(d) Flash welding

IAS-2000

Consider the following welding processes:

1. TIG welding
2. Submerged arc welding
3. Electro-slag welding
4. Thermit welding

Which of these welding processes are used for welding thick pieces of metals?

- (a) 1, 2 and 3 (b) 1, 2 and 4
(c) 1, 3 and 4 (d) 2, 3 and 4

Electron Beam Welding

- A beam of electrons is magnetically focused on the work piece in a vacuum chamber.
- Heat of fusion is produced by electrons decelerate.
- Allows precise beam control and deep weld penetration.
- No shield gas (vacuum chamber used)

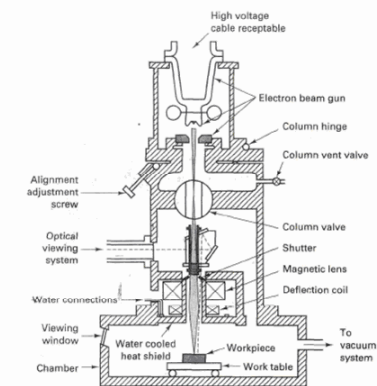


FIGURE Schematic diagram of the electron beam welding process. (Courtesy of American Machinist.)

IES-2004

Assertion (A): In electron beam welding process, vacuum is an essential process parameter

Reason (R): Vacuum provides a highly efficient shield on weld zone

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2002

In which one of the following welding techniques is vacuum environment required?

- (a) Ultrasonic welding
- (b) Laser beam welding
- (c) Plasma arc welding
- (d) Electron beam welding

IES-1993

Electron beam welding can be carried out in

- (a) Open air
- (b) A shielding gas environment
- (c) A pressurized inert gas chamber
- (d) Vacuum

IAS-2004

Which one of the following welding processes consists of smaller Heat Affected Zone (HAZ)?

- (a) Arc welding
- (b) Electron beam welding
- (c) MIG welding
- (d) Thermit welding

Laser Beam Welding

- Used a focused laser beam provides power intensities in excess of 10 kW/cm^2
- The high-intensity beam produces a very thin column of vaporized metal with a surrounding liquid pool.
- Depth-to-width ratio greater than 4: 1.

Contd...

- Very thin HAZ and little thermal distortion.
- Filler metal and inert gas shield may or may not be used.
- Deep penetration.
- No vacuum needed.
- No direct contact needed.

Contd...

- Heat input is very low, often in the range 0.1 to 10 J.
- Adopted by the electronics industry.
- Possible to weld wires without removing the polyurethane insulation.

IES 2007

Consider the following statements in respect of the laser beam welding:

1. It can be used for welding any metal or their combinations because of very high temperature of the focal points.
 2. Heat affected zone is very large because of quick heating.
 3. High vacuum is required to carry the process.
- Which of the statements given above is/are correct?
- (a) 1 and 2 only
 - (b) 2 and 3 only
 - (c) 1 only
 - (d) 1, 2 and 3

IES-2006

Which one of the following welding processes consists of minimum heat affected zone (HAZ)?

- (a) Shielded Metal Arc Welding (SMA W)
- (b) Laser Beam Welding (LBW)
- (c) Ultrasonic Welding (USW)
- (d) Metal Inert Gas Welding (MIG)

GATE-2012 (PI)

Which of the following welding processes results in the smallest heat affected zone?

- (a) Shielded metal arc welding
- (b) Gas welding
- (c) Laser beam welding
- (d) Thermit welding

IAS-2007

Consider the following welding processes:

- | | |
|-----------------------|--------------------------|
| 1. Arc welding | 2. MIG welding |
| 3. Laser beam welding | 4. Submerged arc welding |

Select the correct sequence in increasing order of Heat affected zone (HAZ) using the code given below:

- (a) 1 - 2 - 3 - 4 (b) 1 - 4 - 2 - 3
(c) 3 - 2 - 4 - 1 (d) 4 - 3 - 2 - 1

IAS-1999

Match List I (Shielding method) with List II (Welding process) and select the correct answer using the codes given below the lists:

List I

- A. Flux coating
- B. Flux granules
- C. CO_2
- D. Vacuum

List II

- 1. Gas metal arc welding
- 2. Submerged arc welding
- 3. Shielded metal arc welding
- 4. Laser beam welding
- 5. Electron beam welding

Codes:	A	B	C	D	A	B	C	D	
(a)	1	2	5	3	(b)	1	4	2	5
(c)	3	5	1	4	(d)	3	2	1	5

Forge Welding

- Blacksmith do this.
- Borax is used as a flux.
- The ends to be joined were then overlapped on the anvil and hammered to the degree necessary to produce an acceptable weld.
- Quality depends on the skill of the worker and not used by industry.

Friction Welding

- Heat is obtained by the friction between the ends of the two parts to be joined.
- One part is rotated at a high speed and other part is axially aligned and pressed tightly against it.
- Friction raises the temperature of both the ends. Then rotation is stopped abruptly and the pressure is increased to join.

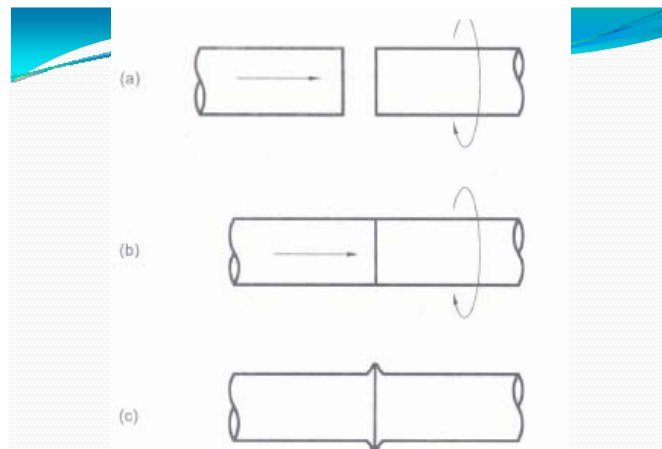
Contd...

- Machine is similar to a centre lathe.
- Power requirements 25 kVA to 175 kVA.
- The axial pressure depends on the strength and hardness of the metals being joined.
- Pressure 40 MPa for low-carbon steels to as high as 450 MPa for alloy steels.

Contd...

- Very efficient.
- Wide variety of metals or combinations of metals can be joined such as aluminium to steel.
- Grain size is refined
- Strength is same as base metal.
- Only round bars or tubes of the same size, or connecting bars or tubes to flat surfaces can join.
- One of the components must be ductile.
- Friction welding is a solid state welding.
- A low contact pressure may be applied initially to permit cleaning of the surfaces by polishing action.

Contd...



Page 59 of 240
Fig. Friction welding process

GATE-2007

Which one of the following is a solid state joining process?

- (a) Gas tungsten arc welding
- (b) Resistance spot welding
- (c) Friction welding
- (d) submerged arc welding

Rev.0

GATE-2014

In solid-state welding, the contamination layers between the surfaces to be welded are removed by

- (a) alcohol
- (b) plastic deformation
- (c) water jet
- (d) sand blasting

GATE-2013

Match the CORRECT pairs.

Processes	Characteristics/Applications
P. Friction Welding	1. Non-consumable electrode
Q. Gas Metal Arc Welding	2. Joining of thick plates
R. Tungsten Inert Gas Welding	3. Consumable electrode wire
S. Electroslag Welding	4. Joining of cylindrical dissimilar materials

- (a) P-4, Q-3, R-1, S-2 (b) P-4, Q-2, R-3, S-1
(c) P-2, Q-3, R-4, S-1 (d) P-2, Q-4, R-1, S-3

GATE -2010 (PI)

Two steel bars, each of diameter 10 mm, are coaxially friction welded, end to end, at an axial pressure of 200 MPa and at a rotational speed of 4000 rpm. The coefficient of friction between the mating faces of the rotating bars is 0.50. The torque is assumed to act at the $3/4^{\text{th}}$ radius of the rotating bar. The power (in KW) consumed at the interface for welding is

- (a) 12.33 (b) 16.44 (c) 18.50 (d) 24.66

IFS-2011

Discuss with figure the various steps required for friction welding, mentioning at least two methods of control.

[5-marks]

Ultrasonic Welding (USW)

- USW is a solid-state welding.
- High-frequency (10 to 200, KHz) is applied.
- Surfaces are held together under light normal pressure.
- Temp. do not exceed one-half of the melting point.
- The ultrasonic transducer is same as ultrasonic machining.

Contd...

- Restricted to the lap joint
- Weld thin materials-sheet, foil, and wire--or the attaching thin sheets to heavier structural members.
- Maximum thickness 2.5 mm for aluminum and 1.0 mm for harder metals.
- Number of metals and dissimilar metal combinations and non metals can be joined such as aluminum to ceramics or glass.
- Equipment is simple and reliable.
- Less surface preparation and less energy is needed.

Contd...

Applications

- Joining the dissimilar metals in bimetallics
- Making microcircuit electrical contacts.
- Welding refractory or reactive metals
- Bonding ultrathin metal.

For-2015 (IES, GATE & PSUs)

Explosion Welding

- Done at room temperature in air, water or vacuum.
- Surface contaminants tend to be blown off the surface.
- Typical impact pressures are millions of psi.
- Well suited to metals that is prone to brittle joints when heat welded, such as,
 - Aluminum on steel
 - Titanium on steel

Page 60 of 240

Contd...

Important factors are,

- Critical velocity
- Critical angle
- The cladding plate can be supported with tack welded supports at the edges, or the metal inserts.

Rev.0

Contd...

- Typically the detonation velocity should not exceed 120% of the sonic velocity in the metal.

Contd...

High velocity explosives, 4572-7620 m/s.

- TNT
- RDX
- PETN
- Composition B
- Composition C₄
- Datasheet
- Primacord

Medium velocity explosives, 1524-4572 m/s

- Ammonium nitrate
- Ammonium perchlorate
- Amatol
- Nitroguanidine
- Dynamites
- diluted PETN

Contd...

Advantages,

- Can bond many dissimilar, normally unweldable metals
- The lack of heating preserves metal treatment
- The process is compact, portable, and easy to contain
- Inexpensive
- No need for surface preparation

Contd...

Disadvantages,

- The metals must have high enough impact resistance, and ductility (at least 5%)
- The cladding plate cannot be too large.
- Noise and blast can require worker protection, vacuum chambers, buried in sand/water.

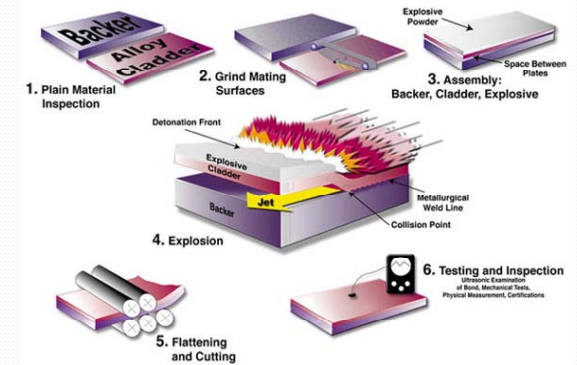
Contd...

Typical applications:

- Very large plates can be cladded.
- Joins dissimilar metals.
(titanium to steel, Al to steel, Al to Cu etc.)
- Join tube to tube sheets of large heat exchangers.

Contd...

Explosion Clad Plate Manufacturing



GATE-1992

In an explosive welding process, the.....
(maximum/minimum) velocity of impact is fixed
by the velocity of sound in the.....
(flyer/target) plate material

- Maximum; target
- Minimum; target
- Maximum; flyer
- Minimum; flyer

For-2015 (IES, GATE & PSUs)

IES 2011 S-1 Contd...

Match List -I with List -II and select the correct answer using the code given below the lists:

List-I	List -II
A. Laser beam welding	1. Can be applied for welding or refractory metals like niobium, tantalum, molybdenum and tungsten.
B. Electron beam welding	2. A sound and clean welded joint is created due to rubbing of two parts against each other with adequate speed and pressure producing intense heat raising temperature above melting point.
C. Ultrasonic welding	3. Clean heat source created much away from job, a narrow spot is heated, work chamber operates in a high vacuum.
D. Friction welding	4. Clean heat source very quick heating, very small focal spot, no vacuum chamber is required.

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IES 2011

From S-1

Codes :

A	B	C	D	A	B	C	D
(a) 4	3	1	2	(b) 2	3	1	4
(c) 4	1	3	4	(d) 2	1	3	4

Rev.0

IES-2009

Match List-I with List-II and select the correct answer using the code given below the Lists:

List-I (Welding Process)	List-II (Application)
A. Laser welding	1. Uniting large-area sheets
B. Friction welding	2. Repairing large parts
C. Ultrasonic welding	3. Welding a rod to a flat surface
D. Explosive welding	4. Fabrication of nuclear reactor components
	5. Welding very thin materials

Code:									
(a)	A	B	C	D	(b)	A	B	C	D
	5	4	3	2		1	4	2	5
(c)	A	B	C	D	(d)	A	B	C	D
	1	3	4	2		5	3	4	1

IAS-2002

Match List I, (Welding) with List II (Application) and select the correct answer using the codes given below the Lists:

List I (Welding)				List II (Application)					
A.	Explosive			1.	Joining thick sheets				
B.	Ultrasonic			2.	Manufacture of heat exchangers				
C.	Thermit			3.	Joining thin sheets or wires of similar/dissimilar metals				
D.	Projection			4.	Joining hydraulic piston rods for agricultural machinery				
				5.	Joining rails, pipes and thick steel sections				
Codes:	A	B	C	D	A	B	C	D	
(a)	2	5	1	3	(b)	4	5	1	3
(c)	2	3	5	1	(d)	4	3	5	1

IFS - 2009

Two plates of aluminium and stainless steel are to be welded back to back to create a single plate of thickness equal to the sum of the thicknesses of the two plates. Suggest the suitable process and explain it in brief.

[10 – marks]

Autogeneous Welding

- Autogeneous welding or fusion of the parent material in an inert gas shield without the use of filler metals.

Micro Plasma Arc Weld (PAW)

- Similar to GTAW except the plasma caused by the arc is constricted by a water-cooled orifice
- Capable of high welding speeds where size permits
- Argon is used as the shielding gas.

Diffusion Welding

- It is a **solid state** welding process which produces coalescence of the faying surfaces by the application of **pressure** and elevated **temperatures** (about 50 to 80% of absolute melting point of the parent materials) for a time ranging from a couple of minutes to a few hours.
- Produces high quality bonds with good strength with little or no distortion.
- Can join very dissimilar materials.
- A solid filler metal may or may not be inserted.
- Materials welded for **aircraft and rocket industry**: Boron, Titanium, Aluminium, Ceramic, Composite, Graphite, Magnesium etc.

GATE – 2008 (PI)

Which pair among the following solid state welding processes uses heat from an external source?

- P – Diffusion welding; Q- Friction welding
- R – Ultrasonic welding S – Forge welding
- (a) P and R (b) R and S
- (c) Q and S (d) P and S

For-2015 (IES, GATE & PSUs)

IAS-2001

Match List I (Welding processes) with List II (Features) and select the correct answer using the codes given below the Lists:

List I			List II				
A.	Ultrasonic welding	1.	Gas heated to ionized condition for conduction of electric current				
B.	Electron beam welding	2.	High frequency and high intensity vibrations				
C.	Plasma arc welding	3.	Concentrated stream of high-energy electrons				
		4.	Exothermal chemical reaction				
Codes:	A	B	C	A	B	C	
(a)	1	2	4	(b)	4	3	1
(c)	2	1	4	(d)	2	3	1

IJWM 2010

Match List-I with List-II and select the correct answer using the code given below the lists :

List I		List II	
A. Atomic hydrogen welding		1. Two pieces are brought together and power supply is switched on	
B. Plasma-arc welding		2. Nugget is formed at the interface of two plates	
C. Spot welding		3. Gas is ionized	
D. Flash welding		4. Inert gas shielded arc welding	

Code:	A	B	C	D		A	B	C	D
(a)	4	3	2	1	(b)	1	3	2	4
(c)	4	2	3	1	(d)	1	2	3	4

IES 2011 Conventional

Discuss the process capabilities and applications of Gas Metal Arc Welding, Gas tungsten Arc Welding, and Diffusion Bonding processes.

[15 Marks]

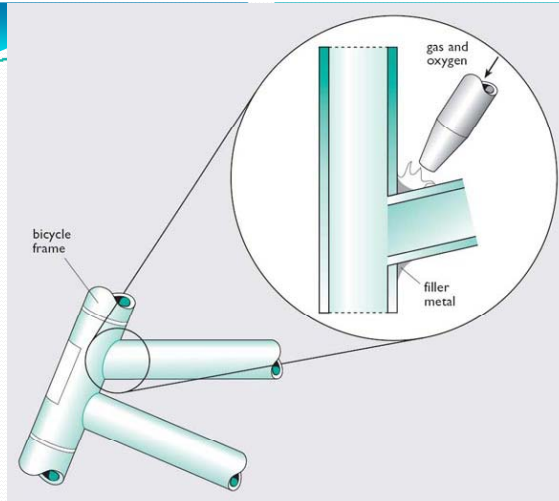
Brazing and Soldering

Brazing and Soldering

- Brazing is the joining of metals through the use of heat and a filler metal whose melting temperature is above 450°C; but below the melting point of the metals being joined.

Comparison with welding and the brazing process

- The **composition** of the brazing alloy is significantly different from that of the base metal.
- The **strength** of the brazing alloy is substantially lower than that of the base metal.
- The **melting point** of the brazing alloy is lower than that of the base metal, so the base metal is not melted.
- Capillary action** or **capillary attraction** draws the molten filler metal into the joint, even against the flow of gravity.



Brazing process has several distinct advantages:

- All metals can be joined.
- Suited for dissimilar metals.
- Quick and economical.
- Less defects.
- Corrosion prone

Contd...

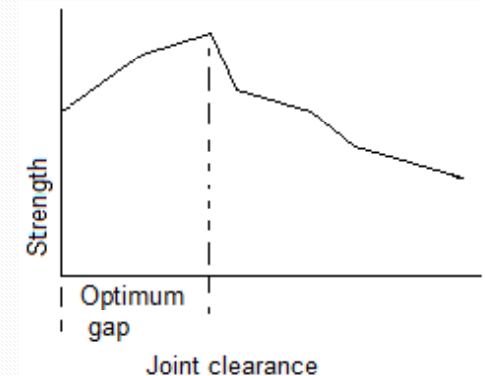
Brazing metals are typically alloys such as,

- Brazing brass (60% Cu, 40%Zn)
- Manganese bronze
- Nickel silver
- Copper silicon
- Silver alloys (with/without phosphorous)
- Copper phosphorous

Contd...

- Extremely clean surface needed.
- Fluxes used are combinations of borax, boric acid, chlorides, fluorides, tetra-borates and other wetting agents.

- A popular composition is 75% borax and 25% boric acid.
- Sodium cyanide is used in brazing tungsten to copper.
- Base materials not melted.



GATE-2005

The strength of a brazed joint

- (a) Decreases with increase in gap between the two joining surfaces
- (b) Increases with increase in gap between the two joining surfaces
- (c) Decreases up to certain gap between the two joining surfaces beyond which it increases
- (d) Increases up to certain gap between the two joining surfaces beyond which it decreases

IES-2006

Which one of the following is not a fusion welding process?

- (a) Gas welding
- (b) Arc welding
- (c) Brazing
- (d) Resistance welding

ISRO-2010

Which is not correct statement about the function of flux in brazing

- (a) To avoid thermal distortion and cracking
- (b) To dissolve surface oxide coatings which have formed prior to brazing
- (c) To prevent oxides from forming during the brazing operation on both the base metal and the brazing material
- (d) To facilitate the wetting process by reducing the viscosity of the melt

Braze Welding

- Capillary action is not required.
- Edge preparation needed.
- Can join cast iron.

Contd...

- Done with an oxyacetylene torch.

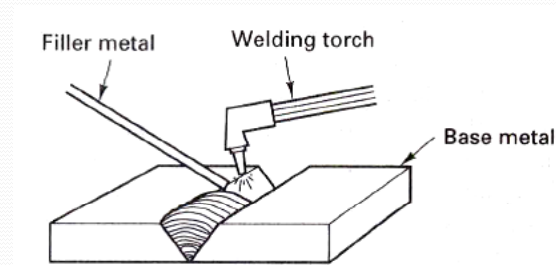


Fig. Braze Welding

Soldering

- By definition, **soldering** is a brazing type of operation where the filler metal has a melting temperature **below 450°C**.
- Strength of the filler metal is low.
- Soldering is used for a **neat leak-proof joint** or a low resistance electrical joint.
- Not suitable for high-temp. application.

Contd...

Effective soldering generally involves six important steps:

- (1) Design of an acceptable solder joint,
- (2) Selection of the correct solder for the job,
- (3) Selection of the proper type of flux,
- (4) Cleaning the surfaces to be joined,
- (5) Application of flux, solder, and sufficient heat to allow the molten solder to fill the joint by capillary action and solidify, and
- (6) Removal of the flux residue, if necessary.

Solder Metals

- Most solders are alloys of lead and tin.
- Three commonly used alloys contain 60, 50, and 40% tin and all melt below 240°C.

Contd...

Solder Flux

- Ammonium chloride or rosin for soldering tin
- Hydrochloric acid and zinc chloride for soldering galvanized iron
- Some fluxes are corrosive and should be removed after use

- **Silver solders** uses for higher-temperature service, Electrical and Electronic purpose.

GATE-2014(PI)

Brazing and Soldering are

- plastic joining methods
- homogeneous joining methods
- autogenous joining methods
- heterogeneous joining methods

Difficulties with Grey Cast Iron

Soldering and brazing are difficult of grey cast Iron due to surface contamination with graphite having a very low surface energy.

IES-1994

Match List - I with List - II and select the correct answer using the codes given below the Lists:

List - I (Filler)

- Cu, Zn, Ag alloy
- Cu, Sn, alloy
- Pb, Sb, alloy
- Iron oxide and aluminium powder

List - II (Joining process)

- Braze welding.
- Brazing
- Soldering
- TIG welding of aluminium

Codes: A B C D A B C D
 (a) 2 1 3 - (b) 1 2 4 -
 (c) 2 1 3 4 (d) 2 - 3 4

IAS-1996

Match List I with List II and select the correct answer using the codes given below the lists

**List -I
(Filler rod material)**

- Mild steel
- Bronze
- Brass
- Lead and tin alloy

**List-II
(Joining process)**

- MIG welding
- Soldering
- Brazing
- Thermit welding
- Braze welding

Codes: A B C D A B C D
 (a) 1 5 3 2 (b) 4 3 2 5
 (c) 4 3 5 2 (d) 1 3 5 4

Welding design and defect

Welding Problem	Causes
Cracking of weld metal	High joint rigidity
Cracking of base metal	Excessive stresses
Splatter	Arc blow
Distortion	Poor joint selection
Slag inclusion	Improper cleaning in multi-pass welding
Porosity	Excessive H ₂ , O ₂ , N ₂ , in the welding atmosphere or Damp electrodes
Lamellar Tearing	inclusions such as Mn Fe and S in the base metal and/or residual stress

IES-2004

Match List I (Welding problems) with List II (Causes) and select the correct answer using the codes given below the Lists:

List I

- Cracking of weld metal
- Cracking of base metal
- Porosity
- Inclusions

List II

- Excessive stresses
- High joint rigidity
- Failure to remove slag from previous deposit
- Oxidation
- Excessive H₂, O₂, N₂, in the welding atmosphere

Codes: A B C D A B C D
 (a) 2 1 5 3 (b) 3 4 2 1
 (c) 2 4 5 3 (d) 3 1 4 2

IES-2003, ISRO-2011

Match List I(Welding Defects) with List II (Causes) and select the correct answer using the codes given below the Lists:

**List-I
(Welding Defects)**

- Splatter
- Distortion
- Slag inclusion
- Porosity

**List II
(Causes)**

- Damp electrodes
- Arc blow
- Improper cleaning in multi-pass welding
- Poor joint selection

Codes: A B C D A B C D
 (a) 4 2 3 1 (b) 4 2 1 3
 (c) 2 4 1 3 (d) 2 4 3 1

Cracks

- Cracks may be of micro or macro size and may appear in the weld metal or base metal or base metal and weld metal boundary.
- Different categories of cracks are longitudinal cracks, transverse cracks or radiating/star cracks and cracks in the weld crater.
- Cracks occur when localized stresses exceed the ultimate tensile strength of material.
- These stresses are developed due to shrinkage during solidification of weld metal.

Cracks may be developed due to poor ductility of base metal, high sulphur and carbon contents, high arc travel speeds i.e. fast cooling rates, too concave or convex weld bead and high hydrogen contents in the weld metal.

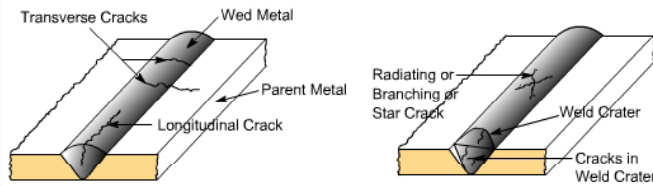


Fig. Various Types of Cracks in Welds

HAZ Cracking

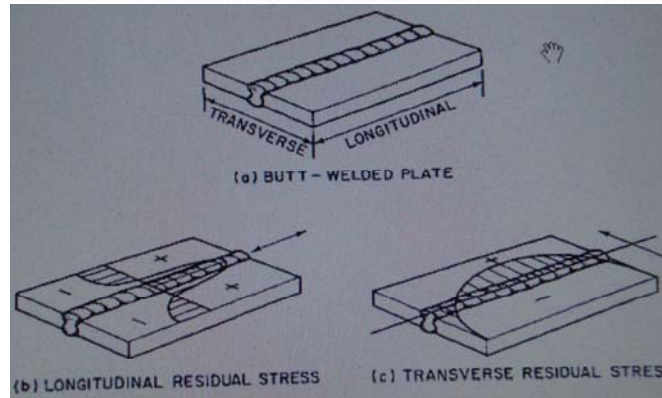
- Cracking in heat affected zone may be caused by:
 - (i) Hydrogen in welding atmosphere
 - (ii) hot cracking
 - (iii) low ductility
 - (iv) high residual stresses
 - (v) brittle phase in the microstructure

Hydrogen Induced Cracking

- Due to the presence of moisture, grease, rust etc., hydrogen may enter the weld pool and get dissolved in the weld metal.
- During cooling hydrogen diffuses to the HAZ.
- Cracking may develop due to residual stresses assisted by hydrogen coalescence.
- The factors that determine the probability of hydrogen induced embrittlement and cracking of weld are:
 - (a) Hydrogen content
 - (b) fracture toughness of weld and HAZ
 - (c) stress to which the joint is exposed as a result of the weld thermal cycle.

Residual stress

- The residual stresses result from the restrained expansion and contraction that occur during localized heating and cooling in the region of weld deposit.
- The magnitude of residual stresses depends on the weldment design, support and clamping of the components being welded, their materials, welding process used, part dimensions, welding sequence, post weld treatment, size of the deposited weld beads, etc.
- Residual stresses should not have a harmful effect on the strength performance of weldments, reduces fatigue strength. May cause distortion. This residual stress may result in the cracking of a brittle material and is not important as far as a ductile material.



Porosity

- Porosity results when the gases are entrapped in the solidifying weld metal.
- These gases are generated from the flux or coating constituents of the electrode or shielding gases used during welding or from absorbed moisture in the coating.
- Porosity can also be controlled if excessively high welding currents, faster welding speeds and long arc lengths are avoided flux and coated electrodes are properly baked.

Solid Inclusion

- Solid inclusions may be in the form of slag or any other nonmetallic material entrapped in the weld metal as these may not be able to float on the surface of the solidifying weld metal.
- During arc welding flux either in the form of granules or coating after melting, reacts with the molten weld metal removing oxides and other impurities in the form of slag and it floats on the surface of weld metal due to its low density.
- Slag inclusion can be prevented if proper groove is selected, all the slag from the previously deposited bead is removed, too high or too low welding currents and long arcs are avoided.

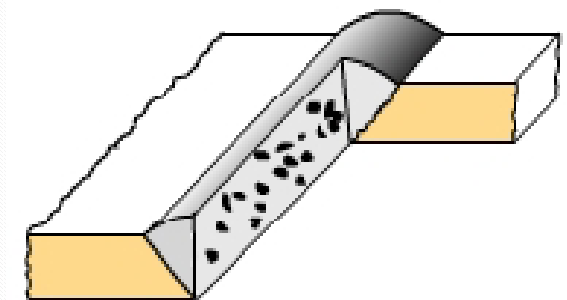


Fig. Slag Inclusion in Weldments
Rev.0

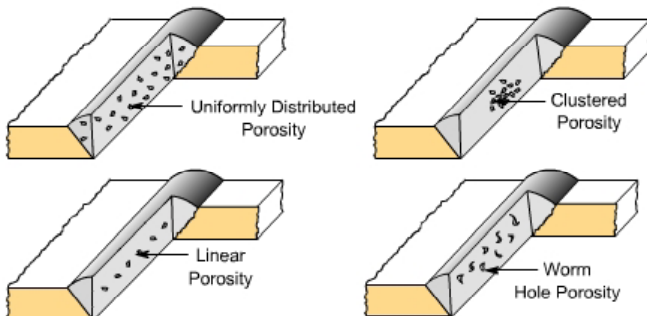
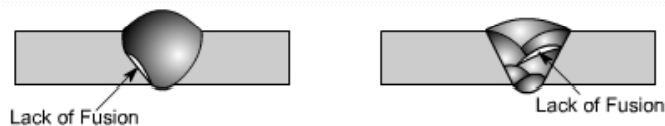


Fig. Different Forms of Porosities
For-2015 (IES, GATE & PSUs)

Lack of Fusion

- Lack of fusion is the failure to fuse together either the base metal and weld metal or subsequent beads in multipass welding because of failure to raise the temperature of base metal or previously deposited weld layer to melting point during welding.
- Lack of fusion can be avoided by properly cleaning of surfaces to be welded, selecting proper current, proper welding technique and correct size of electrode.



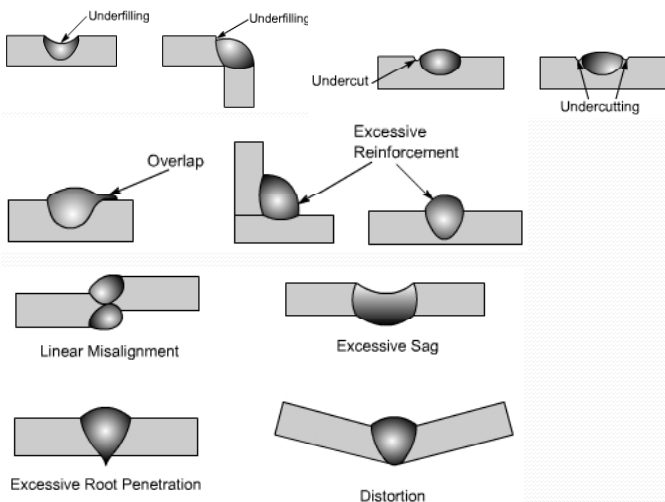
Incomplete Penetration

- Incomplete penetration means that the weld depth is not upto the desired level or root faces have not reached to melting point in a groove joint.
- If either low currents or larger arc lengths or large root face or small root gap or too narrow groove angles are used then it results into poor penetration.



Imperfect Shape, Distortions

- Imperfect shape means the variation from the desired shape and size of the weld bead.
- During undercutting a notch is formed either on one side of the weld bead or both sides in which stresses tend to concentrate and it can result in the early failure of the joint. Main reasons for undercutting are the excessive welding currents, long arc lengths and fast travel speeds.
- Underfilling may be due to low currents, fast travel speeds and small size of electrodes. Overlap may occur due to low currents, longer arc lengths and slower welding speeds.
- Excessive reinforcement is formed if high currents, low voltages, slow travel speeds and large size electrodes are used. Excessive root penetration and sag occur if excessive high currents and slow travel speeds are used for relatively thinner members.
- Distortion is caused because of shrinkage occurring due to large heat input during welding.



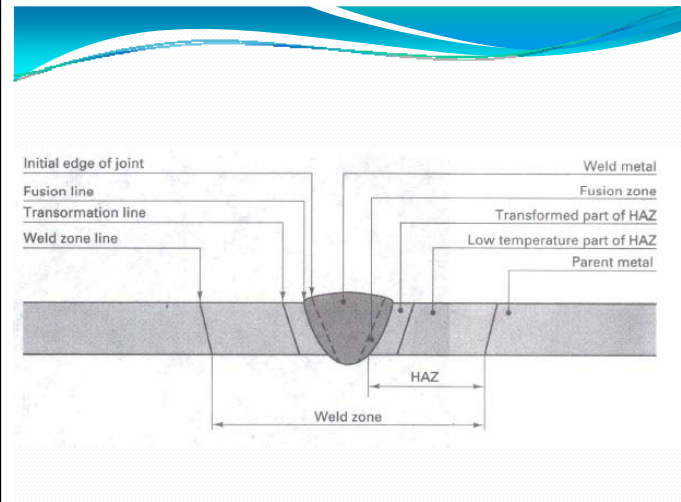
IES 2011 Conventional

- Enumerate four defects caused due to residual stresses in welded joints.

[2 Marks]

Ans.

- Distortion
- Cracking in the base metal
- Lamellar Tearing
- Reduction of fatigue strength



IES-2004

Consider the following statements:

The magnitude of residual stresses in welding depends upon

- Design of weldment
- Support and clamping of components
- welding process used
- Amount of metal melted / deposited

Which of the statements given above are correct?

- (a) 1, 2 and 4 (b) 1, 2 and 3
(c) 1 and 3 (d) 2 and 3

For-2015 (IES, GATE & PSUs)

GATE-2003

Match the following

Work material

- P. Aluminium
Q. Die Steel
R. Copper Wire
S. Titanium sheet

Type of joining

- Submerged Arc Welding
- Soldering
- Thermit Welding
- Atomic Hydrogen Welding
- Gas Tungsten Arc Welding
- Laser Beam Welding
- Brazing

- (a) P - 2 Q - 5 R - 1 S - 3
(b) P - 6 Q - 3 R - 4 S - 4
(c) P - 4 Q - 1 R - 6 S - 2
(d) P - 5 Q - 4 R - 2 S - 6

Page 67 of 240

IES-2004

Consider the following statements:

The size of the heat affected zone (HAZ) will increase with

- Increased starting temperature
- Increased welding speed
- Increased thermal conductivity of the base metal
- Increase in base metal thickness

Which of the statements given above are correct?

- (a) 1, 2 and 3 (b) 1 and 3
(c) 1 and 4 (d) 2 and 3

Rev.0

IES-1992

Weld spatter occurs due to any of the following except

- (a) High welding current
- (b) Too small an electrode
- (c) Arc
- (d) Wrong polarity

JWM 2010

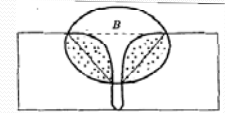
Assertion (A) : Spatter is one of the welding defects.
Reason (R) : In submerged arc welding process, there is no spatter of molten metal.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-1998

An arc welded joint is shown in the above figure. The part labelled 'B' in the figure is known as

- (a) Weld preparation
- (b) Penetration
- (c) Reinforcement
- (d) Slag



IES-2004

Assertion (A): A sound welded joint should not only be strong enough but should also exhibits a good amount of ductility

Reason (R): Welding process is used for fabricating mild steel components only

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IAS-2003

Tool material not suited to resistance welding is

- (a) Aluminium oxide
- (b) Stellite
- (c) High speed steel
- (d) Masonite

GATE-1996

Preheating before welding is done to

- (a) Make the steel softer
- (b) Bum away oil, grease, etc, from the plate surface
- (c) Prevent cold cracks
- (d) Prevent plate distortion

IES 2011

Cold-cracking in steel weldments depends on

- 1. Carbon equivalent
 - 2. Heat input
 - 3. Effective thickness
 - 3. Hydrogen content in weld pool
- (a) 1, 2 and 3 only
 - (b) 1, 2 and 4 only
 - (c) 2, 3 and 4 only
 - (d) 1, 2, 3 and 4

GATE-2001

Two plates of the same metal having equal thickness are to be butt welded with electric arc. When the plate thickness changes, welding is achieved by

- (a) Adjusting the current
- (b) Adjusting the duration of current
- (c) Changing the electrode size
- (d) Changing the electrode coating

IES - 2012

Brittle welds are mainly obtained due to

- (a) Wrong electrode, faulty preheating and metal hardened by air
- (b) Faulty welds, faulty sequence and rigid joints
- (c) Wrong speed, current improperly adjusted and faulty preparation
- (d) Uneven heat, improper sequence and deposited metal shrinks

IES - 2012

Which of the following are associated with Heat Affected Zone?

1. Cold cracking
2. Notch toughness
3. Hydrogen embrittlement
4. Stress corrosion cracking

- (a) 1, 2 and 3 only
(b) 1, 3 and 4 only
(c) 2, 3 and 4 only
(d) 1, 2, 3 and 4

GATE-2014

Within the Heat Affected Zone (HAZ) in a fusion welding process, the work material undergoes

- (a) microstructural changes but does not melt
(b) neither melting nor microstructural changes
(c) both melting and microstructural changes after solidification
(d) melting and retains the original microstructure after solidification

IES - 2012

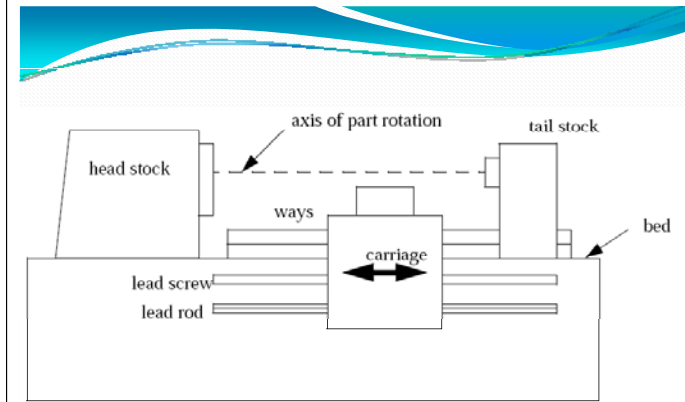
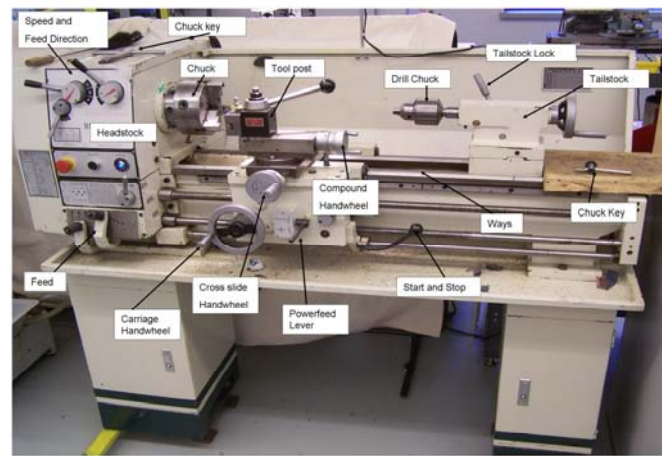
Statement (I): Hydrogen induced cracking occurs in the heat effected zone adjacent to fusion zone and classified as solid state cracking

Statement (II):Hydrogen from burning of flux coating penetrates martensitic micro cracks preventing healing as well as enlarging them.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

Lathe

By S K Mondal



Lathe

- A **lathe** is a large machine that rotates the work, and cutting is done with a non-rotating cutting tool. The shapes cut are generally round, or helical. The tool is typically moved parallel to the axis of rotation during cutting.
- **head stock** - this end of the lathe contains the driving motor and gears. Power to rotate the part is delivered from here. This typically has levers that let the speeds and feeds be set.
- **ways** - these are hardened rails that the carriage rides on.
- **tail stock** - this can be used to hold the other end of the part.

Lathe

- **Bed** - this is a bottom pan on the lathe that catches chips, cutting fluids, etc.
- **carriage** - this part of the lathe carries the cutting tool and moves based on the rotation of the lead screw or rod.
- **Lead screw** - A large screw with a few threads per inch used for cutting threads. It has ACME threads with included angle of 29° for easy engagement and disengagement of half nut.
- **Lead rod** - a rod with a shaft down the side used for driving normal cutting feeds.
- The critical parameters on the lathe are speed of rotation (speed in RPM) and how far the tool moves across the work for each rotation (feed in IPR)

General classifications used when describing lathes

- **Swing** - the largest diameter of work that can be rotated.
- **Distance Between Centres** - the longest length of workpiece
- **Length of Bed** - Related to the Distance Between Centres
- **Power** - The range of speeds and feeds, and the horsepower available

Number of Spindle Speed

- Number of spindle speed is in a geometric progression.
- If n number of spindle speed is required with N_1 is the minimum speed then

$$N_1, N_1 r, N_1 r^2, N_1 r^3, \dots, N_1 r^{n-1}$$

$$N_1 = N_{\min} \quad \text{and} \quad N_1 r^{n-1} = N_{\max}$$

$$\text{Therefore, Step Ratio } (r) = \left(\frac{N_{\max}}{N_{\min}} \right)^{\frac{1}{n-1}}$$

- The values of step ratios are 1.06, 1.12, 1.26, 1.41, 1.58 and 2

IES - 2001

The spindle speed range in a general purpose lathe is divided into steps which approximately follow

- Arithmetic progression
- Geometric progression
- Harmonic progression
- Logarithmic progression

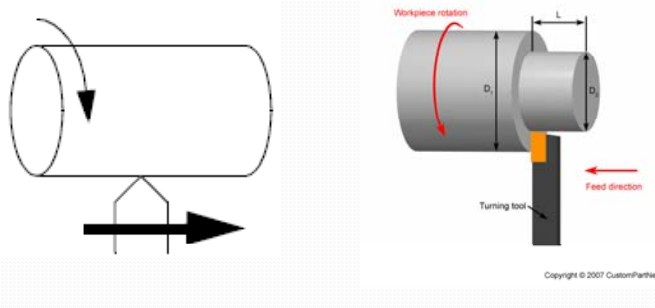
IES - 1992

Feed gear box for a screw cutting lathe is designed on the basis of

- Geometric progression
- Arithmetic progression
- Harmonic progression
- None.

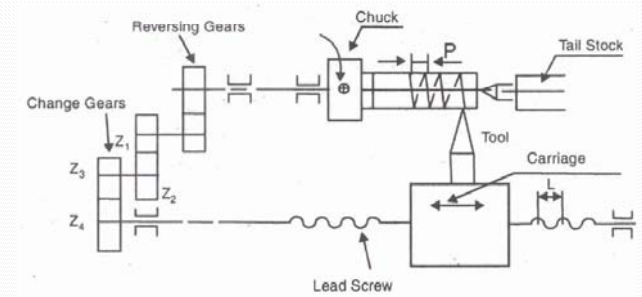
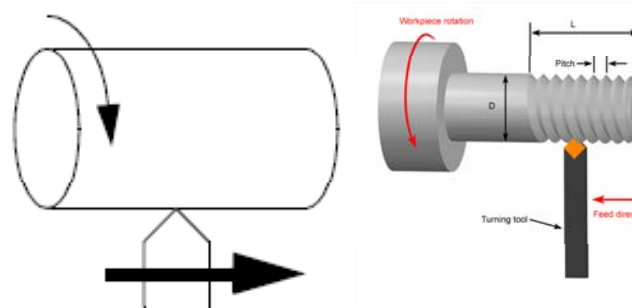
Turning

- Turning - produces a smooth and straight outside radius on a part.



Threading

- Threading - The cutting tool is moved quickly cutting threads.



Threading

- In one revolution of the spindle, carriage must travel the pitch of the screw thread to be cut.

$$N_s P z_s = N_L z_L$$

P = Pitch of the screw thread to be cut

L = Pitch of the lead screw

z_s = Number of start of the screw thread to be cut

z_L = Number of start of the lead screw

i_{cg} = gear ratio of spindle (N_s) to carriage (N_L) gear train

IES - 1998

A single start thread of pitch 2 mm is to be produced on a lathe having a lead screw with a double start thread of pitch 4 mm. The ratio of speeds between the spindle and lead screw for this operation is

- (a) 1 : 2 (b) 2 : 1
(c) 1 : 4 (d) 4 : 1

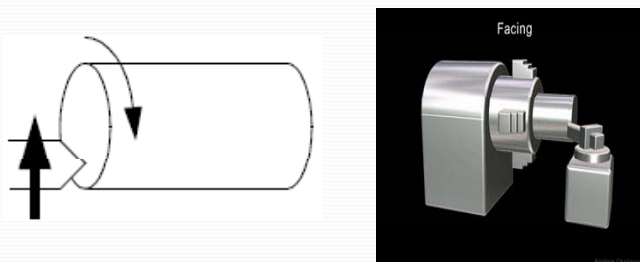
IES – 1993, ISRO-2009

It is required to cut screw threads of 2 mm pitch on a lathe. The lead screw has a pitch of 6 mm. If the spindle speed is 60 rpm, then the speed of the lead screw will be

- (a) 10 rpm (b) 20 rpm
(c) 120 rpm (d) 180 rpm

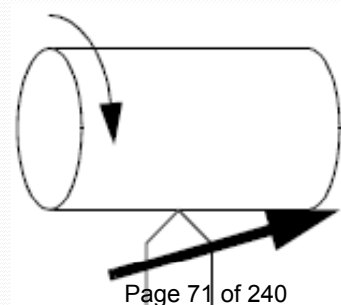
Facing

- Facing - The end of the part is turned to be square.



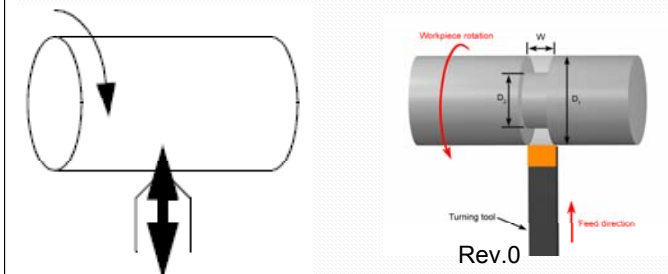
Tapering

- Tapering - the tool is moves so as to cut a taper (cone shape).



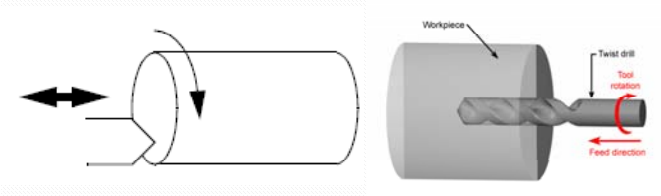
Parting/Slotting/Grooving

- A tool is moved in/out of the work. shallow cut will leave a formed cut, a deep cut will cut off the unsupported part.



Drilling/Boring

- Drilling/Boring - a cutter or drill bit is pushed into the end to create an internal feature.



Knurling

- **Knurling is a manufacturing process whereby a visually-attractive diamond-shaped (criss-cross) pattern is cut or rolled into metal.**
- **This pattern allows human hands or fingers to get a better grip on the knurled object than would be provided by the originally-smooth metal surface.**



Spinning

- Metal Spinning is a process by which circles of metal are shaped over mandrels (also called forms) while mounted on a spinning lathe by the application of levered force with various tools.



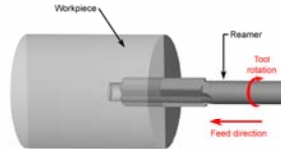
ISRO-2007

Spinning operation is carried out on

- (a) Hydraulic press
- (b) Mechanical press
- (c) Lathe
- (d) Milling machine

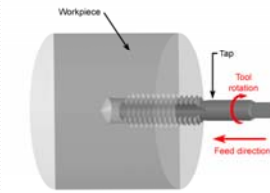
Reaming

- A reamer enters the workpiece axially through the end and enlarges an existing hole to the diameter of the tool. Reaming removes a minimal amount of material and is often performed after drilling to obtain both a more accurate diameter and a smoother internal finish.



Tapping

- A tap enters the workpiece axially through the end and cuts internal threads into an existing hole. The existing hole is typically drilled by the required tap drill size that will accommodate the desired tap.



Work holding Devices for Lathes

- Held between centers
- 3 jaw self centering chuck (Disc type jobs being held in chucks)
- 4 jaw independently adjusted chuck
- Held in a collet (Slender rod like jobs being held in collets)
- Mounted on a face plate (Odd shape jobs, being held in face plate)
- Mounted on the carriage
- Mandrels
- Magnetic chuck - for thin job

Lathe chucks

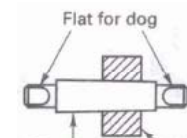
- Lathe chucks are used to support a wider variety of workpiece shapes and to permit more operations to be performed than can be accomplished when the work is held between centers.
- Three-jaw, self-centering chucks are used for work that has a round or hexagonal cross section.
- Each jaw in a four-jaw independent chuck can be moved inward and outward independent of the others by means of a chuck wrench. Thus they can be used to support a wide variety of work shapes.
- Combination four-jaw chucks are available in which each jaw can be moved independently or can be moved simultaneously by means of a spiral cam.



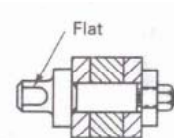
3 Jaw Chuck



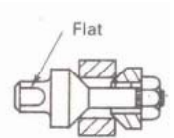
4 Jaw Chuck



Plain solid mandrel

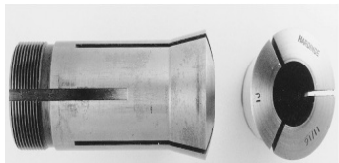


Gang mandrel



Cone mandrel

Rev.0



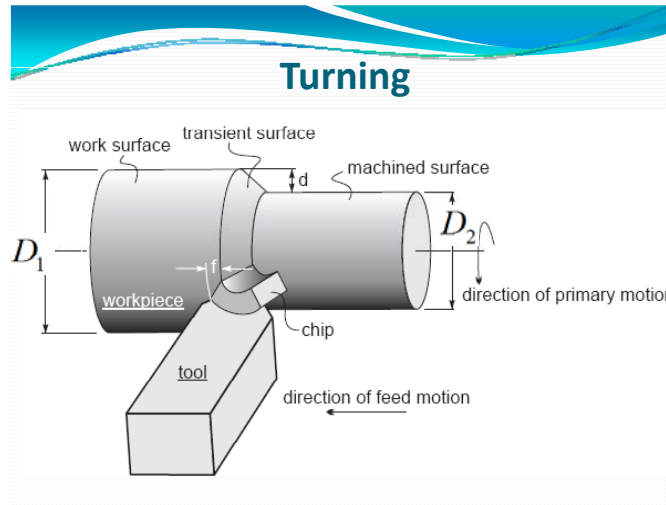
Collets



Magnetic Chuck



Face Plate



Turning

Formula for Turning

- Depth of cut, $d = \text{DOC} = \frac{D_1 - D_2}{2}$ mm
- Average diameter of workpiece $D_{\text{avg}} = \frac{D_1 + D_2}{2}$ mm
- Cutting Time $C_T = \frac{L + A + O}{fN}$
- Metal Removal Rate $MRR = \frac{(\pi D_1^2 - \pi D_2^2)}{4 / fN} = \pi D_{\text{avg}} d fN$
- Cutting Speed, $V = \frac{\pi D_1 N}{1000}$, m / min

Example

How much machining time will be required to reduce the diameter of a cast iron rod from 120 mm to 116 mm over a length of 100 mm by turning using a carbide insert. Cutting velocity is 100 m/min and feed rate = 0.2 mm/rev.

IES 2010

In turning a solid round bar, if the travel of the cutting tool in the direction of feed motion is 1000 mm, rotational speed of the workpiece is 500 rpm, and rate of feed is 0.2 mm/revolution, then the machining time will be

- (a) 10 seconds (b) 100 seconds
(c) 5 minutes (d) 10 minutes

IES - 2003

The time taken to face a workpiece of 72 mm diameter, if the spindle speed is 80 r.p.m. and cross-feed is 0.3 mm/rev, is

- (a) 1.5 minutes (b) 3.0 minutes
(c) 5.4 minutes (d) 8.5 minutes

GATE-2013 (PI) Common Data

A disc of 200 mm outer and 80 mm inner diameter is faced of 0.1 mm/rev with a depth of cut of 1 mm. The facing operation is undertaken at a constant cutting speed of 90 m/min in a CNC lathe. The main (tangential) cutting force is 200 N.

Assuming approach and over-travel of the cutting tool to be zero, the machining time in min is

- (a) 2.93 (b) 5.86 (c) 6.66 (d) 13.33

IAS - 2002

A 150 mm long, 12 mm diameter 304 stainless steel rod is being reduced in diameter to 11.5 mm by turning on a lathe. The spindle rotates at $N = 400$ rpm and the tool is travelling at an axial speed of 200 mm/min. The time taken for cutting is given by

- (a) 30 s (b) 36 s
(c) 1 minute (d) 45 s

IES - 2004

A medium carbon steel workpiece is turned on a lathe at 50 m/min. cutting speed 0.8 mm/rev feed and 1.5 mm depth of cut. What is the rate of metal removal?

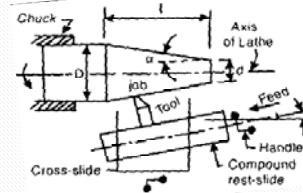
- (a) 1000 mm³/min
(b) 60,000 mm³/min
(c) 20,000 mm³/min
(d) Can not be calculated with the given data

Turning Tapers on Lathes

- Using a compound slide,
- Using form tools,
- Offsetting the tailstock, and
- Using taper turning attachment.

Using a Compound Slide

- Limited movement of the compound slide
- Feeding is by hand and is non-uniform. This is responsible for low-productivity and poor surface finish.
- Can be employed for turning short internal and external tapers with a large angle of (steep) taper.



Using a Compound Slide contd..

- The angle is determined by

$$\tan \alpha = \frac{D-d}{2l}$$

α = Half taper angle

D = Diameter of stock

d = smaller diameter

l = length of the taper

IES - 2006

For taper turning on centre lathes, the method of swiveling the compound rest is preferred for:

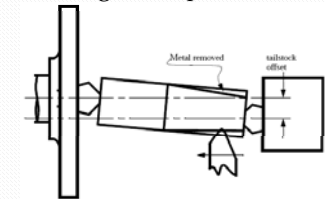
- Long jobs with small taper angles
- Long jobs with steep taper angles
- Short jobs with small taper angles
- Short jobs with steep taper angles

Example

Find the angle at which the compound rest should be set up to turn taper on the workpiece having a length of 200 mm, larger diameter 45 mm and the smaller 30 mm.

Offsetting the tailstock

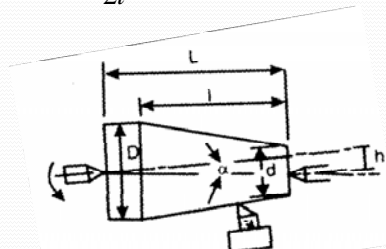
- It is necessary to measure the tailstock offset when using this method.
- This method is limited to small tapers (Not exceeding 8°) over long lengths.
- By offsetting the tailstock, the axis of rotation of the job is inclined by the half angle of taper.



Offsetting the tailstock Contd..

- Tailstock offset (h) can be determined by

$$h = \frac{L(D-d)}{2l} \text{ or } h = L \tan \alpha$$



For-2015 (IES, GATE & PSUs)

IES - 1992

Tail stock set over method of taper turning is preferred for

- Internal tapers
- Small tapers
- Long slender tapers
- Steep tapers

IAS - 2002

The amount of offset of tail stock for turning taper on full length of a job 300 mm long which is to have its two diameters at 50 mm and 38 mm respectively is

- 6 mm
- 12 mm
- 25 mm
- 44 mm

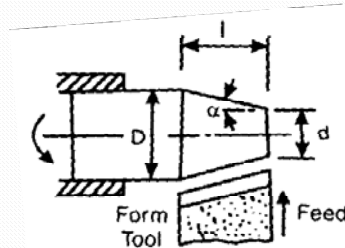
IES - 1998

A 400 mm long shaft has a 100 mm tapered step at the middle with 4° included angle. The tailstock offset required to produce this taper on a lathe would be

- (a) $400 \sin 4^\circ$ (b) $400 \sin 2^\circ$
(c) $100 \sin 4^\circ$ (d) $100 \sin 2^\circ$

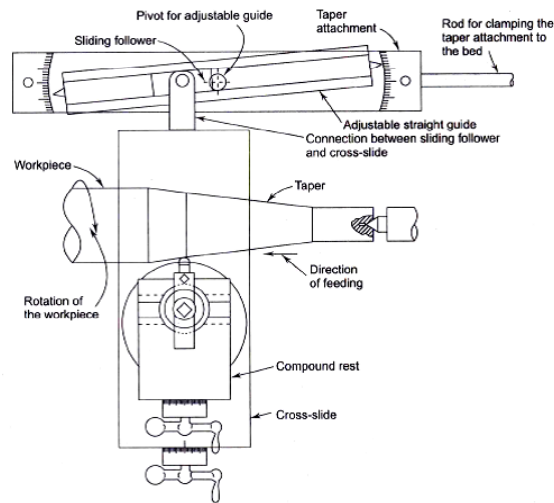
Form tool

- Special form tool for generating the tapers is used. The feed is given by plunging the tool directly into the work. This method is useful for short external tapers, where the steepness is of no consequence, such as for chamfering.

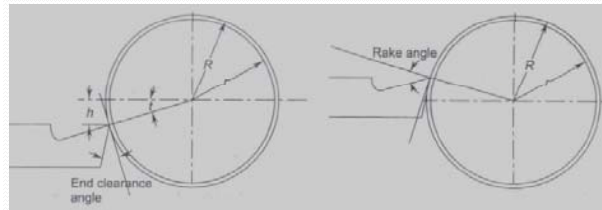


Taper Turning Attachment

- Additional equipment is attached at the rear of the lathe.
- The cross slide is disconnected from the cross feed nut.
- The cross slide is then connected to the attachment.
- As the carriage is engaged, and travels along the bed, the attachment will cause the cutter to move in/out to cut the taper.
- For turning tapers over a comprehensive range is the use of taper turning attachment.



Errors in tool settings



- Setting the tool below the centre decrease actual rake angle, while clearance angle increases by the same amount. Thus cutting force increased.
- Setting the tool above the centre causes the rake angle to increase, while clearance angle reduces. More rubbing with flank.

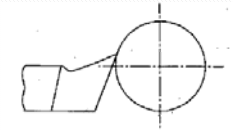
IES 2010

The effect of centering error when the tool is set above the center line as shown in the figure results effectively in

- Increase in rake angle.
- Reduction in rake angle.
- Increase in clearance angle.
- Reduction in clearance angle.

Which of these statements is/are correct?

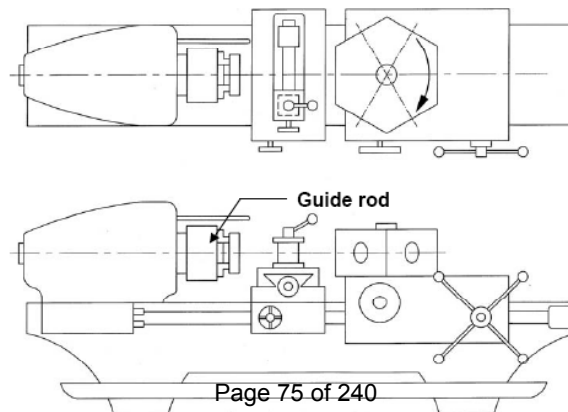
- (a) 1 only (b) 1 and 4 only
(c) 2 and 4 only (d) 1, 2, 3 and 4



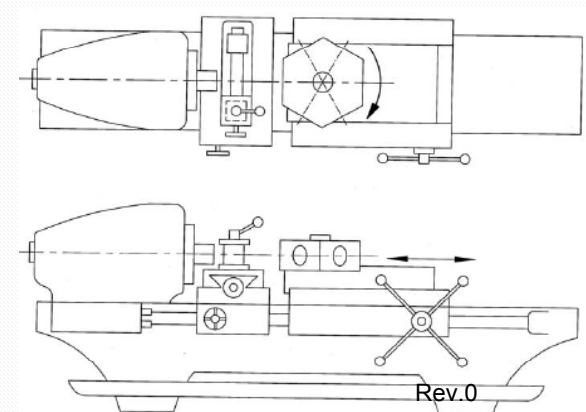
Turret Lathe

A turret lathe, a number of tools can be set up on the machine and then quickly be brought successively into working position so that a complete part can be machined without the necessity for further adjusting, changing tools, or making measurements.

Turret Lathe



Capstan Lathe



Capstan lathe	Turret lathe
Short slide, since the saddle is clamped on the bed in position.	Saddle moves along the bed, thus allowing the turret to be of large size.
Light duty machine, generally for components whose diameter is less than 50 mm.	Heavy duty machine, generally for components with large diameters, such as 200 mm.
Too much overhang of the turret when it is nearing cut.	Since the turret slides on the bed, there is no such difference.
Ram-type turret lathe, the ram and the turret are moved up to the cutting position by means of the capstan Wheel. As the ram is moved toward the headstock, the turret is automatically locked into position.	Saddle-type lathes, the main turret is mounted directly on the saddle, and the entire saddle and turret assembly reciprocates.

IES - 2012

Lathe machine with turret can turn a work piece of limited length only because,

- Cross slide motion is obstructed by turret
- Turret cannot work on a long job
- Chuck cannot be replaced by a face plate
- Turret replaces the loose centre

Turret indexing mechanism

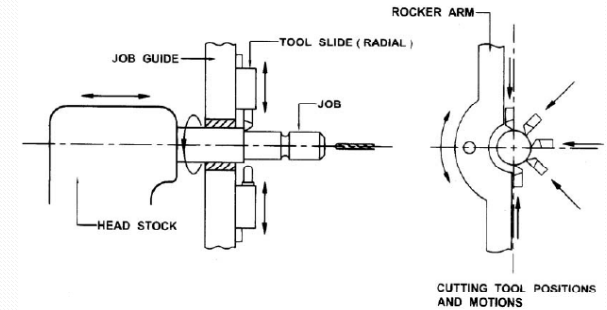
- The hexagonal turret is rotated (for indexing) by a Geneva mechanism where a Geneva disc having six radial slots is driven by a revolving pin. Before starting rotation, the locking pin is withdrawn by a cam lever mechanism. The single rotation of the disc holding the indexing pin is derived from the auxiliary shaft with the help of another single revolution clutch as indicated.
- For automatic lathe: Ratchet and Pawl mechanism

Automatic Lathe

- The term automatic is somewhat loosely applied, but is normally restricted to those machine tools capable of producing identical pieces without the attention of an operator, after each piece is completed. Thus, after setting up and providing an initial supply of material, further attention beyond replenishing the material supply is not required until the dimensions of the work pieces change owing to tool wear.
- A number of types of automatic lathes are developed that can be used for large volume manufacture application, such as single spindle automatics, Swiss type automatics, and multi-spindle automatics.

Swiss type Automatic Lathe Or Sliding Headstock Automatics

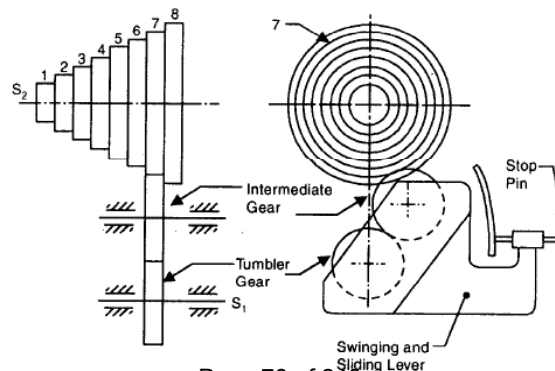
- Headstock travels enabling axial feed of the bar stock against the cutting tools.
- There is no tailstock or turret
- High spindle speed (2000 – 10,000 rpm) for small job diameter
- The cutting tools (upto five in number including two on the rocker arm) are fed radially
- Used for lot or mass production of thin slender rod or tubular jobs, like components of small clocks and wrist watches, by precision machining.



Multi Spindle Automatic Lathe

- For increase in rate of production of jobs usually of smaller size and simpler geometry.
- Having four to eight parallel spindles are preferably used.
- Multiple spindle automats also may be parallel action or progressively working type.

Norton type Tumbler-gear quick-change Gear box



Norton type Tumbler-gear quick-change Gear box

- It comprises a cone of gears 1 to 8 mounted on shaft S2.
- The tumbler gear can slide on shaft S1. It can mesh with any gear on shaft S2 through an intermediate gear which is located on a swinging and sliding lever so that it can engage gears 1 to 8 of different diameters, on shaft S2.
- The lever can be fixed in any desired ratio position with the help of a stop pin.
- The drive is usually from the driving shaft S1 to the driven shaft S2.

GATE - 2002

A lead-screw with half nuts in a lathe, free to rotate in both directions has

- (a) V-threads
- (b) Whitworth threads
- (c) Buttress threads
- (d) ACME threads

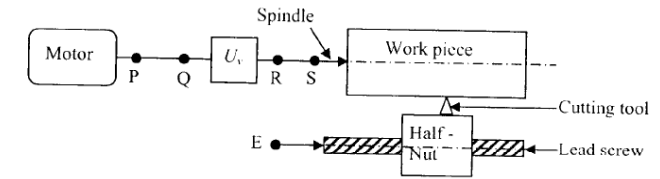
GATE – 2008

The figure shows an incomplete schematic of a conventional lathe to be used for cutting threads with different pitches. The speed gear box U_v is shown and the feed gear box U_s is to be placed. P, Q, R and S denote locations and have no other significance. Changes in U_v should NOT affect the pitch of the thread being cut and changes in U_s should NOT affect the cutting speed.

Contd.....

GATE -2008

Contd....



The correct connections and the correct placement of U_s are given by

- (a) Q and E are connected. U_s is placed between P and Q.
- (b) S and E are connected. U_s is placed between R and S.
- (c) Q and E are connected. U_s is placed between Q and E.
- (d) S and E are connected. U_s is placed between S and E.

IES - 2004

Match List I (Cutting tools) with List II (Features) and select the correct answer using the codes given below the Lists:

List I

- A. Turning tool
- B. Reamer
- C. Milling cutter

List II

- 1. Chisel edge
- 2. Flutes
- 3. Axial relief
- 4. Side relief

Codes:	A	B	C	A	B	C	
(a)	1	2	3	(b)	4	3	2
(c)	4	2	3	(d)	1	3	2

GATE-1994

To get good surface finish on a turned job, one should use a sharp tool with afeed and..... speed of rotation of the job.

- (a) Minimum, minimum
- (b) Minimum, maximum
- (c) Maximum, maximum
- (d) Maximum, minimum

IES - 1996

In turning of slender rods, it is necessary to keep the transverse force minimum mainly to

- (a) Improve the surface finish
- (b) Increase productivity
- (c) Improve cutting efficiency
- (d) Reduce vibrations and chatter.

IES - 2009

What is the number of jaws in self-centred chuck?

- (a) Eight
- (b) Six
- (c) Four
- (d) Three

IES - 1999

Which one of the following sets of forces are encountered by a lathe parting tool while groove cutting?

- (a) Tangential, radial and axial
- (b) Tangential and radial
- (c) Tangential and axial
- (d) Radial and axial

IES - 2009

Which one of the following methods should be used for turning internal taper only?

- (a) Tailstock offset
- (b) Taper attachment
- (c) Form tool
- (d) Compound rest

IES - 1992

Which of the following statement is incorrect with reference of lathe cutting tools?

- (a) The flank of the tool is the surface below and adjacent to the cutting edges
- (b) The nose is the corner, or chamfer joining the side cutting and the end cutting edges
- (c) The heel is that part of the which is shaped to produce the cutting edges and face
- (d) The base is that surface of the shank which against the support and takes tangent

IES - 2006

It is required to cut screw threads with double start and 2 mm pitch on a lathe having lead screw pitch of 6 mm. What is the speed ratio between lathe spindle and lead screw?

- (a) 1 : 3 (b) 3 : 1
- (c) 2 : 3 (d) 3 : 2

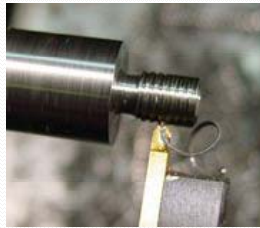
IES - 1997

Consider the following operations:

- 1. Under cutting 2. Plain turning
- 3. Taper turning 4. Thread cutting

The correct sequence of these operations in machining a product is

- (a) 2, 3, 4, 1 (b) 3, 2, 4, 1
- (c) 2, 3, 1, 4 (d) 3, 2, 1, 4



IES - 2009

A capstan lathe is used to mass-produce, in batches of 200, a particular component. The direct material cost is Rs 4 per piece, the direct labour cost is Rs 3 per piece and the overhead costs are 400% of the labour costs. What is the production cost per piece?

- (a) Rs 19 (b) Rs 23
- (c) Rs 16 (d) Rs 15

IES - 2007

Assertion (A): In a multi-spindle automatic lathe, the turret tool holder is indexed to engage the cutting tools one by one for successive machining operations.

Reason (R): Turret is a multiple tool holder so that for successive machining operation, the tools need not be changed.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1995

Consider the following characteristics:

- 1. Multiple operations can be performed
- 2. Operator's fatigue is greatly reduced.
- 3. Ideally suited for batch production
- 4. A break-down in one machine does not affect the flow of products.
- 5. Can accommodate modifications in design of components, within certain limits.

The characteristics which can be attributed to special purpose machines would include

- (a) 1, 3 and 4 (b) 1, 2 and 4
- (c) 2, 3 and 5 (d) 1, 2 and 3

IES - 1996

Assertion (A): Special purpose machine tools and automatic machine tools are quite useful for job shops

Reason (R): Special purpose machine tools can do special types of machining work automatically

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2003

Which one of the following mechanisms is employed for indexing of turret in an automatic lathe?

- (a) Whitworth (b) Rack and pinion
- (c) Ratchet and pawl (d) Geneva wheel

IES - 2009

For the manufacture of screw fasteners on a mass scale, which is the most suitable machine tool?

- (a) Capstan lathe
- (b) Single-spindle automatic lathe
- (c) CNC turning centre (lathe)
- (d) CNC machining centre

IES - 2001

The indexing of the turret in a single-spindle automatic lathe is done using

- (a) Geneva mechanism
- (b) Ratchet and Pawl mechanism
- (c) Rack and pinion mechanism
- (d) Whitworth mechanism

IES - 1995

Assertion (A): In a Swiss - type automatic lathe, the turret is given longitudinal feed for each tool in a specific order with suitable indexing.

Reason (R): A turret is a multiple tool holder to facilitate machining with each tool by indexing without the need to change the tools.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1992

Maximum production of small and slender parts is done by

- (a) Watch maker's lathe
- (b) Sliding head stock automatic lathe
- (c) Multi-spindle automatic lathe
- (d) Capstan lathe

IAS - 2007

Which one of the following is the characteristic for capstan lathe?

- (a) Rate of production is low
- (b) Labour cost is high
- (c) Used for handling jobs of varying shapes and sizes
- (d) Capstan head is mounted on a slide

IAS - 2002

Consider the following statements related to Turret lathe:

1. Turret is mounted directly on the saddle.
2. Turret is mounted on an auxiliary slide.
3. Much heavier and larger jobs than Capstan lathe can be produced.

Which of the above statements is/are correct?

- (a) 1 and 3
- (b) 2 and 3
- (c) 1 only
- (d) 2 only

IAS - 1996

Apart from hexagonal turret, the element(s) in a turret lathe include(s)

- (a) Cross-slide tool post
- (b) Cross-slide tool post and rear tool post
- (c) Cross-slide tool post and tail stock
- (d) Tool post and tail stock

IAS - 2004

Swiss type screw machines have

- (a) Turrets
- (b) Radial slides
- (c) Spindle carriers
- (d) Tool posts

IAS - 2001

Consider the following operations and time required on a multi spindle automatic machine to produce a particular job

1. Turning ...1.2 minutes
2. Drilling ...1.6 minutes
3. Forming ...0.2 minute
4. Parting ...0.6 minute

The time required to make one piece (cycle time) will be

- (a) 0.6 minutes
- (b) 1.6 minutes
- (c) 3.6 minutes
- (d) 0.9 minute

Rev.0

IAS - 1995

Assertion (A): In a multi-spindle automat, the turret is indexed to engage each of the cutting tool mounted on it.

Reason(R): Turret is a multiple tool holder so that the machining can be continued with each tool without the need to change the tool.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is **not** the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

IAS - 1994

A multi-spindle automat performs four operations with times 50, 60, 65 and 75 seconds at each of its work centers. The cycle time (time required to manufacture one work piece) in seconds will be

- (a) $50 + 60 + 65 + 75$
 (b) $(50 + 60 + 65 + 75) / 4$
 (c) $75/4$
 (d) 75

IAS - 1998

Assertion (A): For thread cutting, the spindle speed selected on a lathe, is very low.

Reason (R): The required feed rate is low in threading operation.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is **not** the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

IAS - 1998

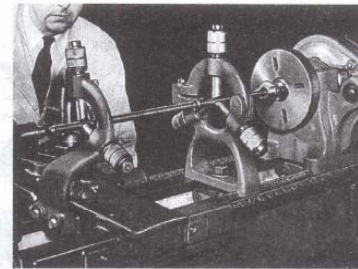
Consider the following statements associated with the lathe accessories:

1. Steady rest is used for supporting a long job in between head stock and tail stock.
2. Mandrel is used for turning small cylindrical job.
3. Collects are used for turning disc-shaped job.

Of these statements:

- (a) 1 and 2 are correct (b) 2 and 3 are correct
 (c) 3 alone is correct (d) 1 alone is correct

FIGURE 23-39 Cutting a thread on a long, slender workpiece, using a follow rest (left) and a steady rest (right) on an engine lathe. Note the use of a dog and face plate to drive the workpiece. (Courtesy of South Bend Lathe.)



IES 2011

In Norton type feed gearbox for cutting Whitworth standard threads with a standard TPI Leadscrew, power flows from:

- (a) Spindle to Tumbler gear to Norton cone to Meander drive to Leadscrew
 (b) Spindle to Norton cone to Tumbler gear to Meander drive to Leadscrew
 (c) Spindle to Tumbler gear to Meander drive to Norton cone to Leadscrew
 (d) Spindle to Norton cone to Meander drive to Tumbler gear to Leadscrew

IAS - 2000

Consider the following features:

1. All spindles operate simultaneously,
2. One piece is completed each time the tools are withdrawn and the spindles are indexed
3. The tool slide indexes or revolves with the spindle carrier

Which of these features are characteristics of a multi-spindle automatic machine used for bar work?

- (a) 1, 2 and 3 (b) 1 and 2
 (c) 2 and 3 (d) 1 and 3

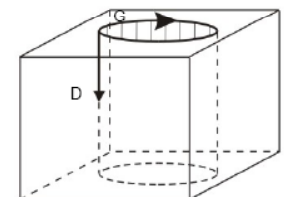
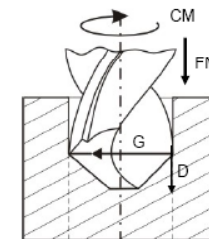
For-2015 (IES, GATE & PSUs)

Drilling



Drilling

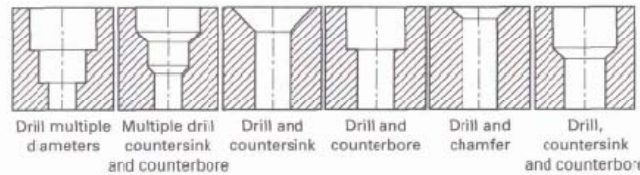
- Drilling is a operation that cuts cylindrical holes.



TYPES OF DRILL PRESSES

- Vertical or pillar type
- Radial Arm type
- Gang drill
- Multi Spindle drill
- Numerical Control drill

Drilling Operations

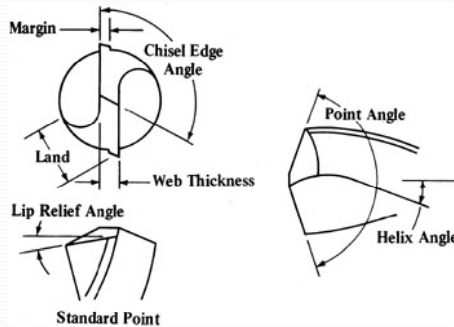


Chip formation of a drill

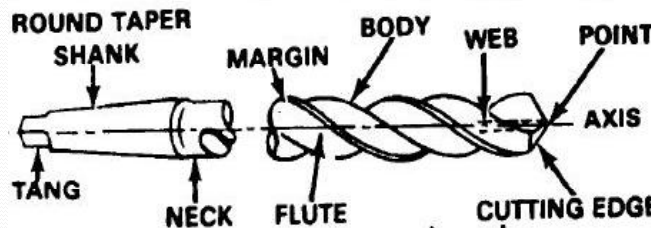


Drill

- The twist drill does most of the cutting with the tip of the bit.
- There are flutes to carry the chips up from the cutting edges to the top of the hole where they are cast off.



Drill



IES - 2004

Consider the following statements:

The helical flute in a twist drill provides the necessary

1. Clearance angle for the cutting edge
2. Rake angle for the cutting edge
3. Space for the chip to come out during drilling
4. Guidance for the drill to enter into the workpiece

Which of the statements given above are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

IES - 2003

The purpose of helical grooves in a twist drill is to

1. Improve the stiffness
2. Save a tool material
3. Provide space for chip removal
4. Provide rake angle for the cutting edge

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1 and 4

Drill

- Axial rake angle is the angle between the face and the line parallel to the drill axis. At the periphery of the drill, it is equivalent to the helix angle.
- The lip clearance angle is the angle formed by the portion of the flank adjacent to the land and a plane at right angles to the drill axis measured at the periphery of the drill.
- Lead of the helix is the distance measured parallel to the drill axis, between corresponding point on the leading edge of the land in one complete revolution.

Drill

- Drill sizes are typically measured across the drill points with a micrometer
- Most widely used material is High Speed Steel
- The drill blanks are made by forging and then are twisted to provide the torsional rigidity. Then the flutes are machined and hardened before the final grinding of the geometry.
- Deep hole drilling requires special precautions to take care of the removal of large volume of chips.

GATE- 1996

The rake angle in a drill

- (a) Increases from centre to periphery
- (b) decreases from centre to periphery
- (c) Remains constant
- (d) Is irrelevant to the drilling operation

IES - 1997

The rake angle in a twist drill

- (a) Varies from minimum near the dead centre to a maximum value at the periphery
- (b) Is maximum at the dead centre and zero at the periphery
- (c) Is constant at every point of the cutting edge
- (d) Is a function of the size of the chisel edge.

Point Angle (2β)

- The point angle is selected to suit the hardness and brittleness of the material being drilled.
- Harder materials have higher point angles, soft materials have lower point angles.
- An increase in the drill point angle leads to an increase in the thrust force and a decrease in the torque due to increase of the orthogonal rake angle.
- This angle (half) refers to side cutting edge angle of a single point tool.
- Standard Point Angle is 118°
- It is 116° to 118° for medium hard steel and cast iron
- It is 125° for hardened steel
- It is 130° to 140° for brass and bronze
- It is only 60° for wood and plastics

Helix Angle (ψ)

- Helix angle is the angle between the leading edge of the land and the axis of the drill. Sometimes it is also called as spiral angle.
- The helix results in a positive cutting rake
- This angle is equivalent to back rake angle of a single point cutting tool.
- Usual – 20° to 35° – most common
- Large helix : 45° to 60° suitable for deep holes and softer work materials
- Small helix : for harder / stronger materials
- Zero helix : spade drills for high production drilling micro-drilling and hard work materials

IES - 1992

A drill for drilling deep holes in aluminum should have

- (a) High helix angle
- (b) Taper shank
- (c) Small point angle
- (d) No lip

GATE- 1997

Helix angle of fast helix drill is normally

- (a) 35°
- (b) 60°
- (c) 90°
- (d) 5°

IES - 1992

Low helix angle drills are preferred for drilling holes in

- (a) Plastics
- (b) Copper
- (c) Cast steel
- (d) Carbon steel

IFS-2011

Discuss deep-hole drilling keeping in mind speed and feed, mentioning the technique of applying coolant.

[5-marks]

Cutting Speed in Drilling

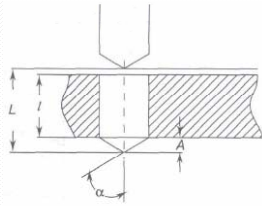
- The cutting speed in drilling is the surface speed of the twist drill.

$$V = \frac{\pi DN}{1000} \quad m / \min$$

Drilling Time

- Time for drilling the hole

$$T = \frac{L}{fN}, \text{ min}$$



MRR in Drilling

$$MRR = \left(\frac{\pi D^2}{4} \right) fN, \text{ mm}^3 / \text{min}$$

Example

A hole with 40-mm diameter and 50-mm depth is to be drilled in mild steel component. The cutting speed can be taken as 65 m/min and the feed rate as 0.25 mm/rev. Calculate the machining time and the material removal rate.

Some Formulae for Drilling

$$\text{Cone height } (h) = \frac{D}{2 \tan \beta}$$

$$\text{Uncut chip thickness } (t) = \frac{f}{2} \sin \beta$$

$$\text{Width of cut } (b) = \frac{D}{2 \sin \beta}$$

$$\text{Orthogonal rake angle } (\alpha) = \tan^{-1} \left[\frac{(2r/D) \tan \psi}{\sin \beta} \right]$$

GATE- 2002

The time taken to drill a hole through a 25 mm thick plate with the drill rotating at 300 r.p.m. and moving at a feed rate of 0.25 mm/revolution is

- (a) 10 sec (b) 20 sec
(c) 60 sec (d) 100 sec

GATE- 2004

Through holes of 10 mm diameter are to be drilled in a steel plate of 20 mm thickness. Drill spindle speed is 300 rpm, feed 0.2 mm/ rev and drill point angle is 120°. Assuming drill over travel of 2 mm, the time for producing a hole will be

- (a) 4 seconds (b) 25 seconds
(c) 100 seconds (d) 110 seconds

GATE- 2012

In a single pass drilling operation, a through hole of 15 mm diameter is to be drilled in a steel plate of 50 mm thickness. Drill spindle speed is 500 rpm, feed is 0.2 mm/rev and drill point angle is 118°. Assuming 2 mm clearance at approach and exit, the total drill time (in seconds) is

- (a) 35.1 (b) 32.4

- (c) 31.2 For-2015 (IES, GATE & PSUs)

IES - 2002

The arm of a radial drilling machine is being raised at a speed of 3.9 m/min by single start square threads of 6 mm pitch and 30 mm diameter. The speed of the screw

- (a) Is 650 rpm
(b) Is 180 rpm
(c) Is 130 rpm
(d) Cannot be determined as the data is insufficient

IES - 1994

The ratio between two consecutive spindle speeds for a six-speed drilling machine using drills of diameter 6.25 to 25 mm size and at a cutting velocity of 18 m/min is

- (a) 1.02 (b) 1.32
(c) 1.62 (d) 1.82

IES - 2009

What is the drilling time for producing a hole in an MS sheet of 25 mm thickness using an HSS drill of 20 mm diameter? The cutting speed and feed for drill are 20 m/min and 0.25 mm/revolution respectively, Neglect time taken for setting up, approaching and travelling of tools.

- (a) 0.314 min (b) 0.236 min
(c) 0.438 min (d) 0.443 min

IES - 2002

A 31.8 mm H.S.S. drill is used to drill a hole in a cast iron block 100 mm thick at a cutting speed 20 m/min and feed 0.3 mm/rev. If the over travel of drill is 4 mm and approach 9 mm, the time required to drill the hole is

- (a) 1 min 40 s (b) 1 min 44 s
(c) 1 min 49 s (d) 1 min 53 s

GATE - 2014

A hole of 20 mm diameter is to be drilled in a steel block of 40 mm thickness. The drilling is performed at rotational speed of 400 rpm and feed rate of 0.1 mm/rev. The required approach and over run of the drill together is equal to the radius of drill. The drilling time (in minute) is

- (a) 1.00 (b) 1.25 (c) 1.50 (d) 1.75

GATE-2014 (PI)

An HSS drill of 20 mm diameter with 5 mm cone height is used to drill a through hole in a steel work-piece of 50 mm thickness. Cutting speed of 10 m/min and feed rate of 0.3 mm/rev are used. The drilling time, in seconds, neglecting the approach and over travel, is _____

IAS - 1999

To drill a 10 mm diameter hole through a 20 mm thick M.S. plate with a drill bit running at 300 rpm and a feed of 0.25 mm per revolution, time taken will be

- (a) 8 s (b) 16 s
(c) 24 s (d) 32 s

GATE – 2007 (PI) Linked S-1

Blind holes 10 mm diameter, 50 mm deep are being drilled in steel block. Drilling spindle speed is 600 rpm, feed 0.2 mm/rev, point angle of drill is 120°.

Machining time (in minutes) per hole will be
(a) 0.08 (b) 0.31 (c) 0.44 (d) 0.86

GATE – 2007 (PI) Linked S-2

Blind holes 10 mm diameter, 50 mm deep are being drilled in steel block. Drilling spindle speed is 600 rpm, feed 0.2 mm/rev, point angle of drill is 120°.

During the above operation, the drill wears out after producing 200 holes. Taylor's tool life equation is of the form $VT^{0.3} = C$, where V = cutting speed in m/minute and T = tool life in minutes. Taylor's constant C will be

- (a) 15 (b) 72 (c) 93 (d) 490

For-2013 (IES, GATE & PSUs)

IAS - 1994

The time (in minutes) for drilling a hole is given by

$$t = \frac{\text{Depth of the hole} + h}{\text{Feed} \times \text{RPM}}$$

where 'h' is the

- (a) Length of the drill
(b) Drill diameter
(c) Flute length of the drill
(d) Cone height of the drill.

IES - 1999

Match List-I (Drill bits) with List-II (Applications) and select the correct answer using the codes given below the Lists:

List-I

List-II

- | | | |
|-----------------------|----|--|
| A. Core drill | 1. | To enlarge a hole to a certain depth so as to accommodate the bolt head of a screw |
| B. Reamer | 2. | To drill and enlarge an already existing hole in a casting |
| C. Counter bore drill | 3. | To drill a hole before making internal thread |
| D. Tap drill | 4. | To improve the surface finish and dimensional accuracy of the already drilled hole |

Code:	A	B	C	D	A	B	C	D
(a)	1	3	2	4	(b)	2	3	1
(c)	2	4	1	3	(d)	3	2	4

Rev.0



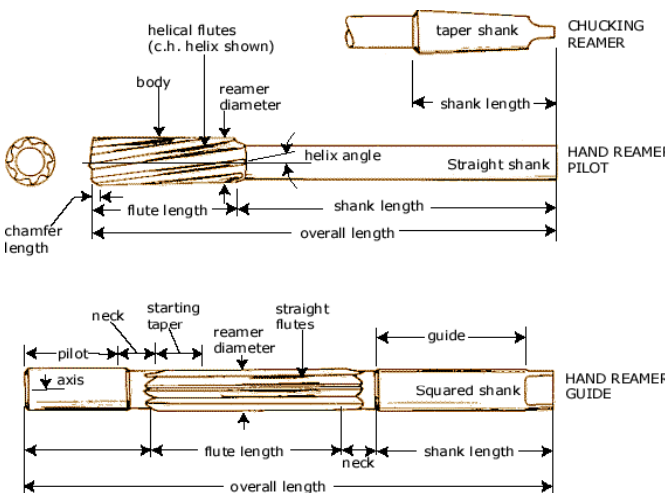
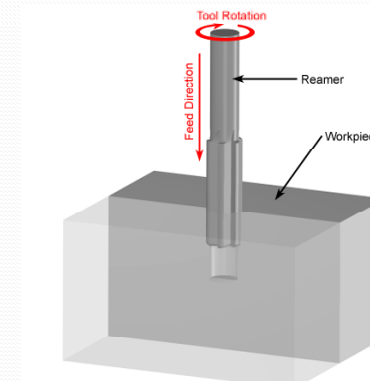
Reaming, Boring, Broaching

By S K Mondal

Reaming

- Reaming removes a small amount of material from the surface of holes.
- **It is done for two purposes:** to bring holes to a more exact size and to improve the finish of an existing hole.
- Multiage cutting tools that has many flutes, which may be straight or in a helix are used.
- No special machines are built for reaming. The same machine that was employed for drilling the hole can be used for reaming by changing the cutting tool.
- Only a minimum amount of materials should be left for removal by reaming. As little as 0.1 mm is desirable, and in no case should the amount exceed 0.4 mm.
- A properly reamed hole will be within 0.025 mm of the correct size and have a fine finish.

Reamer



Reamer Flutes

- The reamer flutes are either straight or helical.
- The helical flutes promote smoother cutting and should be used specifically for holes that are not continuous, such as those with keyways parallel to the axis of the hole.
- The cutting action of the helical flutes is smoother and helps in preventing chatter.
- The reamers are termed as left hand or right hand, depending upon the direction in which they are moved, looking from the shank to the cutting portion.
- The right-hand reamer with right-hand helix is used for roughing cuts, since the tool tends to go into the workpiece more efficiently and thereby promotes the material removal.
- A right-hand reamer with left-hand flutes is used for finishing cuts.

Types of Reamers

The principal types of reamers are:

1. Hand reamers
 - a. Straight
 - b. Taper
2. Machine or chucking reamers
 - a. Rose
 - b. Fluted
3. Shell reamers
4. Expansion reamers
5. Adjustable reamers

Reaming

- To meet quality requirements, including both finish and accuracy (tolerances on diameter, roundness, straightness, and absence of bell-mouth at ends of holes). Reamers must have adequate support for the cutting edges, and reamer deflection must be minimal.
- Reaming speed is usually two-thirds the speed for drilling the same materials. However, for close tolerances and fine finish, speeds should be slower.
- Feeds are usually much higher than those for drilling and depend upon material.
- Recommended cutting fluids are the same as those for drilling.

For-2015 (IES, GATE & PSUs)

Reaming

- Reamers, like drills, should not be allowed to become dull. The chamfer must be reground long before it exhibits excessive wear. Sharpening is usually restricted to the starting taper or chamfer. Each flute must be ground exactly evenly or the tool will cut oversize.
- Reamers tend to chatter when not held securely, when the work or work holder is loose, or when the reamer is not properly ground.
- Irregularly spaced teeth may help reduce chatter. Other cures for chatter in reaming are to reduce the speed, vary the feed rate, chamfer the hole opening, use a piloted reamer, reduce the relief angle on the chamfer, or change the cutting fluid.
- Any misalignment between the work piece and the reamer will cause chatter and improper reaming.

Rose Reamer

Rose chucking reamers are ground cylindrical and have no relief behind the outer edges of the teeth. All cutting is done on the beveled ends of the teeth



Rev.0

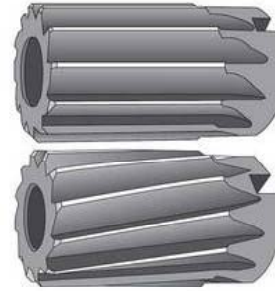
Chucking Reamer

Fluted chucking reamers have relief behind the edges of the teeth as well as beveled ends. They can cut on all portions of the teeth. Their flutes are relatively short and they are intended for light finishing cuts.



Shell Reamer

Shell reamers often are used for sizes over 20 mm to save cutting-tool material. The shell, made of HSS for smaller sizes and with carbide edges for larger sizes or for mass-production work.



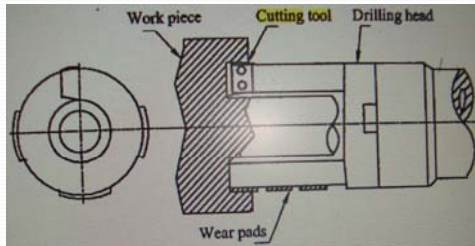
IFS-2011

What is the main difference between rose reamer and chucking reamer ? Write in short about shell reamer.

[5-marks]

Trepanning

- Trepanning is a annular groove producing operation which leaves a solid cylindrical core in the centre. In trepanning a cutter consisting of one or more cutting edges placed along the circumference of a circle is used to produce the annular groove.



Trepanning Tool

IES - 1999

Which one of the following processes results in the best accuracy of the hole made?

- (a) Drilling (b) Reaming
(c) Broaching (d) Boring

IES - 1999

Consider the following statements regarding reaming process:

- Reaming generally produces a hole larger than its own diameter
- Generally rake angles are not provided on reamers.
- Even numbers of teeth are preferred in reamer design.

Which of these statements are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

IES - 1998

Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I

List-II

- | | |
|--------------------|--|
| A. Reaming | 1. Smoothing and squaring surface around the hole for proper seating |
| B. Counter-boring | 2. Sizing and finishing the hole |
| C. Counter-sinking | 3. Enlarging the end of the hole |
| D. Spot facing | 4. Making a conical enlargement at the end of the hole |

Code:	A	B	C	D	A	B	C	D
(a)	3	2	4	1	(b)	2	3	1
(c)	3	2	1	4	(d)	2	3	4

IES - 1994

In reaming process

- (a) Metal removal rate is high
(b) High surface finish is obtained.
(c) High form accuracy is obtained
(d) High dimensional accuracy is obtained.

GATE – 2007 (PI)

Reaming is primarily used for achieving

- (a) Higher MRR
(b) Improved dimensional tolerance
(c) Fine surface finish
(d) Improved positional tolerance

GATE – 2014 (PI)

Reaming is a process used for

- (a) creating a circular hole in metals
- (b) cutting a slot on the existing hole surface
- (c) finishing an existing hole surface
- (d) making non-circular holes in metals

IES - 1993

A hole of 30 mm diameter is to be produced by reaming. The minimum diameter permissible is 30.00 mm while the maximum diameter permissible is 30.05 mm. In this regard, consider the following statements about the reamer size:

1. The minimum diameter of the reamer can be less than 30 mm.
2. The minimum diameter of the reamer cannot be less than 30 mm.
3. The maximum diameter of the reamer can be more than 30.05 mm.
4. The maximum diameter of the reamer must be less than 30.05 mm.

Of these statements

- (a) 1 and 4 are correct
- (b) 1 and 3 are correct
- (c) 2 and 3 are correct
- (d) 2 and 4 are correct

IES - 1998

A component requires a hole which must be within the two limits of 25.03 and 25.04 mm diameter. Which of the following statements about the reamer size are correct?

1. Reamer size cannot be below 25.03 mm.
2. Reamer size cannot be above 25.04 mm.
3. Reamer size can be 25.04 mm.
4. Reamer size can be 25.03 mm.

Select the correct answer using the codes given below:

- (a) 1 and 3
- (b) 1 and 2
- (c) 3 and 4
- (d) 2 and 4

IAS - 1999

For reaming operation of blind hole, the type of reamer required is

- (a) Straight flute reamer
- (b) Right hand spiral fluted reamer
- (c) Left hand spiral fluted reamer
- (d) None of the above

IAS - 2003

Match List I (Operation) with List II (Application) and select the correct answer using the codes given below the lists:

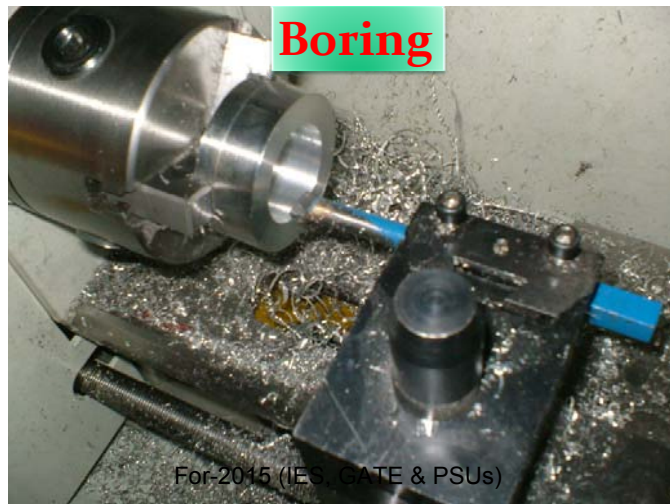
List-I (Operation)	List-II (Application)
(A) Reaming	1. Used for enlarging the end of a hole to give it a conical shape for a short distance
(B) Boring	2. Used for enlarging only a limited portion of the hole
(C) Counter boring	3. Used for finishing a hole
(D) Counter sinking	4. Used for enlarging a hole
Codes:	A B C D
(a) 3 2 4 1	(b) 1 4 2 3
(c) 3 4 2 1	(d) 1 2 4 3

IES - 1992

Shell reamers are mounted on

- (a) Tool holders
- (b) Armour plates
- (c) Arbor
- (d) Shanks

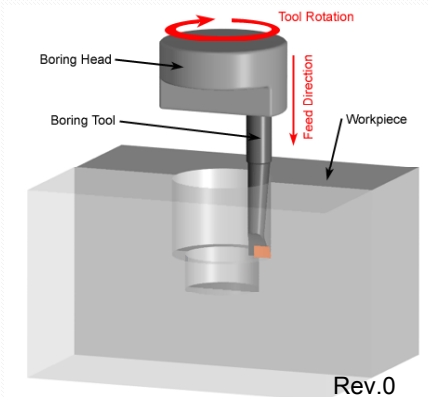
Boring



For-2015 (IES, GATE & PSUs)

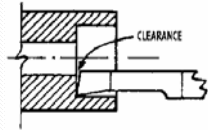
Boring

- Boring always involves the enlarging of an existing hole, which may have been made by a drill or may be the result of a core in a casting.
- An equally important and concurrent purpose of boring may be to make the hole concentric with the axis of rotation of the workpiece and thus correct any eccentricity that may have resulted from the drill drifting off the centerline. Concentricity is an important attribute of bored holes.
- When boring is done in a lathe, the work usually is held in a chuck or on a faceplate. Holes may be bored straight, tapered, or to irregular contours.
- Boring is essentially internal turning while feeding the tool parallel to the rotation axis of the workpiece.



Boring

- The same principles are used for boring as for turning.
- The tool should be set exactly at the same height as the axis of rotation. Slightly larger end clearance angles sometimes have to be used to prevent the heel of the tool from rubbing on the inner surface of the hole.



Boring

- Because the tool overhang will be greater, feeds and depths of cut may be somewhat less than for turning to prevent tool vibration and chatter.
- In some cases, the boring bar may be made of tungsten carbide because of this material's greater stiffness.
- The boring tool is a single-point cutting tool.
- Hole quality, finish boring can typically achieve holes within tolerances of IT9.
- Surface finishes better than Ra 1 micron can be achieved.

IES 2009

Compare the drilling and boring operations in relation to cutting action, accuracy and applications.

Formula for Boring

- Average diameter of workpiece $D_{avg} = \frac{D_1 + D_2}{2}$ mm
- Cutting Time, $CT = \frac{L + A + O}{fN}$
- Metal Removal Rate

$$MRR = \frac{(\pi D_1^2 - \pi D_2^2)}{4 / fN} = \pi D_{avg} d fN$$

IES - 1993

The main purpose of boring operation, as compared to drilling is to:

- Drill a hole
- Finish the drilled hole
- Correct the hole
- Enlarge the existing hole

IES – 1994, ISRO-2008

Enlarging an existing circular hole with a rotating single point tool is called

- Boring
- Drilling
- Reaming
- Internal turning.

IES – 1992, ISRO-2010

Which of the machine tools can be used for boring

- Lathe
 - Drilling machine
 - Vertical milling machine
 - Horizontal milling machine
- (a) 1, 2, 3 (b) 1, 3, 4
(c) 2 and 4 (d) 1, 2, 3, 4

IES - 2000

Which one of the following sets of tools or tools and processes are normally employed for making large diameter holes?

- Boring tool
- BTA tools (Boring and trepanning association) and gun drill
- Gun drill and boring tool
- Boring tools and trepanning

IES - 1996

Which of the following statements are correct?

- A boring machine is suitable for a job shop.
 - A jig boring machine is designed specially for doing more accurate work when compared to a vertical milling machine.
 - A vertical precision boring machine is suitable for boring holes in cylinder blocks and liners.
- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3.

IES - 1995

The effects of setting a boring tool above centre height leads to a/an.

- Increase in the effective rake angle and a decrease in the effective clearance angle.
- Increase in both effective rake angle and effective clearance angle.
- Decrease in the effective rake angle and an increase in the effective clearance angle.
- Decrease in both effective rake angle and effective clearance angle.

JWM 2010

Consider the following operations regarding boring machines :

- Counterboring
- Countersinking
- Trepanning

Which of the above operations is/are correct ?

- 1, 2 and 3
- 1 and 2 only
- 2 and 3 only
- 1 only

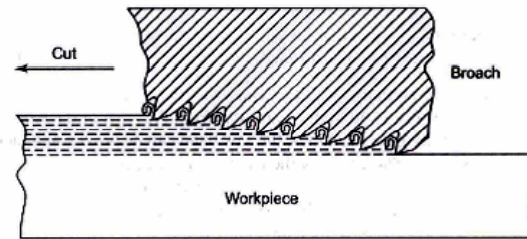


Broaching

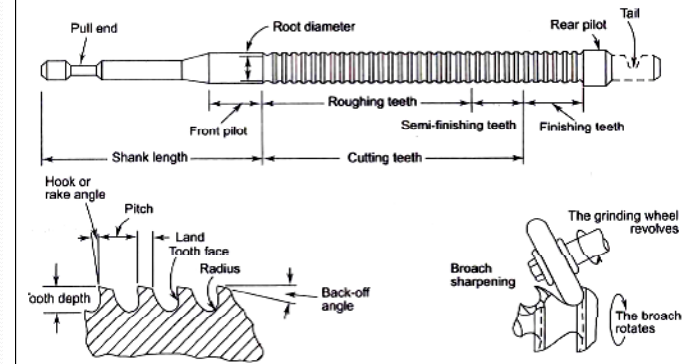
- Broaching is a multiple-tooth cutting operation with the tool reciprocating.
- Since in broaching the machining operation is completed in a single-stroke as the teeth on the cutting tool, called broach, are at gradually increasing height corresponding to the feed per tooth of a milling cutter.
- The shape of the broach determines the shape of the machined part.
- Broaching was originally developed for machining internal keyways, but looking at the advantages, it has been extensively used in the mass production of automobile component manufacture for various other surfaces as well.

Broaching

- The material removal using the broach teeth is shown schematically in Fig. shown in below. The dotted line in the figure indicates the amount of material being removed by successive individual teeth.



Broach Construction



Broach Construction

- The broach is composed of a series of teeth, each tooth standing slightly higher than the previous one. This rise per tooth is the feed per tooth and determines the material removed by the tooth.
- There are basically three sets of teeth present in a broach as shown in Fig. shown above.
- The roughing teeth that have the highest rise per tooth remove bulk of the material.
- The semi-finishing teeth, whose rise per tooth is smaller, remove relatively smaller amounts of material compared to the roughing teeth.

For-2015 (IES, GATE & PSUs)

Broach Construction

- The last set of teeth is called the finishing or sizing teeth. Very little material will be removed by these teeth.
- The necessary size will be achieved by these teeth and hence all the teeth will be of the same size as that required finally. With the progress of time, when the first set of teeth wear out, the next set of teeth will be able to provide the sizing function.
- The pull end of the broach (Fig. shown in above) is attached to the pulling mechanism of the broaching machine with the front pilot aligning the broach properly with respect to the workpiece axis before the actual cutting starts.

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Broach Construction

- The rear pilot helps to keep the broach to remain square with the workpiece as it leaves the workpiece after broaching.
- Broaching speeds are relatively low, of the order of 6 to 15 m/min. However, the production rate is high with the cycle times being about 5 to 30 seconds, including the workpiece and tool handling times. The low cutting speeds are conducive to very high tool life with very small tool wear rates.

Rev.0

Broach Construction

- Broaches are generally made of high speed steel in view of its high impact strength. Sometimes, the titanium nitride coating helps to improve the tool life further. Also, the carbide insert-type broaches are used more for surface broaching of cast iron for very large volume production to reduce the frequent resharpener of the broach, which is a very difficult operation.
- Standard broaches are available for common and more often used forms, such as round and square holes, keyways, etc.

Broach Construction

- For smooth operation, it is essential that at least two or three teeth be simultaneously engaged.
- The thumb rule for tooth spacing, $s = 1.75\sqrt{l}$, mm
- The cut per tooth f is kept in the range 0.05 mm – 0.09 mm.
- In the normal speed BUE may be a problem. To avoid this a copious supply of the cutting fluid is provided.

Advantages of broaching

1. It is the fastest way of finishing an operation with a single stroke.
2. Since all the machining parameters are built into the broach, very little skill is required from the operator.
3. Broaching machine is simple since only a single reciprocating motion is required for cutting.
4. Final cost of the machining operation is one of the lowest for mass production.
5. Any type of surface, internal or external, can be generated with broaching.
6. Many surfaces, which are very difficult or impossible by other means, can be done by broaching. For example, square hole and internal splines.
7. Good surface finish and fine dimensional tolerances can be achieved by broaching, often better than boring or reaming

Limitations of broaching

1. Custom made broaches are very expensive and can therefore be justified only for very large volume production.
2. A broach has to be designed for a specific application and can be used only for that application. Hence, the lead time for manufacture is more for custom designed broaches.
3. Broaching, being a very heavy metal removal operation, requires that the workpiece is rigid and capable of withstanding the large forces.
4. Broaching can only be carried out on the workpiece whose geometry is such that there is no interference for the broach movement for the cutting.

IES - 2007

Among the following machining processes, which can be used for machining flat surfaces?

1. Shaping 2. Milling 3. Broaching
- Select the correct answer using the code given below:
- (a) 1 and 2 only (b) 1 and 3 only
(c) 2 and 3 only (d) 1, 2 and 3

IES - 1993

Assertion (A): Soluble oils are employed with broaching machine.

Reason (R): Soluble oils have excellent cooling effect.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES – 1993, 2001

Assertion (A): No separate feed motion is required during broaching.

Reason (R): The broaching machines are generally hydraulically operated.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES - 2001

The screw and nut in a broaching machine are changed from square thread to ACME thread. The power requirement of the machine at the same r.p.m. will

- (a) Remain same
(b) Decrease
(c) Increase
(d) Depend on the operator

IAS - 2004

Which one of the following is true for the last few teeth of a broach which are meant for fine finishing?

- (a) They have equal diameter
(b) They have increasing diameter
(c) They have decreasing diameter
(d) They have alternately increasing and decreasing diameter.

IES - 2005

Match List I (Tool) with List II (Element of Tool) and select the correct answer using the code given below the Lists:

List I				List II					
A.	Broach			1.	Tang				
B.	Reamer			2.	Pilot				
C.	Drill			3.	Front taper				
D.	Carbide insert face mill			4.	Bond				
				5.	Sweeper tooth				
Codes:	A	B	C	D	A	B	C	D	
(a)	2	5	1	3	(b)	1	3	4	5
(c)	2	3	1	5	(d)	1	5	4	3

IES - 2002

Match List I with List II and select the correct answer:

List I (Machine tool)				List II (Features)					
A.	Lathe			1.	Push or pull tool				
B.	Drilling machine			2.	Ratchet and pawl mechanism				
C.	Shaper			3.	Dividing head				
D.	Broaching machine			4.	Hollow tapered spindle				
				5.	Face plate				
Codes:	A	B	C	D	A	B	C	D	
(a)	2	4	5	1	(b)	5	3	2	4
(c)	2	3	5	4	(d)	5	4	2	1

Milling



Milling

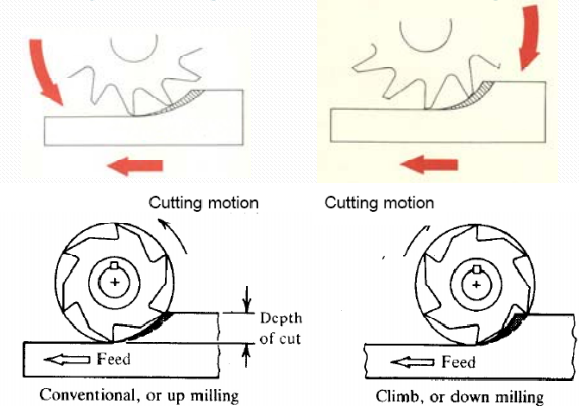
Milling machines of various types are widely used for the following purposes using proper cutting tools called milling cutters:

- Flat surface in vertical, horizontal and inclined planes
- Making slots or ribs of various sections
- Slitting or parting
- Often producing surfaces of revolution
- Making helical grooves like flutes of the drills
- Long thread milling on large lead screws, power screws, worms etc and short thread milling for small size fastening screws, bolts etc.

Milling

- 2-D contouring like cam profiles, clutches etc and 3-D contouring like die or mould cavities
- Cutting teeth in piece or batch production of spur gears, straight toothed bevel gears, worm wheels, sprockets, clutches etc.
- Producing some salient features like grooves, flutes, gushing and profiles in various cutting tools, e.g., drills, taps, reamers, hobs, gear shaping cutters etc.

Up milling and down milling



Up milling and down milling

- In down milling, though the cut starts with a full chip thickness, the cut gradually reduces to zero. This helps in eliminating the feed marks present in the case of up milling and consequently better surface finish.
- Climb milling also allows greater feeds per tooth and longer cutting life between regrinds than the conventional milling.
- Up milling needs stronger holding of the job and down milling needs backlash free screw-nut systems for feeding.

Advantages of Down Milling

1. Suited to machine thin and hard-to-hold parts since the workpiece is forced against the table or holding device by the cutter.
2. Work need not be clamped as tightly.
3. Consistent parallelism and size may be maintained, particularly on thin parts.
4. It may be used where breakout at the edge of the workpiece could not be tolerated.
5. It requires upto 20% less power to cut by this method.
6. It may be used when cutting off stock or when milling deep, thin slots.

Disadvantages of Down Milling

1. It cannot be used unless the machine has a backlash eliminator and the table jibs have been tightened.
2. It cannot be used for machining castings or hot rolled steel, since the hard outer scale will damage the cutter.

IES - 2007

What is the process of removing metal by a milling cutter which is rotated against the direction of travel of the work piece, called?

- (a) Down milling (b) Up milling
(c) End milling (d) Face milling

IES - 1997

Consider the following statements:

In Up milling process,

1. The cutter starts the cut from the machined surface and proceeds upwards.
2. The cutter starts the cut from the top surface and proceeds downwards.
3. The job is fed in a direction opposite to that of cutter rotation.
4. The job is fed in the same direction as that of cutter rotation.

Of these statements correct are:

- (a) 1 and 3 (b) 1 and 4
(c) 2 and 3 (d) 2 and 4

IES 2010

Assertion (A): Climb or down milling operation ensures smoother operation of the machine tool and longer tool life as compared to the conventional up milling operation.

Reason (R): In climb or down milling operation, the rotational motion of the cutter as well as the feed motion of the work-piece are in the same direction, and the depth of cut is maximum at the entry point as the cutter engages the workpiece.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS-2009 main

Define the term 'feed in milling'. [2-Marks]

Classification of milling machines

(a) According to nature of purposes of use:

- General purpose
- Single purpose
- Special purpose

(b) According to configuration and motion of the work-holding table / bed

- Knee type
- Bed type
- Planer type
- Rotary table type

Classification of milling machines

(c) According to the orientation of the spindle(s).

- Plain horizontal knee type
- Horizontal axis (spindle) and swiveling bed type
- Vertical spindle type
- Universal head milling machine

(d) According to mechanization / automation and production rate

- Hand mill (milling machine)
- Planer and rotary table type vertical axis milling machines
- Tracer controlled copy milling machine,
- Milling machines for short thread milling
- Computer Numerical Controlled (CNC) milling machine

Classifications of milling cutters

(a) **Profile sharpened cutters** – where the geometry of the machined surfaces are not related with the tool shape, viz;

- i. Slab or plain milling cutter: – straight or helical fluted
- ii. Side milling cutters – single side or both sided type
- iii. Slotting cutter
- iv. Slitting or parting tools
- v. End milling cutters – with straight or taper shank
- vi. Face milling cutters.

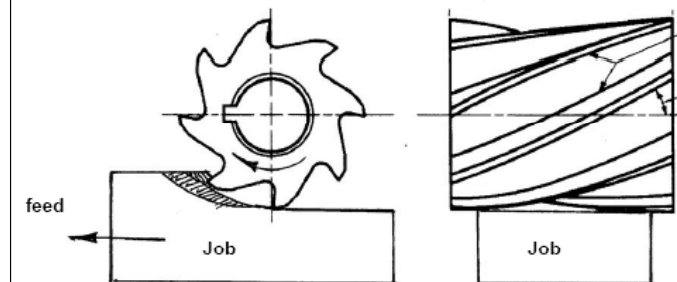
For-2015 (IES, GATE & PSUs)

Classifications of milling cutters

(b) **Form relieved cutters** – where the job profile becomes the replica of the Tool-form, e.g., viz.;

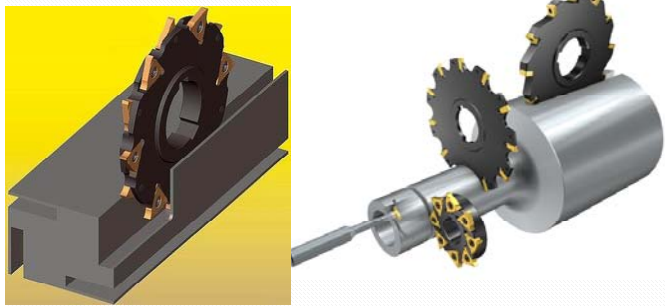
- i. Form cutters
- ii. Gear (teeth) milling cutters
- iii. Spline shaft cutters
- iv. Tool form cutters
- v. T-slot cutters
- vi. Thread milling cutter

Slab or Plain milling cutters

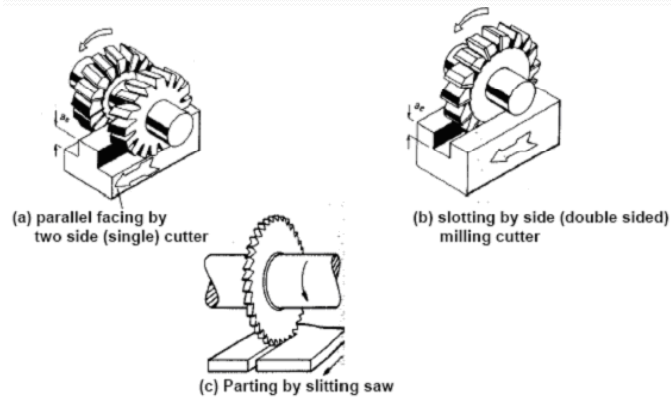


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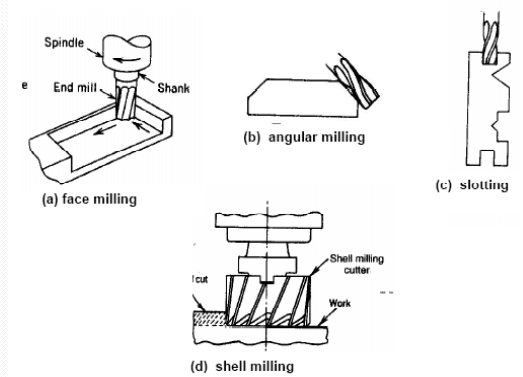
Side and slot milling cutters



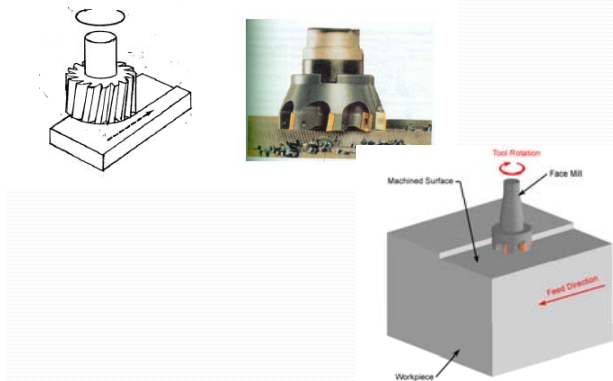
Slitting saw or parting tool



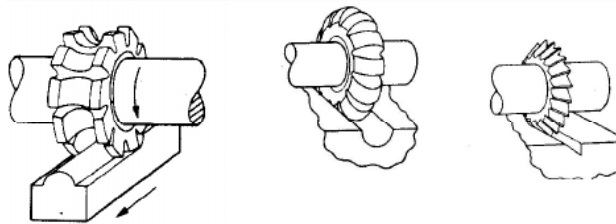
End milling cutters or End mills



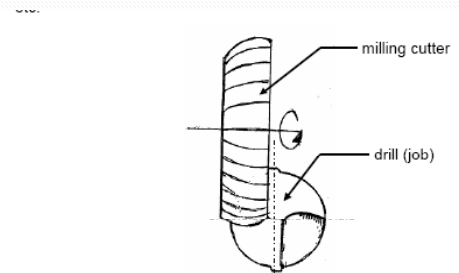
Face milling cutters



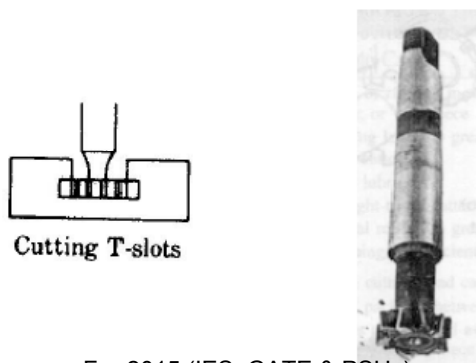
Use of form relieved cutters (milling)



Tool form cutters

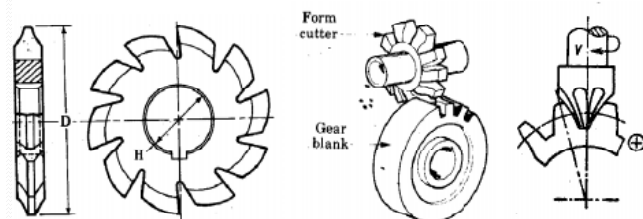


T- slot cutter



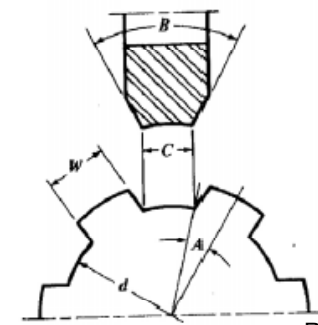
For-2015 (IES, GATE & PSUs)

Gear teeth milling cutters



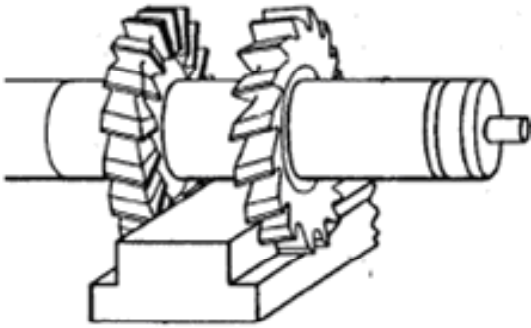
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Spline shaft cutters



Rev.0

Straddle milling

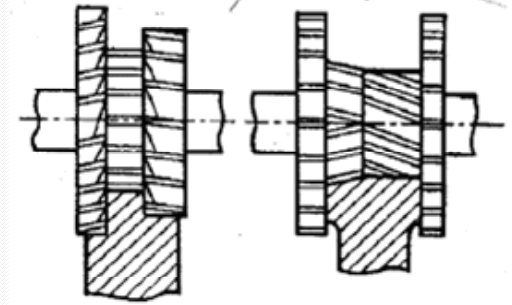


IES – 1995, ISRO-2010

In a milling operation two side milling cutters are mounted with a desired distance between them so that both sides of a work piece can be milled simultaneously. This set up is called.

- (a) Gang milling (b) Straddle milling
(c) String milling (d) Side milling.

Gang milling



IAS-2009 Main

With a sketch, explain the principle of working and variations of bed-type milling machine.

[9-marks]

IES - 2006

Gang milling is a

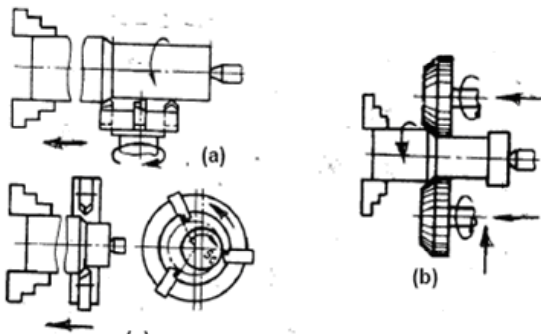
- (a) Milling process for generating hexagonal surfaces
(b) Process of cutting gears
(c) Process in which two or more cutters are used simultaneously
(d) Milling operation combined with turning

IES - 2009

For machining, which one of the following gang milling operations is employed?

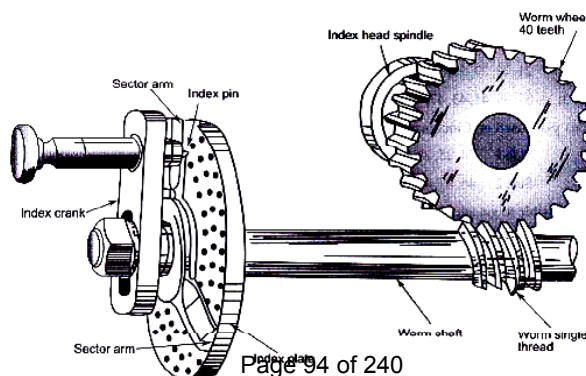
- (a) Threads
(b) Bores
(c) Grooves
(d) Steps on prismatic parts

Turning by rotary tools (milling cutters)



For 2015 (IES, GATE & PSUs)

Indexing



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Simple or Plain Indexing

- Plain indexing is the name given to the indexing method carried out using any of the indexing plates in conjunction with the worm.

Rev.0

IES – 2004, ISRO-2011

One brand of milling machine has the following two index plates supplied along with the indexing head:

Plate 1: 15, 16, 17, 18, 19, 20 hole circles

Plate 2: 21, 23, 27, 29, 31, 33 hole circles

It is proposed to mill a spur gear of 28 teeth using simple indexing method. Which one of the following combinations of index plate and number of revolutions is correct?

- (a) Plate 1: 1 revolution and 9 holes in 18 hole circles
- (b) Plate 2: 1 revolution and 9 holes in 21 hole circles
- (c) Plate 2: 1 revolution and 9 holes in 33 hole circles
- (d) Plate 1: 1 revolution and 9 holes in 15 hole circles

IES - 2000

One of the index plates of a milling machine dividing head has the following hole circles: 15; 16; 17; 18; 19; 20

A gear wheel of 34 teeth has to be milled by simple indexing method. To machine each tooth, the index crank has to be rotated through

- (a) 17 holes in the 20-hole circle
- (b) 18 holes in the 20-hole circle
- (c) 1 revolution and 3 holes in 17-hole circle
- (d) 1 revolution and 2 holes in 18-hole circle

IAS - 1994

A standard dividing head is equipped with the following index plates

1. Plate with 12, 16, 17, 18, 19, 20 holes circles
2. Plate with 21, 23, 27, 29, 31, 33 holes circles
3. Plate with 37, 39, 41, 43, 47, 49 holes circles

For obtaining 24 divisions on a work piece by simple indexing

- (a) Hole plate 2 alone can be used
- (b) Hole plates 1 and 2 can be used
- (c) Hole plates 1 and 3 can be used
- (d) Any of the three hole plates can be used

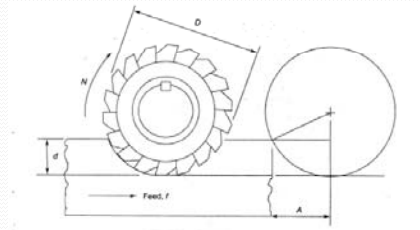
Milling Velocity

- The cutting speed in milling is the surface speed of the milling cutter.

$$V = \frac{\pi DN}{1000}$$

Milling Time

- Time for one pass = $\frac{L + 2 \times A}{fZN}$ minutes
- Approach distance, $A = \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - d\right)^2} = \sqrt{d(D-d)}$



Example

A C50 steel flat surface of dimensions 100 mm × 250 mm is to be produced on a horizontal axis milling machine. An HSS slab mill with a 100 mm diameter and 150 mm width is to be used for the purpose. The milling cutter has 8 teeth.

Calculate the machining time assuming that entire stock can be removed in one depth of 2 mm.

Given,

Feed, $f = 0.13$ mm/tooth,

Cutting speed, $V = 20$ m/min.

MRR in Milling

Considering the parameters defined in the discussion of speeds and feeds, etc, the MRR is given below,

Where,

$$MRR = w \times d \times F$$

where, w = width of cut, d = depth of cut



For 2015 (IES, GATE & PSUs)

Some Formulae for Milling

$$\text{Maximum uncut chip thickness } (t_{\max}) = \frac{2f}{NZ} \sqrt{\frac{d}{D}}$$

$$\text{Average uncut chip thickness } (t_{\text{avg}}) = \frac{f}{NZ} \sqrt{\frac{d}{D}}$$

$$\text{Peak to valley surface roughness } (h_{\max}) = \frac{f^2}{4DN^2Z^2}$$

GATE - 2014

Two separate slab milling operations, 1 and 2, are performed with identical milling cutters. The depth of cut in operation 2 is twice that in operation 1. The other cutting parameters are identical. The ratio of maximum uncut chip thicknesses in operations 1 and 2 is

GATE - 1995

List-I (Manufacturing Processes)	List- II (Condition)
(A) Finish turning	1. Backlash eliminator
(B) Forming	2. Zero rake
(C) Thread cutting	3. Nose radius
(D) Down milling	4. Low speed
Codes: A B C D	A B C D
(a) 2 3 4 1	(b) 3 4 1 2
(c) 1 2 3 4	(d) 4 1 2 3

GATE - 1993

A milling cutter having 8 teeth is rotating at 150 rpm. If the feed per tooth is 0.1 mm, the table speed in mm per minute is

(a) 120 (b) 187
(c) 125 (d) 70

IES - 2003

In milling machine, the cutting tool is held in position by

(a) Chuck (b) Spindle
(c) Arbor (d) Tool holder

IES - 2009

The arbor of a milling machine is used to hold which one of the following?

(a) Spindle (b) Over-arm
(c) Cutting tool (d) Mandrel

IES - 1994

Consider the following operations:

- Cutting key ways on shafts
- Cutting external screw threads.
- Cutting teeth of spur gears
- Cutting external splines.

Those which can be performed with milling cutters would include

(a) 1 and 2 (b) 2,3 and 4
(c) 1 and 3 (d) 1,2,3 and 4 .

IES - 1992

A set of eight form relieved milling cutters for each module is provided to enable cutting of gears of different

(a) Materials
(b) Types e.g. spur, helical, etc.
(c) Number of teeth
(d) Width of gears

GATE - 1992

In horizontal milling process..... (up/down) milling provides better surface finish and..... (up-down) milling provides longer tool life.

IES - 1995

Assertion (A): Up milling or climb milling is commonly used for machining castings and forgings.

Reason (R): Up milling can be done on universal milling machines.

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES - 2005

Which one of the following statements is correct?

In up-milling operation, the undeformed chip thickness,

a) Is zero at the start of the cut and increases to a maximum value just before the tooth disengages the workpiece.
b) Increases to the maximum value at the centre of the travel and decreases towards the end of tooth engagement.
c) Has a maximum value just after the cut is started and drops to zero at the end of the cut.
d) Remains unchanged.

IES - 1993

Climb milling is chosen while machining because

- (a) The chip thickness increases gradually
- (b) It enables the cutter to dig in and depth of cut
- (c) The specific power consumption is reduced
- (d) Better surface finish can be obtained

IES - 2002

Assertion (A): Virtually all modern milling machines are capable of doing down-milling.

Reason (R): In down-milling the cutter tends to push the work along and lift it upward from the table. This action tends to eliminate any effect in looseness in the feed screw and nut of the milling machine table and results in smooth cut.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2004

The cutting speed of a milling cutter while cutting brass is:

- (a) 45 to 60 m/min
- (b) 30 to 40 m/min
- (c) 25 to 35 m/min
- (d) 15 to 20 m/min

IES - 1999

A straight teeth slab milling cutter of 100 mm diameter and 10 teeth rotating at 200 r.p.m. is used to remove a layer of 3 mm thickness from a steel bar. If the table feed is 400 mm/minute, the feed per tooth in this operation will be

- (a) 0.2 mm
- (b) 0.4 mm
- (c) 0.5 mm
- (d) 0.6 mm

IES - 2002

A side and face cutter 125 mm diameter has 10 teeth. It operates at a cutting speed of 14 m/min with a table traverse 100 mm/min. The feed per tooth of the cutter is

- (a) 10 mm
- (b) 2.86 mm
- (c) 0.286 mm
- (d) 0.8 mm

GATE – 2012 (PI) Common Data S1

Data for a plain milling operation are given below.

Length of workpiece	200 mm
Cutter diameter	100 mm
No. of teeth	4
Cutter speed	100 rpm
Feed	200 mm/min
Depth of cut	2 mm
Total clearance (entry and exit)	5 mm

Mean undeformed chip thickness (in microns) is

- (a) 142
- (b) 100
- (c) 71
- (d) 50

GATE – 2012 (PI) Common Data S2

Data for a plain milling operation are given below.

Length of workpiece	200 mm
Cutter diameter	100 mm
No. of teeth	4
Cutter speed	100 rpm
Feed	200 mm/min
Depth of cut	2 mm
Total clearance (entry and exit)	5 mm

Machining time for a single pass (in seconds) is

- (a) 60
- (b) 120
- (c) 180
- (d) 240

IES - 2004

Match List I (Milling problem) with List II (Probable causes) and select the correct answer using the codes given below the Lists:

List I	List II
A. Chatter	1. Too high feed
B. Poor surface finish	2. Lack of rigidity in machine fixtures, bar or workpiece
C. Loss of accuracy	3. High cutting load
D. Cutter burrs	4. Radial relief too great
	5. Not enough lubricant

Codes:	A	B	C	D
(a) 2	1	5	3	4
(b) 2	1	3	5	4
(c) 4	5	2	3	5

IAS - 2001

Which one of the following statements are correct in respect of up-milling and down-milling?

- In up-milling the cutter rotates in a direction opposite to that of workpiece travel whereas in down-milling the cutter rotates in a direction similar to that of workpiece travel.
- In down-milling chip will be thin at the beginning and increase to a maximum at the end of the cut and reverse will be the case for a chip formed by up-milling.
- Down-milling is desirable with milling cutters having a high radial rake angle when compared to up-milling.
- Down-milling forces the work-piece against the milling table to exert more pressure while up-milling tends to lift the workpiece from the table.

Select the correct answer using the codes given below:

Codes:

- (a) 1, 2 and 3
- (b) 1, 2 and 4
- (c) 3 and 4
- (d) 1, 3 and 4

IAS - 1998

Which of the following statements are true of face milling?

1. Face milling cutter is held on an arbor.
2. It has two rake angles- axial rake and radial rake.
3. The maximum chip thickness equals the feed per tooth.
4. The chip thickness varies from a minimum at the start of cut to a maximum at the end of cut.

Select the correct answer using the codes given below:

Codes :

- (a) 1 and 2 (b) 2 and 3
(c) 2 and 4 (d) 3 and 4

IAS - 2001

Which of the following mechanisms are suitable for indexing the table of rotary transfer line?

1. Rack and pinion
2. Ratchet and pawl
3. Lead screw
4. Geneva mechanism

Select the correct answer by using the codes given below:

Codes:

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

IAS - 2000

Consider the following mechanisms:

1. Geneva gearing
2. Rack and pinion
3. Ratchet and pawl

Which of these mechanisms are used to index the work table on a transfer machine?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

IAS - 2003

A milling cutter of 70 mm diameter with 12 teeth is operating at a cutting speed of 22 m/min and a feed of 0.05 mm/tooth. The feed per minute is

- (a) 110 m/min (b) 35 mm/min
(c) 6 mm/min (d) 60 mm/min

IES-1994

Which one of the following operations is carried out at the minimum cutting velocity if the machines are equally rigid and the tool work materials are the same?

- (a) Turning
(b) Grinding
(c) Boring
(d) Milling

IES - 2012

Statement (I): Vibrations in milling are induced due to interrupted cutting operation.

Statement (II): Vibrations can be suppressed to a large extent by using equal spacing of teeth along the periphery of the cutters.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

IES 2011

Match List -I with List -II and select the correct answer using the code given below the lists :

List -I	List -II
A. Lathe	1. Flute
B. Shaper	2. Universal indexing
C. Drilling machine	3. Leadscrew
D. Milling machine	4. Rocker arm

- | | | | | | | | |
|-------|---|---|---|-------|---|---|---|
| A | B | C | D | A | B | C | D |
| (a) 2 | 4 | 1 | 3 | (b) 3 | 4 | 1 | 2 |
| (c) 2 | 1 | 4 | 3 | (d) 4 | 3 | 2 | 1 |

IES- 2002

Match List I with List II and select the correct answer:

List I (Machine tools)

- A. Lathe
B. Milling machine
C. Shaper
D. Drilling machine

List II (Machine tool parts)

1. Lead screw
2. Rocker arm
3. Universal indexing
4. Flute

Codes: A B C D A B C D

- (a) 4 2 3 1 (b) 1 3 2 4
(c) 4 3 2 1 (d) 1 2 3 4



Manufacture of Gears

Manufacture of gears needs several processing operations in sequential stages depending upon the material and type of the gears and quality desired. Those stages generally are:

- Preforming the blank without or with teeth
- Annealing of the blank, if required, as in case of forged or cast steels
- Preparation of the gear blank to the required dimensions by machining
- Producing teeth or finishing the preformed teeth by machining
- Full or surface hardening of the machined gear (teeth), if required
- Finishing teeth, if required, by shaving, grinding etc
- Inspection of the finished gears

Forming and Generation

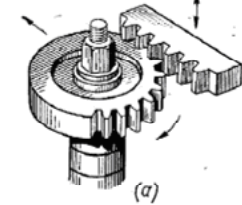
Gear teeth are produced by machining based on

Forming – where the profile of the teeth are obtained as the replica of the form of the cutting tool (edge); e.g., milling, broaching etc.

Generation – where the complicated tooth profile are provided by much simpler form cutting tool (edges) through rolling type, tool – work motions, e.g., hobbing, gear shaping etc.

Sunderland method using rack type cutter

- The rack type HSS cutter (having rake and clearance angles) reciprocates to accomplish the machining (cutting) action while rolling type interaction with the gear blank like a pair of rack and pinion.



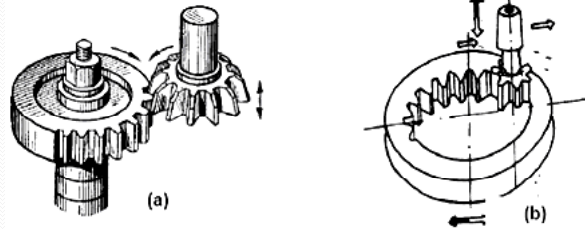
External gear teeth generation by rack type cutter (Sunderland method)

Sunderland method using rack type cutter

- Applications of this method (and machine) include:
- Moderate size straight and helical toothed external spur gears with high accuracy and finish
- Cutting the teeth of double helical or herringbone gears with a central recess (groove)
- Cutting teeth of straight or helical fluted cluster gears
- However this method needs, though automatic, few indexing operations.

Gear shaping

- Gear shaping is similar to the rack type cutting process, excepting that, the linear type rack cutter is replaced by a circular cutter where both the cutter and the blank rotate as a pair of spur gears in addition to the reciprocation of the cutter.

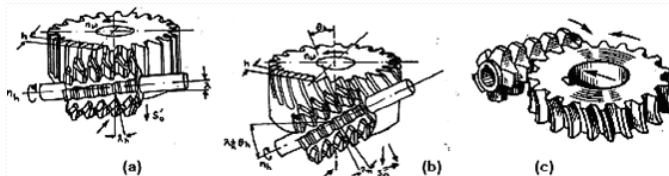


Gear shaping

- Generation method is characterised by automatic indexing and ability of a single cutter to cover the entire range of number of teeth for a given combination of module and pressure angle and hence provides high productivity and economy.
- The gear type cutter is made of HSS and possesses proper rake and clearance angles.
- The additional advantages of gear shaping over rack type cutting are:
 - Separate indexing is not required at all
 - Straight or helical teeth of both external and internal spur gears can be produced with high accuracy and finish
 - Productivity is also higher.

Gear Hobbing

- The HSS or carbide cutter having teeth like gear milling cutter and the gear blank apparently interact like a pair of worm and worm wheel.
- The hob (cutter) looks and behaves like a single or multiple start worms.



(a) Straight (b) helical tooth and (c) worm wheel

Gear Hobbing

- Having lesser number (only three) of tool – work motions, hobbing machines are much more rigid, strong and productive than gear shaping machine.
- But hobbing provides lesser accuracy and finish and is used only for cutting straight or helical teeth (single) of external spur gears and worm wheels.

Advantages of Gear Hobbing

- The method is versatile and can generate spur, helical, worm and worm wheels.
- Since gear hobbing is a continuous process, it is rapid; economical and highly productive.
- The method produces accurate gears and is suitable for medium and large batch production.
- The cutter is universal, because it can cut all gears of same module, irrespective of number of teeth on the gear.

Disadvantages of gear Hobbing

- (a) Gear hobbing cannot generate internal gears and bevel gears.
- (b) Enough space has to be there in component configuration for hob approach.

Applications of Hobbing

- The gears produced by gear hobbing are used in automobiles, machine tools, various instruments, clocks and other equipments.

Milling

- Gear teeth can be produced by both disc and end mill type form milling cutter.

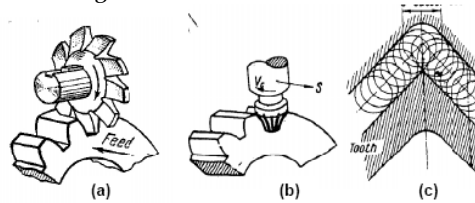


Fig. (a) disc type and end mill type for
(b) single helical and
(c) double helical teeth

Milling

Production of gear teeth by form milling are characterised by:

- Use of HSS form milling cutters
- Use of ordinary milling machines
- Low production rate for
 - Need of indexing after machining each tooth gap
 - Slow speed and feed
- Low accuracy and surface finish
- Inventory problem – due to need of a set of eight cutters for each module – pressure angle combination
- End mill type cutters are used for teeth of large gears and / or module.

Shaping, Planning and Slotting

- Straight toothed spur gear can be produced in shaping machine.
- Both productivity and product quality are very low in this process which therefore, is used, if at all, for making one or few teeth on one or two pieces of gears as and when required for repair and maintenance purpose.
- Planning and slotting machines work on the same principle. Planning machine is used for making teeth of large gears whereas slotting for internal gears.

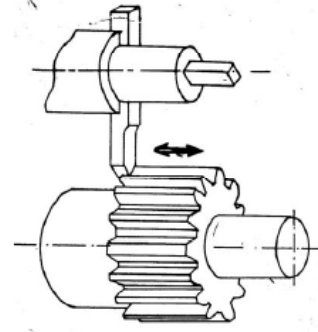
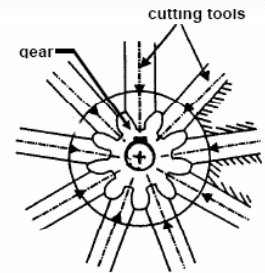


Fig- gear teeth cutting in ordinary shaping machine

Fast production of teeth of spur gears

Parallel multiple teeth shaping

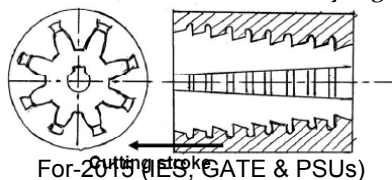
- It is similar to ordinary shaping but all the tooth gaps are made simultaneously, without requiring indexing, by a set of radially in feeding single point form tools.
- This old process was highly productive but became almost obsolete for very high initial and running costs.



Fast production of teeth of spur gears

Broaching

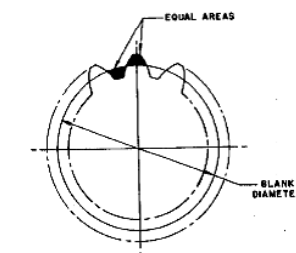
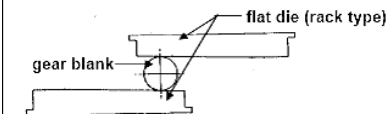
- Teeth of small internal and external spur gears; straight or single helical, of relatively softer materials are produced in large quantity by broaching.
- This method leads to very high productivity and quality but cost of machine and broach are very high.



For-2015 (IES, GATE & PSUs)

Manufacture of gears by rolling

- The straight and helical teeth of disc or rod type external steel gears of small to medium diameter and module are generated by cold rolling by either flat dies or circular dies.
- Such rolling imparts high accuracy and surface integrity of the teeth which are formed by material flow unlike cutting.
- Gear rolling is reasonably employed for high productivity and high quality though initial machinery costs are relatively high.
- Larger size gears are formed by hot rolling and then finished by machining.



Rev.0

Powder Metallurgy

- Small size high quality external or internal spur, bevel or spiral gears are also produced by powder metallurgy process.
- Large size gears are rolled after briquetting and sintering for more strength and life.
- Powder metallurgically produced gears hardly require any further finishing work.

Wire EDM

- Geometrically accurate but moderately finished straight toothed metallic spur gears, both external and internal type, can be produced by wire type Electro-discharge Machining (EDM).



Casting

- Sand casting
- Metal mould casting
- Die casting
- Investment casting
- Shell mould casting
- Centrifugal casting

Gear finishing process

- One of the goals of the gear finishing process in gears is to obtain a certain level of toughness in the gear teeth to reduce and/or eliminate bending and contact fatigue failures.
- Reduction of index undulation errors associated with helical gear teeth caused by the grinding process during the manufacture of the gears without degrading other gear accuracies (e.g. profile, tooth spacing) below levels required for precision (AGMA16 or DIN1) gears.
- A mold of the space between several gear teeth is obtained, with the mold having a length equal to or greater than the wavelength of the undulation error to be reduced.

- A micro finishing film is affixed to the mold and the mold is placed relative to a gear tooth so that the micro finishing film rests against a tooth surface having the undulation error.
- The grit size of the micro finishing film is such as to remove approximately 2 to 3 millionths of gear material with each pass through the teeth by the mold. Multiple passes are made by hand until the undulation error is reduced to an acceptable value. During the process the micro finishing film is replaced after approximately 3 or 4 passes and the process is repeated for each tooth of the gear.

Gear shaving

- Gear shaving is a gear finishing operation with high efficiency and high precision.
- When a work gear has been shaved by a shaving cutter with a true **involute profile**, the "mid-concave" phenomena inevitably exist around the pitch points of the work gear tooth flanks.
- Aiming at this problem, a new-style shaving cutter with unequal depth gashes is designed and manufactured.
- This paper analyses the forming of the gash on the basis of the slotting principle, and proposes a gash-designing method.
- Experiment has proven that the shaved gear has a better surface finish that achieves the anticipated effect.

Gear burnishing

- It is designed to remove or reduce gear tooth nicks and burrs, along with improving the smoothness of the tooth's active profile finish.
- The action of the burnishing dies on the tooth surface allows the machine to accomplish these quality improvements without altering the tooth profile or lead.
- Both internal and external gears are possible to burnish.

Gear Lapping

- Gear lapping is used to finish hardened gears by correcting small errors in spacing, profile, helix angle, and eccentricity.
- The operation is performed with all forms of gears running together with mating gears, and cast iron toothed laps, under a flow of fine oil mixed with an abrasive compound.

IES - 1992

Gear lapping

- (a) An operation after heat treatment
- (b) An operation prior to heat treatment
- (c) An independent operation for gear reconditioning
- (d) None of the above

IES - 1999

Consider the following processes for the manufacture of gears:

1. Casting
2. Powder metallurgy
3. Machining from bar stock
4. Closed die forging

The correct sequence in increasing order of bending strength of gear teeth is

- (a) 1, 2, 3, 4 (b) 1, 2, 4, 3
(c) 2, 1, 4, 3 (d) 2, 1, 3, 4

IES - 2006

Which of the following is/are used for cutting internal gears?

1. Gear hobber 2. Gear shaper
3. Rack cutter 4. Jig borer

Select the correct answer using the codes given below:

- (a) Only 1 and 2 (b) Only 2 and 3
(c) Only 1 and 4 (d) Only 2

IES - 2005

In helical milling, the ratio of the circumference of the gear blank to the lead of the helix determines the:

- (a) Proper speed to use
(b) Proper feed and depth of cut required
(c) Angle setting of the machine table
(d) Gear ratio for table screw and dividing head

IES 2010

Match List I with List II and select the correct answer using the code given below the lists:

List I

(Type of work)

List II

(Manufacturing)

- | | |
|--|-----------------|
| A. High rate production of worm Gears and worm wheel | 1. Gear shaving |
| B. Generating internal gears and Cluster gears | 2. Gear milling |
| C. Finishing of gear tooth profiles | 3. Gear hobbing |
| D. Repair and piece production of gears | 4. Gear shaping |

- | | A | B | C | D | | A | B | C | D |
|-----|---|---|---|---|-----|---|---|---|---|
| (a) | 2 | 1 | 4 | 3 | (b) | 3 | 1 | 4 | 2 |
| (c) | 2 | 4 | 1 | 3 | (d) | 3 | 4 | 1 | 2 |

IES - 1996

Gear cutting on a milling machine using an involute profile cutter is a

- (a) Gear forming process
(b) Gear generating process.
(c) Gear shaping process
(d) Highly accurate gear producing process.

IES - 2000

Which one of the following processes of gear manufacture results in best accuracy of the involute gear tooth profile?

- (a) Milling
(b) Hobbing
(c) Rotary gear shaper
(d) Rack type gear shaper

IES - 2009

Assertion (A): Gears produced by employing form-cutting principle using gear-milling cutter on a milling machine are not very accurate.

Reason (R): Production of the correct gear tooth profile employing form-cutting principle would require a separate cutter for cutting different numbers of teeth even for the same module and also errors are associated with inaccurate operation of indexing mechanism.

- (a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES - 1996

Consider the following processes of gear manufacture:

1. Milling with form cutter
2. Rack type gear shaper (gear planer)
3. Rotary gear shaper (gear shaper)
4. Gear hobbing

The correct sequence of these processes in increasing order of accuracy of involute profile of the gear

- (a) 3, 2, 4, 1 (b) 2, 3, 4, 1
(c) 3, 2, 1, 4 (d) 2, 3, 1, 4

IES - 2009

By which one of the following machines the teeth of an internal spur gear can be cut accurately?

- (a) Milling machine
(b) Slotting machine
(c) Hobbing machine
(d) Gear-shaping machine

IES - 2004

Gear shaping is a process of manufacturing gears.

Which one of the following principles is employed by it?

- (a) Form cutting with cutter
- (b) Generating tooth form with a reciprocating cutter
- (c) Generating tooth form by a rotating cutter
- (d) Generating form with a reciprocating and revolving cutter

IES - 1992

In gear hobbing

- (a) Only hob rotates
- (b) Only gear blank rotates
- (c) Both hob and gear blank rotate
- (d) Neither hob nor gear blank rotates

IES - 2003

A spur gear of 40 teeth is machined in a gear hobbing machine using a double start hob cutter. The speed ratio between the hob and the blank is

- (a) 1:20 (b) 1:40
- (c) 40:1 (d) 20:1

IES - 2008

Which machining processes are used for gear manufacture?

- 1. Form milling
- 2. Broaching
- 3. Roll forming
- 4. Hobbing

Select the correct answer using the code given below:

- (a) 1, 2 and 3 (b) 1, 3 and 4
- (c) 1, 2 and 4 (d) 2, 3 and 4

IES - 1999

A 60-teeth gear when hobbled on a differential hobber with a two-start hob, the index change gear ratio is governed by which one of the following kinematic balance equations?

- (a) 1 revolution of gear blank = $1/60$ of hob revolutions
- (b) 1 revolution of gear blank = $2/60$ of hob revolutions
- (c) 1 revolution of hob = $2/60$ of blank revolutions
- (d) 1 revolution of hob = $1/60$ of blank revolutions

IES - 1997

Which of the following motions are not needed for spur gear cutting with a hob?

- 1. Rotary motion of hob
- 2. Linear axial reciprocator motion of hob
- 3. Rotary motion of gear blank
- 4. Radial advancement of hob.

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1, 3 and 4
- (c) 1, 2 and 4 (d) 2, 3 and 4

IES - 2007

Which of the following methods are gear generating processes?

- 1. Gear shaping
- 2. Gear hobbing
- 3. Gear milling

Select the correct answer using the code given below:

- (a) 1, 2 and 3 (b) 1 and 2 only
- (c) 2 and 3 only (d) 1 and 3 only

GATE – 2007 (PI)

Which one of the following gear manufacturing processes is NOT based on generation principle?

- (a) Gear Hobbing (b) Gear Shaping
- (c) Gear Milling (d) Gear Shaving

IES - 1993

Internal gear cutting operation can be performed by

- (a) Milling
- (b) Shaping with rack cutter
- (c) Shaping with pinion cutter
- (d) Hobbing

IAS - 1998

Assertion (A): Internal gears are cut on a gear shaper.

Reason (R): Hobbing is not suitable for cutting internal gear.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2006

Which of the following cannot be cut by hobbing process?

- (a) Helical gears
- (b) Bevel gears
- (c) Worm gears
- (d) Spur gears

IES - 1996

For the manufacture of full depth spur gear by hobbing process, the number of teeth to be cut = 30, module = 3 mm and pressure angle = 20° . The radial depth of cut to be employed should be equal to

- (a) 3.75 mm
- (b) 4.50 mm
- (c) 6.00 mm
- (d) 6.75 mm

IES - 1995

While cutting helical gears on a non-differential gear hobber, the feed change gear ratio is

- (a) Independent of index change gear ratio
- (b) dependent on speed change gear ratio
- (c) Interrelated to index change gear ratio
- (d) Independent of speed and index change gear ratio.

IES - 1992

Gear burnishing process for

- (a) Removing residual stresses from teeth roots
- (b) Surface finishing
- (c) Under-cut gears
- (d) Cycloidal gears

IAS - 2003

Which one of the following is not a feature of gear hobbing process?

- (a) High rate of production
- (b) Generation of helical gears
- (c) Very accurate tooth profile
- (d) Generation of internal gears

IAS - 2001

Consider the following motions and setting in a hobbing machine:

- 1. Hob rotation
- 2. Job rotation
- 3. Axial reciprocating hob rotation
- 4. Tilting of hob to its helix angle

Which of these motions and setting in a hobbing machine are required to machine a spur gear?

- (a) 1, 2 and 3
- (b) 2, 3 and 4
- (c) 1, 2 and 4
- (d) 1, 3 and 4

For-2015 (IES, GATE & PSUs)

IES - 1994

Consider the following machine tools:

- 1. Hobbing machine
- 2. Gear shaping machine
- 3. Broaching machine.

The teeth of internal spur gears can be cut in

- (a) 1, 2 and 3
- (b) 1 and 2
- (c) 1 and 3
- (d) 2 and 3



Processes, Machines and Tools Used For Producing Screw Threads

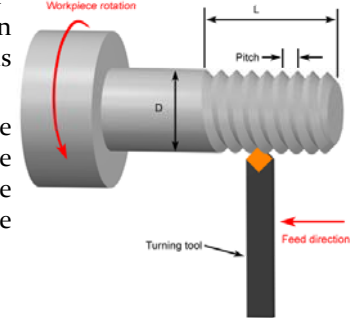
- (a) Machining
- (b) Rolling
- (c) Grinding

Thread Cutting

External	Internal
<ul style="list-style-type: none"> • Threading on a lathe • Threading on a NC lathe • With a die held in a stock (manual) • With an automatic die (turret lathe or screw machine) or NC lathe • By milling • By Grinding 	<ul style="list-style-type: none"> • Threading (on a lathe or NC lathe) • With a tap and holder (manual NC, machine, semiautomatic, or automatic) • With a collapsible tap (turret lathe, screw machine, or special threading machine) • By milling

Thread Cutting on Lathe

- Can cut both external and Internal thread
- Thread cutting is a form-cutting operation an accurately shaped tool is used (with zero rake)
- The lead screw and the split nut, which provide positive motion of the carriage relative to the rotation of the spindle.



Cutting Threads with Dies

- Straight and tapered external threads can be cut quickly manually by means of threading dies.
- Dies are made of carbon or high-speed tool steel



(a) Solid threading die; (b) solid-adjustable threading die

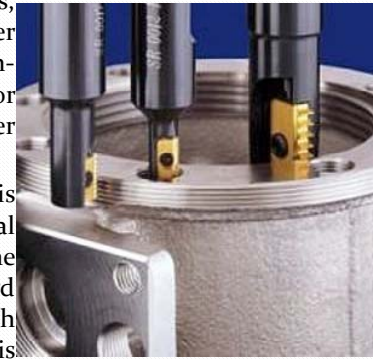
Thread Tapping

- Cutting internal thread by a multiple-point tool is called thread tapping, and the tool is called a tap.
- A hole of diameter slightly larger than the minor diameter of the thread must already exist.
- The flutes on tap create cutting edges on the thread profile and provide space for the chips and the passage of cutting fluid.
- Taps are made of either carbon or high-speed steel and coated with TiN.



Thread Milling

- Highly accurate threads, particularly in larger sizes, are often form-milled. Either a single or a multiple-form Cutter may be used.
- The milling cutter is tilted at an angle equal to the helix angle of the thread and is fed inward radially to full depth while the work is stationary.



Thread Grinding

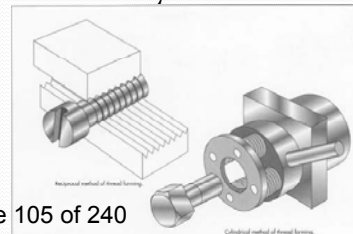
- Grinding can produce very accurate threads, and it also permits threads to be produced in hardened materials.
- A single-ribbed grinding wheel is employed, but multiple-ribbed wheels are used occasionally.
- Centerless thread grinding is used for making headless sets screws.



For-2015 (IES, GATE & PSUs)

Thread Rolling

- Thread rolling is used to produce threads in substantial quantities.
- Cold-forming process operation in which the threads are formed by rolling a thread blank between hardened dies that cause the metal to flow radially into the desired shape.
- Chip less process, fast and economical.
- Mechanical properties are good.



GATE - 2003

Quality screw threads are produced by

- (a) Thread milling
- (b) Thread chasing
- (c) Thread cutting with single point tool
- (d) Thread casting

IES 2011

External threads can be produced by :

1. Rolling
 2. Grinding
 3. Milling
- (a) 1 and 3 only
(b) 1 and 2 only
(c) 2 and 3 only
(d) 1, 2 and 3

IES 2010

For producing both internal and external screw threads, the method used is

- (a) Thread chasing with multiple-rib chasers
(b) Thread milling and multiple-thread cutters
(c) Thread tapping with taps
(d) Die threading with self-opening die heads

IES - 2007

Screw threads are produced on solid rods by using which of the following?

- (a) Dies (b) Punch
(c) Mandrel (d) Boring bar

ISRO-2011

Which of the following screw thread is adapted for power transmission in one direction

- (a) Acme threads
(b) Buttress threads
(c) Square threads
(d) Multiple threads

ISRO-2010

Internal and external threads can be produced on tapered surfaces conveniently by

- (a) Universal milling machine
(b) Plano miller
(c) Planetary milling machine
(d) lathe

IES - 2012

The differential screw is used in a

- (a) Turnbuckle
(b) Micrometer
(c) Vernier Caliper
(d) Coupler

IES - 2012

Multistart threads are used to get

- (a) Smaller linear displacement
(b) Larger linear displacement with assured self locking
(c) Larger linear displacement with no guarantee of self locking
(d) None of the above

IES - 2012

Which of the following screw threads is adopted for power transmission in either direction

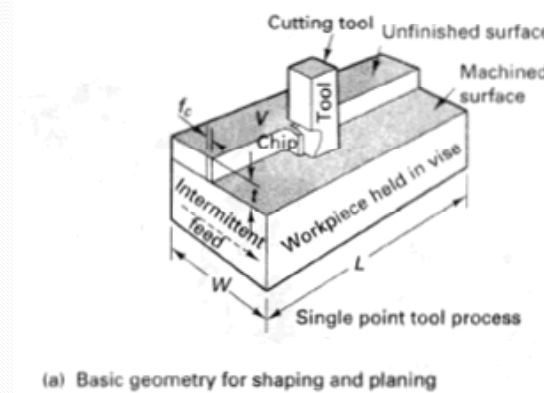
- (a) ACME threads
(b) Square threads
(c) Buttress threads
(d) Multiple threads



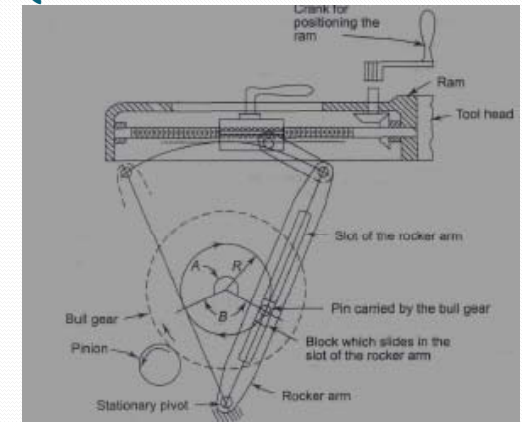
Shaper

- The relative motions between the tool and the workpiece, shaping and planing use a straight-line cutting motion with a single-point cutting tool to generate a flat surface.
- In shaping, the workpiece is fed at right angles to the cutting motion between successive strokes of the tool.
- For either shaping or planing, the tool is held in a clapper box which prevents the cutting edge from being damaged on the return stroke of the tool.
- Relatively skilled workers are required to operate shapers and planers, and most of the shapes that can be produced on them also can be made by much more productive processes, such as milling, broaching, or grinding.

Shaper



Quick return motion Mechanism



Quick return motion Mechanism

- In shaping, the cutting tool is held in the tool post located in the ram, which reciprocates over the work with a forward stroke, cutting at velocity V and a quick return stroke at velocity V_R .
- The rpm rate of the drive crank (N_s) drives the ram and determines the velocity of the operation.
- The stroke ratio, $R_s = \frac{\text{cutting stroke angle}}{360^\circ}$

Ram Drive

- The mechanical ram drive is a slotted arm quick return motion mechanism,

Feed Mechanism

- Table feed is intermittent and is accomplished on the return (non cutting) stroke when the tool has cleared the workpiece.
- The cross feed is given to the table with the help of a cross feed screw which is actuated by a pawl which engages a notched wheel (ratchet) keyed to the screw.

Classification of Shaper Machine

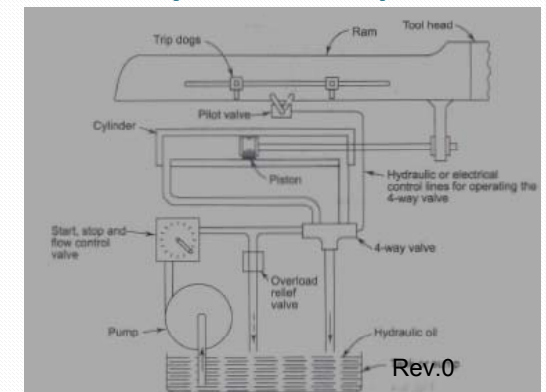
Shapers, as machine tools usually are classified according to their general design features as follows,

1. Horizontal
 - a. Push-cut
 - b. Pull-cut or draw cut shaper
2. Vertical
 - a. Regular or slotters
 - b. Keyseaters
3. Special purpose

Formula

- Cutting speed, $V = \frac{NL(1+m)}{1000}$
- Number of strokes, $N_s = \frac{w}{f}$
- Time of one stroke, $t = \frac{L(1+m)}{1000V}$ min
- Total time, $T = \frac{L(1+m)}{1000v} N_s = \frac{Lw(1+m)}{1000vf}$ min

Hydraulic Shaper



Advantages of hydraulic shaping

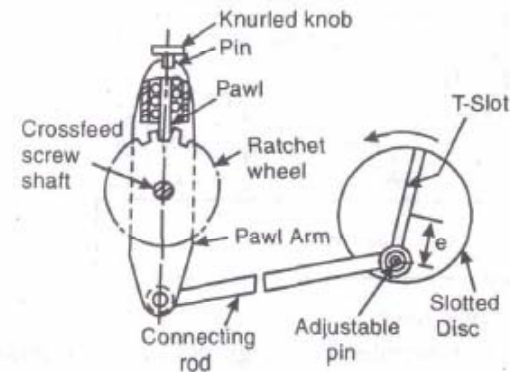
- 1. Cutting speed remains constant throughout most of the cutting stroke, unlike the crank shaper where the speed changes continuously.
- 2. Since the power available remains constant throughout, it is possible to utilise the full capacity of the cutting tool during the cutting stroke.
- 3. The ram reverses quickly without any shock due the hydraulic cylinder utilised. The inertia of the moving parts is relatively small.
- 4. The range and number of cutting strokes possible are relatively large in hydraulic shaper.
- 5. More strokes per minute can be achieved by consuming less time for reversal and return strokes.

Planer

- Planing can be used to produce horizontal, vertical, or inclined flat surfaces on workpieces that are too large to be accommodated on shapers.
- Planing is much less efficient than other basic machining processes, such as milling, that will produce such surfaces.
- Planing and planers have largely been replaced by planer milling machines or machines that can do both milling and planing.

Slotter

- Slotting machine is basically a vertical axis shaper. Thus the workpieces, which cannot be conveniently held in shaper, can be machined in a slotter.
- Generally, keyways, splines, serrations, rectangular grooves and similar shapes are machined in a slotting machine.
- The stroke of the ram is smaller in slotting machines than in shapers to account for the type of the work that is handled in them.



Slotter



Slotter

- The types of tools used in a slotter are very similar to those in a shaper, except that the cutting actually takes place in the direction of cutting.
- However, in view of the type of surfaces that are possible in the case of slotter, a large variety of boring bars or single-point tools with long shanks are used.

IAS - 1994

Stroke of a shaping machine is 250 mm. It makes 30 double strokes per minute. Overall average speed of operation is

- (a) 3.75 m/min (b) 5.0 m/min
(c) 7.5 m/min (d) 15 m/min

GATE-2012 (PI)

In a shaping process, the number of double strokes per minute is 30 and the quick return ratio is 0.6. If the length of the stroke is 250 mm, the average cutting velocity in m/min is

- (a) 3.0 (b) 4.5 (c) 7.5 (d) 12.0

GATE - 2005

A 600 mm x 30 mm flat surface of a plate is to be finish machined on a shaper. The plate has been fixed with the 600 mm side along the tool travel direction. If the tool over-travel at each end of the plate is 20 mm, average cutting speed is 8 m/min, feed rate is 0.3 mm/stroke and the ratio of return time to cutting time of the tool is 1:2, the time required for machining will be

- (a) 8 minutes (b) 12 minutes
(c) 16 minutes (d) 20 minutes

IES – 1994, ISRO-2008

Given that, average cutting speed = 9 m/min, the return time to cutting time ratio is = 1 : 2, the feed rate = 0.3 mm/stroke, the clearance at each end of cut = 25 mm and that the plate is fixed with 700 mm side along the direction of tool travel, the time required for finishing one flat surface of a plate of size 700 x 30 mm in a shaper, will be

- (a) 10 min (b) 12.5 min
- (c) 15 min (d) 20 min

GATE-2014

A cast iron block of 200 mm length is being shaped in a shaping machine with a depth of cut of 4 mm, feed of 0.25 mm/stroke and the tool principal cutting edge angle of 30° . Number of cutting strokes per minute is 60. Using specific energy for cutting as 1.49 J/mm^3 the average power consumption (in watt) is

IES - 2004

Consider the following alignment tests on machine tools

- 1. Straightness 2. Flatness
- 3. Run out 4. Parallelism

Which of the above alignment tests on machine tools are common to both lathe and shaper?

- (a) 1 and 2 (b) 2 and 3
- (c) 3 and 4 (d) 1 and 4

IES - 2001

In a shaper machine, the mechanism for tool feed is

- (a) Geneva mechanism
- (b) Whitworth mechanism
- (c) Ratchet and Pawl mechanism
- (d) Ward- Leonard system

IES 2010

Assertion (A): Longitudinal cutting motion of the tool and cross-wise feed motion of the job generates flat surfaces in planning process.

Reason (R): Jobs used in planning machines are generally long and heavy compared to shaping.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1997

Which of the following are the advantages of a hydraulic shaper over a mechanically driven shaper?

- 1. More strokes per minute can be obtained at a given cutting speed.
- 2. The cutting stroke has a definite stopping point.
- 3. It is simpler in construction.
- 4. Cutting speed is constant throughout most of the cutting stroke.

Select the correct answer using the codes given below:

- (a) 1 and 2 (b) 1 and 4
- (c) 2 and 4 (d) 1, 3 and 4

IES - 1995

In a mechanical shaper, the length of stroke is increased by

- (a) Increasing the centre distance of bull gear and crank pin
- (b) Decreasing the centre distance of bull gear and crank pin
- (c) Increasing the length of the ram
- (d) Decreasing the length of the slot in the slotted lever

IAS - 1995

Size of a shaper is given by

- (a) Stroke length (b) Motor power
- (c) Weight of the machine (d) Table size.

ISRO-2010

The cutting speed of the tool in a mechanical shaper is

- (a) Maximum at the beginning of the cutting stroke
- (b) Maximum at the end of the cutting stroke
- (c) Maximum at the middle of the cutting stroke
- (d) Minimum at the middle of the cutting stroke

GATE-2014 (PI)

Match the following

Group I (Mechanism)	Group II (Machines)
P Quick return	1 Lathe
Q Apron	2 Shaping
R Intermittent indexing	3 Gear hobbing
S Differential mechanism	4 Milling

- (a) P1-Q2-R4-S3 (b) P2-Q1-R4-S3
(c) P4-Q1-R2-S3 (d) P2-Q3-R1-S4



Abrasive Machining Processes

Process	Features
Grinding	Uses wheels, accurate sizing, finishing, low MRR; can be done at high speeds .
Creep feed grinding	Uses wheels with long cutting arc, very slow feed rate and large depth of cut
Abrasive machining	High MRR, to obtain desired shapes and approximate sizes
Abrasive water jet Machining	Water jets with velocities up to 1000 m/sec carry abrasive particles (silica and garnet)
Honing	"Stones" containing fine abrasives; primarily a hole - finishing process
Lapping	Fine particles embedded in soft metal or cloth; primarily a surface-finishing process

Grinding

- Grinding is the most common form of abrasive machining.
- It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as **grit**.
- These grits are characterized by sharp cutting points, high hot hardness, and chemical stability and wear resistance.
- The grits are held together by a suitable bonding material to give shape of an abrasive tool.
- Grinding can be compared with milling with an infinite number of cutting edge.

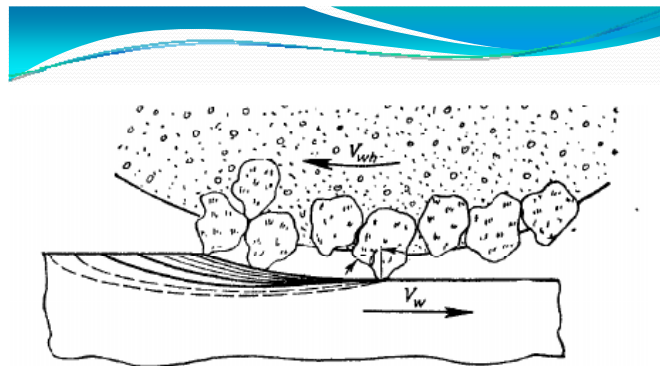


Fig- cutting action of abrasive grains

Why is high velocity desired in grinding?

- It is desired to off set the adverse effect of very high negative rake angle of the working grit, to reduce the force per grit as well as the overall grinding force.

Advantages of Grinding

- Dimensional accuracy
- Good surface finish
- Good form and locational accuracy
- Applicable to both hardened and unhardened material

Applications of Grinding

- Surface finishing
- Slitting and parting
- Descaling, deburring
- Stock removal (abrasive milling)
- Finishing of flat as well as cylindrical surface
- Grinding of tools and cutters and sharpening of the same

On which factors does the transverse roughness of workpiece depend during grinding?

- It mainly depends on the shape of the grits and overlap cuts made by the grits in the transverse direction. Lateral plastic flow of the material as a result of ploughing also influences the surface roughness.

Grinding

- If each abrasive grain is viewed as a cutting tool then in grinding operation.

High

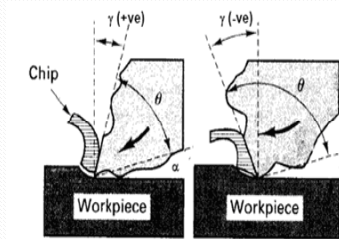
- Rake angle can be positive, zero, or negative ranging from $+45^\circ$ to -60° , dull, rounded grits has large negative rake angle
- Cutting speed is very high
- Very high specific energy of cutting

Low

- Low shear angle
- Low feed rate
- Low depth of cut

Interaction of the grit with the workpiece

- Shape of grit is very important because it determines the grit geometry e.g. rake and clearance angle.
- The grits do not have definite geometry unlike a cutting tool.



Interaction of the grit with the workpiece

- Grit with favourable geometry can produce chip in shear mode.
- However, grits having large negative rake angle or rounded cutting edge do not form chips but may rub or make a groove by ploughing leading to lateral flow of the workpiece material.

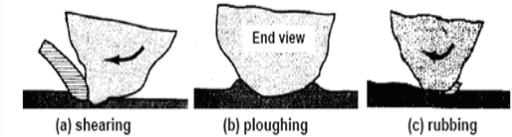
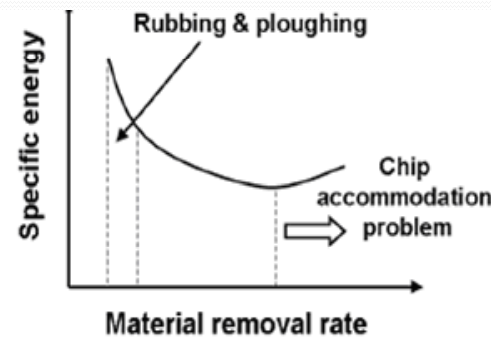


Fig- Grits engage shearing, ploughing and rubbing

How is chip accommodation volume is related to material removal rate?

- Volume of chip accommodation space ahead of each grit must be greater than the chip volume produced by each grit to facilitate easy evacuation of the chip from the grinding wheel.

Specific energy consumption in grinding



How may the specific grinding energy vary with material removal rate in grinding?

- Specific grinding energy will start decreasing with material removal rate because rake angle of the grit becomes more favourable with increase of grit depth of cut. However, if increase of material removal rate causes chip accommodation problem in the available inter-grit space then specific energy may increase.

G Ratio

- The grinding ratio or G ratio is defined as the cubic mm of stock removed divided by the cubic mm of wheel lost.
- In conventional grinding, the G ratio is in the range 20: 1 to 80: 1.
- The G ratio is a measure of grinding production and reflects the amount of work a wheel can do during its useful life.
- As the wheel losses material, it must be reset or repositioned.

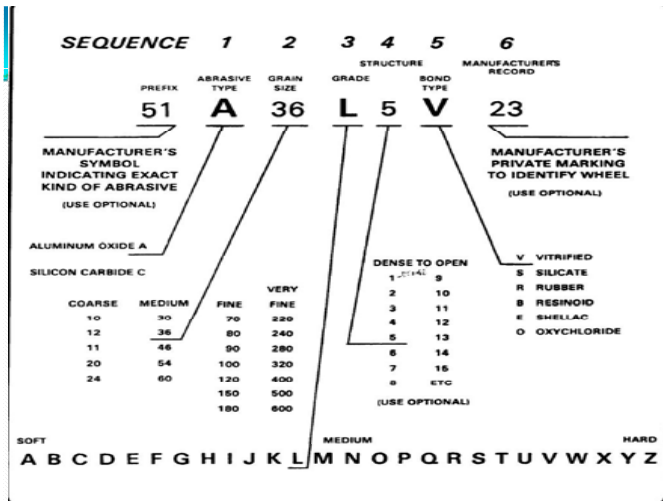
GATE -2011 (PI)

Grinding ratio is defined as

- $\frac{\text{volume of wheel wear}}{\text{volume of work material removed}}$
- $\frac{\text{volume of work material removed}}{\text{volume of wheel wear}}$
- $\frac{\text{cutting speed}}{\text{feed}}$
- $\frac{\text{longitudinal feed}}{\text{transverse feed}}$

Parameters for specify a grinding wheel

- 1) The type of grit material
- 2) The grit size
- 3) The bond strength of the wheel, commonly known as wheel hardness
- 4) The structure of the wheel denoting the porosity i.e. the amount of inter grit spacing
- 5) The type of bond material
- 6) Other than these parameters, the wheel manufacturer may add their own identification code prefixing or suffixing (or both) the standard code.



Abrasive Material	Comments and Uses
Aluminium oxide	Softer and tougher than silicon carbide; use on steel, iron, brass
Silicon carbide	Used for brass, bronze, aluminum, stainless steel and cast iron
cBN (cubic boron nitride)	For grinding hard, tough tool steels, stainless steel, cobalt and nickel based superalloys, and hard coatings
Diamond	Used to grind nonferrous materials, tungsten carbide and ceramics

IES 2009

- 2 marks

What does the following marking on a grinding wheel denote ?

55 - C - 36 - D - 9 - S - 28

Why is aluminium oxide preferred to silicon carbide in grinding steel?

- Al_2O_3 is tougher than SiC. Therefore it is preferred to grind material having high tensile strength like steel. Moreover, Al_2O_3 shows higher chemical inertness than SiC towards steel leading to much improved wear resistance during grinding.

Grit size

- The grain size affects material removal rate and the surface quality of workpiece in grinding.
- Large grit- big grinding capacity, rough workpiece surface
- Fine grit- small grinding capacity, smooth workpiece surface

Why does single layer grinding wheel show progressive rise of force during grinding of high speed steel?

- The geometry of grit undergoes irreversible change in the form of rounding or flattening due to wear caused by rubbing action of hard carbides present in high speed steel.

Grade

- The worn out grit must pull out from the bond and make room for fresh sharp grit in order to avoid excessive rise of grinding force and temperature.
- A soft wheel should be chosen for grinding hard material.
- A hard wheel should be chosen for grinding soft material.

Structure / concentration

- The structure should be open for grinding wheels engaged in high material removal to provide chip accommodation space.
- The space between the grits also serves as pocket for holding grinding fluid.
- Dense structured wheels are used for longer wheel life, for holding precision forms and profiles.

Why is coarse grain and open structured wheel is preferred for stock removal grinding?

- Coarse grit allows large grit protrusion and open structure provides large inter grit chip space. Thus in combination those two provide large space for chip accommodation during stock removal grinding and risk of wheel loading is minimized.

Bonding Materials for Grinding wheels

Type of Bond	Attributes
Vitrified bonds	Composed of clays and other ceramic substances, porous, strong, rigid, and unaffected by oils, water, or temperature. Brittle and can not be used for high wheel speed.
Resinoid, or phenolic resins	Plastic bond, replaced shellac and rubber wheels, not with alkaline grinding fluid.
Shellac bond	For flexible cut off wheels, replaced by resin bond.

Bonding Materials for Grinding wheels

Type of Bond	Attributes
Rubber bond	For use in thin wheels, replaced by resin bond.
Oxychloride bond	Limited use.
Metal bond	Extensively used with super abrasive wheels, high toughness, high accuracy, large stock removal.
Electroplated bond	Used for small wheel, form wheel and thin super abrasive wheels, for abrasive milling and ultra high speed grinding. Replace by electroplated bond

Bonding Materials for Grinding wheels

Vitrified bonds

- They are composed of clays and other ceramic substances.
- Vitrified wheels are porous, strong, rigid, and unaffected by oils, water, or temperature over the ranges usually encountered in metal cutting.
- The operating speed range in most cases is 1500 to 5000 m/min.

What is the main short coming of vitrified bond?

Vitrified bond is brittle and can not with stand high impact loads. This bond can not be used for high wheel speed due to risk of wheel breakage under centrifugal force.

Resinoid, or phenolic resins

- Because plastics can be compounded to have a wide range of properties, such wheels can be obtained to cover a variety of work conditions.
- They have, to a considerable extent, replaced shellac and rubber wheels.
- Resin bond is not recommended with alkaline grinding fluid for a possible chemical attack leading to bond weakening.

Shellac bond

- At one time this bond was used for flexible cut off wheels.
- At present use of shellac bond is limited to grinding wheels engaged in fine finish of rolls.

Rubber bond

- Its principal use is in thin wheels for wet cut-off operation.
- Rubber bond was once popular for finish grinding on bearings and cutting tools.

Oxychloride bond

- It is less common type bond, but still can be used in disc grinding operation. It is used under dry condition.

Metal bond

- Metal bond is extensively used with super abrasive wheels. Extremely high toughness of metal bonded wheels makes these very effective in those applications where form accuracy as well as large stock removal is desired.

Electroplated bond

- This bond allows large (30-40%) crystal exposure above the bond without need of any truing or dressing. This bond is specially used for making small diameter wheel, form wheel and thin super abrasive wheels. Presently it is the only bond for making wheels for abrasive milling and ultra high speed grinding.

Brazed bond

- This is relatively a recent development, allows crystal exposure as high 60-80%. In addition grit spacing can be precisely controlled. This bond is particularly suitable for very high material removal either with diamond or cBN wheel. The bond strength is much greater than provided by electroplated bond. This bond is expected to replace electroplated bond in many applications.

Glazing

- With continuous use a grinding wheel becomes dull with the sharp abrasive grains becoming rounded.
- This condition of a dull grinding wheel with worn out grains is termed as glazing.

Loading

- Some grinding chips get lodged into the spaces between the grits resulting in a condition known as loaded wheel.
- Loading is generally caused during the grinding of soft and ductile materials.
- A loaded grinding wheel cannot cut properly and need dressing.

Dressing

- Dressing is the conditioning of the wheel surface which ensures that grit cutting edges are exposed from the bond and thus able to penetrate into the workpiece material.
- In dressing attempts are made to splinter the abrasive grains to make them sharp and free cutting and also to remove any residue left by material being ground.
- Dressing therefore produces micro-geometry.

GATE-2014

Match the Machine Tools (Group A) with the probable Operations (Group B):

Group A				Group B			
P: Center Lathe				1: Slotting			
Q: Milling				2: Counter-boring			
R: Grinding				3: Knurling			
S: Drilling				4: Dressing			

	P	Q	R	S		P	Q	R	S
(a)	1	2	4	3	(b)	2	1	4	3
(c)	3	1	4	2	(d)	3	4	2	1

Can a resin bonded cBN wheel be electrochemically dressed?

- Electrochemical dressing is not possible with resin bonded wheel because it is not electrically conducting.

Is dressing necessary for single layer wheel?

- Conventional macro level dressing is not required because the wheel inherently has an open structure. However, touch dressing is carried out to obtain better uniformity in grit height in order to improve surface finish of the workpiece.

Truing

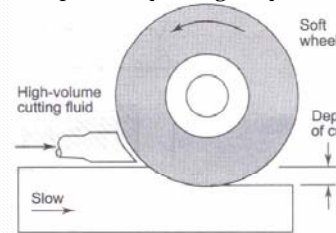
- Truing is the act of regenerating the required geometry on the grinding wheel.
- Truing is also required on a new conventional wheel to ensure concentricity with specific mounting system.
- Truing and dressing are commonly combined into one operation for conventional abrasive grinding wheels, but are usually two distinctly separate operation for super abrasive wheel.

Balancing Grinding Wheels

- Because of the high rotation speeds involved, grinding wheels must never be used unless they are in good balance.
- Grinding wheel must be balanced Statically and Dynamically.
- A slight imbalance will produce vibrations that will cause waviness in the work surface. It may cause a wheel to break, with the probability of serious damage and injury.

Creep feed grinding

- This machine enables single pass grinding of a surface with a larger down feed but slower table speed than that adopted for multi-pass conventional surface grinding.
- In creep-feed grinding, the entire depth of cut is completed in one pass only using very small in-feed rates.



State the basic advantage of a creep feed grinder over a conventional surface

- Productivity is enhanced and life of the grinding wheel is extended.

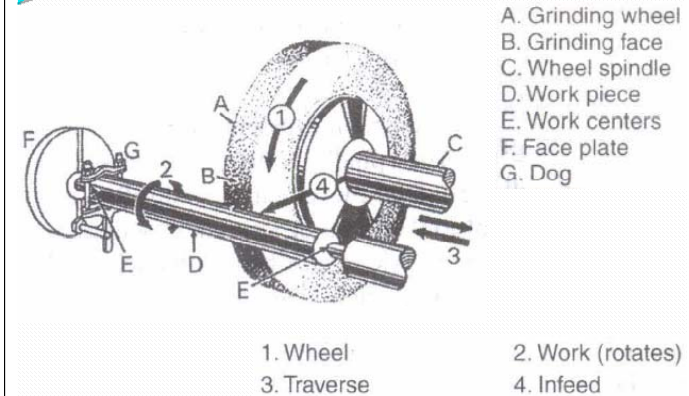
IES 2011 Conventional

What is creep feed grinding? Discuss its salient features, advantages, and application.

[10 marks]

Cylindrical Grinding

- Center-type cylindrical grinding is commonly used for producing external cylindrical surfaces.
- The grinding wheel revolves at an ordinary cutting speed, and the workpiece rotates on centers at a much slower speed.
- Grinding machines are available in which the workpiece is held in a chuck for grinding both external and internal cylindrical surfaces.



What are the characteristic features of a universal cylindrical grinder?

- Characteristic features of a universal cylindrical grinder not possessed by plain cylindrical grinder are:
 - Swivelling wheel head
 - Swivelling wheel head slide
 - Swivelling head stock

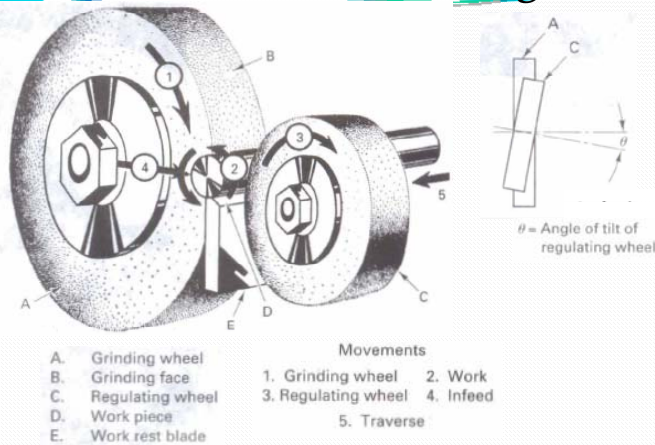
Centerless Grinding

- Centerless grinding makes it possible to grind both external and internal cylindrical surfaces without requiring the workpiece to be mounted between centers or in a chuck.
- This eliminates the requirement of center holes in some workpieces and the necessity for mounting the workpiece, thereby reducing the cycle time.
- Two wheels are used. The larger one operates at regular grinding speeds and does the actual grinding. The smaller wheel is the regulating wheel. It is mounted at an angle to the plane of the grinding wheel.

Centerless Grinding

- The regulating wheel controls the rotation and longitudinal motion of the workpiece and usually is a plastic- or rubber-bonded wheel with a fairly wide face.
- The workpiece is held against the work-rest blade by the cutting forces exerted by the grinding wheel and rotates at approximately the same surface speed as that of the regulating wheel.

Centerless Grinding



Centerless Grinding

The axial feed is calculated by the equation

$$F = \pi d N \sin \theta$$

where

F – feed (mm/min)

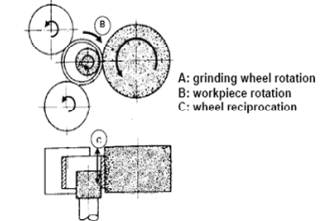
d = diameter of the regulating wheel (mm)

N = revolutions per minute of the regulating wheel

θ = angle of inclination of the regulating wheel

Centreless internal Grinding

- This machine is used for grinding cylindrical and tapered holes in cylindrical parts (e.g. cylindrical liners, various bushings etc).
- The workpiece is rotated between supporting roll, pressure roll and regulating wheel and is ground by the grinding wheel.



State the disadvantages of centreless cylindrical grinding machine?

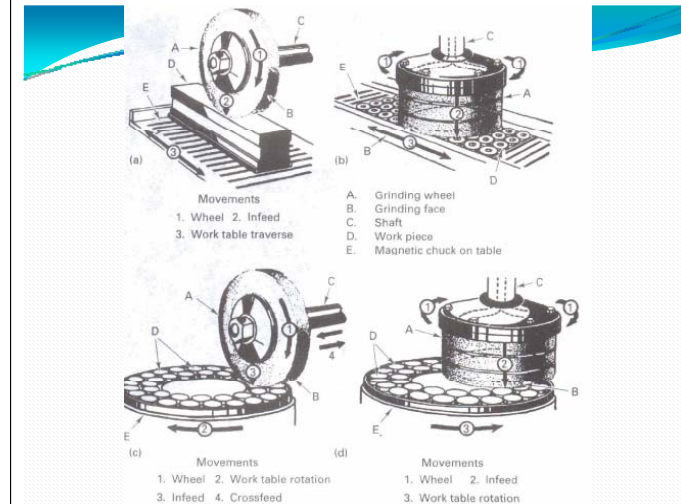
- It does not grind concentrically with centres.
- Large diameter short workpiece are difficult to control in the process
- It may not improve workpiece perpendicularity.

Surface Grinding Machines

- Surface grinding machines are used primarily to grind flat surfaces.
- However formed, irregular surfaces can be produced on some types of surface grinders by use of a formed wheel.

Four basic types of surface grinding machines are:

- Horizontal spindle and reciprocating table
- Vertical spindle and reciprocating table
- Horizontal spindle and rotary table
- Vertical spindle and rotary table

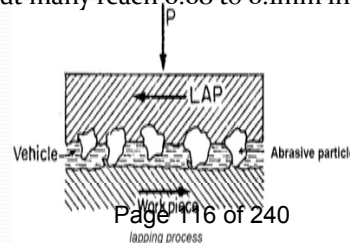


Is transverse feed provided in vertical spindle reciprocating table surface grinder?

- Usually no transverse feed is provided in such machine. The wheel diameter is kept larger than the width of the workpiece surface to be ground.

Lapping

- Lapping is basically an abrasive process in which loose abrasives function as cutting points finding momentary support from the laps.
- Material removal in lapping usually ranges from .003 to .03 mm but many reach 0.08 to 0.1mm in certain cases.



Characteristics of lapping process

- Use of loose abrasive between lap and the workpiece
- Usually lap and workpiece are not positively driven but are guided in contact with each other
- Relative motion between the lap and the work should change continuously so that path of the abrasive grains of the lap is not repeated on the workpiece.
- Cast iron is the mostly used lap material. However, soft steel, copper, brass, hardwood as well as hardened steel and glass are also used.

Abrasives of lapping

- Al_2O_3 and SiC , grain size 5 ~ 100 μm
- Cr_2O_3 , grain size 1 ~ 2 μm
- B_4C_3 , grain size 5 - 60 μm
- Diamond, grain size 0.5 ~ 5 μm

Vehicle materials for lapping

- Machine oil
- Rapeside oil
- grease

Technical parameters affecting lapping processes are

- unit pressure
- the grain size of abrasive
- concentration of abrasive in the vehicle
- lapping speed

Honing

- Honing is a finishing process, in which a tool called hone carries out a combined rotary and reciprocating motion while the workpiece does not perform any working motion.
- Most honing is done on internal cylindrical surface, such as automobile cylindrical walls. The honing stones are held against the workpiece with controlled light pressure. The honing head is not guided externally but, instead, floats in the hole, being guided by the work surface.

Honing

- It is desired that
 1. Honing stones should not leave the work surface
 2. Stroke length must cover the entire work length.
 3. In honing rotary and oscillatory motions are combined to produce a cross hatched lay pattern.
- The honing stones are given a complex motion so as to prevent every single grit from repeating its path over the work surface.

Honing

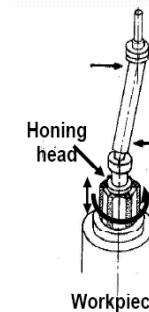


Fig. Honing tool

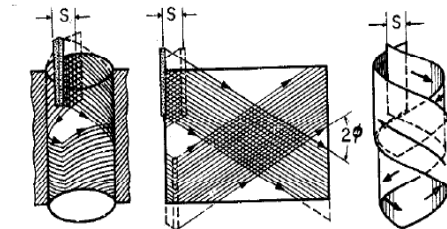
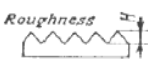
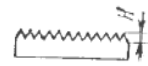
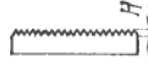




Fig. Lay pattern produced by combination of rotary and oscillatory motion

The critical process parameters are

- 1. rotation speed
- 2. oscillation speed
- 3. length and position of the stroke
- 4. honing stick pressure

Process	Diagram of resulting surface	Height of micro irregularity (μm)
Precision Turning		1.25-12.50
Grinding		0.90-5.00
Honing		0.13-1.25
Lapping		0.08-0.25
Super Finishing		0.01-0.25

Buffing

- Buffing is a polishing operation in which the workpiece is brought into contact with a revolving cloth wheel that has been charged with a fine abrasive, such as polishing rough.
- The wheels are made of disks of linen, cotton, broadcloth, or canvas, and achieve the desired degree of firmness through the amount of stitching used to fasten the layers of cloth together.
- Negligible amount of material is removed in buffing while a very high luster is generated on the buffed surface.
- The dimensional accuracy of the parts is not affected by the buffing operation.

Super Finishing

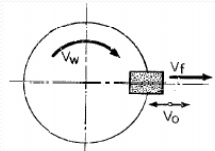


Fig. super finishing of end face of a cylindrical work piece in radial mode

In this both feeding and oscillation of the super finishing stone is given in the radial direction.

Super Finishing

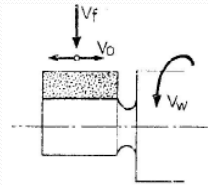


Fig. super finishing operation in plunge mode

In this case the abrasive stone covers the section of the workpiece requiring super finish. The abrasive stone is slowly fed in radial direction while its oscillation is imparted in the axial direction. It reduce surface roughness and increase bearing load capacity.

State the specific application of a planetary internal grinder.

- Planetary internal grinders find application for grinding holes in workpieces of irregular shape or large heavy workpieces.

GATE - 1995

Among the conventional machining processes, maximum specific energy is consumed in

- (a) Turning (b) Drilling
(c) Planning (d) Grinding

GATE - 1998

Ideal surface roughness, as measured by the maximum height of unevenness, is best achieved when, the material is removed by

- (a) An end mill
(b) A grinding wheel
(c) A tool with zero nose radius
(d) A ball mill.

GATE - 1998

In machining using abrasive material, increasing abrasive grain size

- (a) Increases the material removal rate
(b) Decreases the material removal rate
(c) First decreases and then increases the material removal rate
(d) First increases and then decreases the material removal rate

GATE - 2000

Abrasive material used in grinding wheel selected for grinding ferrous alloys is

- (a) Silicon carbide (b) Diamond
(c) Aluminium oxide (d) Boron carbide

GATE - 2002

The hardness of a grinding wheel is determined by the

- (a) Hardness of abrasive grains
(b) Ability of the bond to retain abrasives
(c) Hardness of the bond
(d) Ability of the grinding wheel to penetrate the work piece

GATE - 2006

If each abrasive grain is viewed as a cutting tool, then which of the following represents the cutting parameters in common grinding operations?

- (a) Large negative rake angle, low shear angle and high cutting speed
(b) Large positive rake angle, low shear angle and high cutting speed
(c) Large negative rake angle, high shear angle and low cutting speed
(d) Zero rake angle, high shear angle and high cutting speed

GATE - 1997

List I

- (A) Grinding
- (B) Honing

List II

- 1. Surface for oil retention
- 2. Surface for max. load capacity
- 3. Surface of limiting friction
- 4. Surface of matte finish
- 5. Surface for pressure sealing
- 6. Surface for interference fit.

- (C) Super-finishing
- (D) Burnishing

IES - 2005

Consider the following statements in respect of grinding?

- 1. The pitch of the grit cutting edges is larger than the pitch of the milling cutter.
- 2. The cutting angles of the grits have a random geometry.
- 3. The size of the chip cuts is very small for grinding.

Which of the statements given above are correct?

- (a) 1 and 2
- (b) 2 and 3
- (c) 1 and 3
- (d) 1, 2 and 3

IES - 2009

Which one of the following is **NOT** used as abrasive material in grinding wheels?

- (a) Aluminium oxide
- (b) Silicon carbide
- (c) Cubic boron nitride
- (d) Manganese oxide

IES - 1997

Which one of the following materials is used as the bonding material for grinding wheels?

- (a) Silicon carbide
- (b) Sodium silicate
- (c) Boron carbide
- (d) Aluminum oxide

IES - 1996

Grinding wheel is said to be loaded when the

- (a) Metal particles get embedded in the wheel surface blocking the interspaces between cutting grains.
- (b) Bonding material comes on the surface and the wheel becomes blunt.
- (c) Work piece being ground comes to a stop in cylindrical grinding.
- (d) Grinding wheel stops because of very large depth of cut

IES - 2001

Specific cutting energy is more in grinding process compared to turning because

- (a) Grinding (cutting) speed is higher
- (b) The wheel has multiple cutting edges (grains)
- (c) Plaguing force is significant due to small chip size
- (d) Grinding wheel undergoes continuous wear

IES - 1996

Specific energy requirements in a grinding process are more than those in turning for the same metal removal rate because of the

- (a) Specific pressures between wheel and work being high.
- (b) Size effect of the larger contact areas between wheel and work.
- (c) High cutting velocities
- (d) High heat produced during grinding.

IES - 1994

The ratio of thrust force to cutting force is nearly 2.5 in

- (a) Turning
- (b) Broaching
- (c) Grinding
- (d) Plain milling

IES - 1992

Assertion (A): Vitrified bond is preferred for thin grinding wheels.

Reason (R): Vitrified bond is hard brittle.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 2000

Assertion (A): The ratio of cutting force to thrust force is very high in grinding process as compared to other machining processes.

Reason (R): Random orientation and effective negative rake angles of abrasive grains increase the cutting force and adversely affect the cutting action and promote rubbing action.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1995

Soft materials cannot be economically grind due to

- (a) The high temperatures involved
- (b) Frequent wheel clogging
- (c) Rapid wheel wear
- (d) Low work piece stiffness

IES 2010

In relation to the peripheral or surface speeds of the grinding wheel and that of the workpiece in cylindrical grinding of alloy steel workpieces, the grinding wheel speed is

- (a) Less than the speed of the workpiece
- (b) Same as the speed of the workpiece
- (c) Double the speed of the workpiece
- (d) 65 to 75 times the speed of the workpiece.

IES - 2009

Given that the peripheral speed of the grinding wheel of 100 mm diameter for cylindrical grinding of a steel work piece is 30 m/s, what will be the estimated rotational speed of the grinding wheel in revolution per minute (r.p.m.)?

- (a) 11460 (b) 5730
- (c) 2865 (d) 95

IES - 2002

Which of the following materials are used in grinding wheel?

- 1. Aluminium oxide
- 2. Cubic boron nitride
- 3. Silicon carbide

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1 and 2
- (c) 2 and 3 (d) 1 and 3

IES – 2001, ISRO-2009

The marking on a grinding wheel is '51 A 36 L 5 V 93'. The code '36' represents the

- (a) Structure
- (b) Grade
- (c) Grain- size
- (d) Manufacturer's number

IES - 2000

The sequence of markings "S 14 K 14 S" on a grinding wheel represents respectively

- (a) Bond type, structure, grade, grain size and abrasive type
- (b) Abrasive type, grain size, grade, structure and bond type
- (c) Bond type, grade, structure, grain size and abrasive type
- (d) Abrasive type, structure, grade, grain size and bond type

IES - 1995

In the grinding wheel of A 60 G 7 B 23, B stands for

- (a) Resinoid bond (b) Rubber bond
- (c) Shellac bond (d) Silicate bond.

IES - 1993

Tool life in the case of a grinding wheel is the time

- (a) Between two successive regrinds of the wheel
- (b) Taken for the wheel to be balanced
- (c) Taken between two successive wheel dressings
- (d) Taken for a wear of 1mm on its diameter

IES - 2001

Assertion (A): Hard wheels are chosen for grinding hard metals.

Reason (R): In hard wheels only the abrasive grains are retained for long time.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1994

Consider the following statements regarding grinding of high carbon steel:

- 1. Grinding at high speed results in the reduction of chip thickness and cutting forces per grit.
 - 2. Aluminium oxide wheels are employed.
 - 3. The grinding wheel has to be of open structure.
- Of these statements
- (a) 1, 2 and 3 are correct
 - (b) 1 and 2 are correct
 - (c) 1 and 3 are correct
 - (d) 2 and 3 are correct

IES - 1999

Consider the following reasons:

- 1. Grinding wheel is soft
- 2. RPM of grinding wheel is too low
- 3. Cut is very fine
- 4. An improper cutting fluid is used

A grinding wheel may become loaded due to reasons stated at

- (a) 1 and 4
- (b) 1 and 3
- (c) 2 and 4
- (d) 2 and 3

IES - 2001

Dry and compressed air is used as cutting fluid for machining

- (a) Steel
- (b) Aluminium
- (c) Cast iron
- (d) Brass

IES - 1993

In centre less grinding, the work piece centre will be

- (a) Above the line joining the two wheel centres
- (b) Below the line joining the two wheel centres
- (c) On the line joining the two wheel centres
- (d) At the intersection of the line joining the wheel centres with the work plate plane.

IES - 2000

Consider the following advantages:

- 1. Rapid process
- 2. Work with keyways can be ground
- 3. No work holding device is required.

Which of these are the advantages of centre less grinding?

- (a) 1, 2 and 3
- (b) 1 and 2
- (c) 2 and 3
- (d) 1 and 3

IES - 1996

A grinding wheel of 150 mm diameter is rotating at 3000 rpm. The grinding speed is

- (a) 7.5π m/s
- (b) 15π m/s
- (c) 45π m/s
- (d) 450π m/s

IES - 1993

Consider the following parameters:

- 1. Grinding wheel diameter.
- 2. Regulating wheel diameter.
- 3. Speed of the grinding wheel.
- 4. Speed of the regulating wheel.
- 5. Angle between the axes of grinding and regulating wheels.

Among these parameters, those which influence the axial feed rate in centreless grinding would include

- (a) 2, 4 and 5
- (b) 1, 2 and 3
- (c) 1, 4 and 5
- (d) 3, 4 and 5

IES - 2007

Honing Process gives surface finish of what order?

- (a) $10 \mu\text{m}$ (CLA)
- (b) $1.0 \mu\text{m}$ (CLA)
- (c) $0.1 \mu\text{m}$ (CLA)
- (d) $0.01 \mu\text{m}$ (CLA)

IES - 1992

CLA value for Honing process is

- (a) 6 (b) 0.05 - 3.0
(c) 0.05 - 1.0 (d) 0.025 - 0.1

IES - 2012

Statement (I): Honing is an abrading process to remove stock from metallic surfaces.

Statement (II): Honing is commonly done on internal surfaces.

- (a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)
(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)
(c) Statement (I) is true but Statement (II) is false
(d) Statement (I) is false but Statement (II) is true

IES - 2001

Match List-I (Cutting Tools) with List-II (Applications) and select the correct answer using the codes given below the lists:

List I

- A. Trepanning tool
B. Side milling cutter
C. Hob cutter
D. Abrasive sticks

List II

1. For surface finishing by honing
2. For machining gears
3. For cutting keyways in shafts
4. For drilling large diameter holes

Codes:	A	B	C	D		A	B	C	D
(a)	1	3	2	4	(b)	4	3	2	1
(c)	1	2	3	4	(d)	4	2	3	1

IES - 1992

A surface finish of 0.025 - 0.1 micrometer CLA values is to be produced. Which machining process would you recommend?

- (a) Grinding (b) Rough turning
(c) Lapping (d) Honing

IES - 1992

Buffing wheels are made of

- (a) Softer metals (b) Cotton fabric
(c) Carbon (d) Graphite

IAS - 2004

The size effect refers to the increase in specific cutting energy at low values of undeformed chip thickness. It is due to which one of the following?

- (a) Existence of ploughing force
(b) Work hardening
(c) High strain rate
(d) Presence of high friction at chip-tool interface.

IAS - 2000

Consider the following statements in respect of a grinding wheel of specification, 51-A-36-L-7-R-23, using the standard alphanumeric codification:

1. Abrasive used in the wheel is aluminum oxide
2. The grain size of abrasive is medium
3. The wheel grade is medium hard
4. It has an open structure
5. It has resinoid as bonding agent

Which (If these statements are correct)?

- (a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2, 3 and 5 (d) 1, 4 and 5

IAS - 1999

Assertion (A): The grade of a grinding wheel is a measure of hardness of the abrasive used for the wheel.

Reason (R): Grading is necessary for making right selection of the wheel for a particular work.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS - 2001

Consider the following statements:

The set-up for internal centreless grinding consists of a regulating wheel, a pressure roll and a support roll, between which the tubular workpiece is supported with the grinding wheel within the tube, wherein

1. The grinding wheel, workpiece and regulating wheel centers must lie on one line
2. The directions of rotation of workpiece and grinding wheel are same
3. The directions of rotation of pressure roll, support roll and regulating wheel are same
4. The directions of rotation of grinding wheel and regulating wheel are same

Which of these statements are correct?

- (a) 1, 2 and 3 (b) 1, 3 and 4
(c) 2 and 3 (d) 3 and 4

Rev.0

IAS - 1997

Which of the following pairs are correctly matched?

1. Drill press : Trepanning
2. Centreless grinding: Through feeding
3. Capstan lathe: Ram type turret

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2 (b) 1, 2 and 3
(c) 1 and 3 (d) 2 and 3

IAS - 2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I

(Machine Tool/ Cutting Tool)

- A. Screw cutting lathe
- B. Drill
- C. End mill
- D. Grinding wheel

List II

(Part/ Characteristics)

1. Self locking taper
2. Chasing dial
3. Wiper insert
4. Self releasing taper
5. Balance weights

Code:A	B	C	D	A	B	C	D
(a) 4	5	3	1	(b) 2	1	4	5
(c) 4	1	3	5	(d) 2	5	4	1

IAS - 1999

Which one of the following processing sequences will give the best accuracy as well as surface finish?

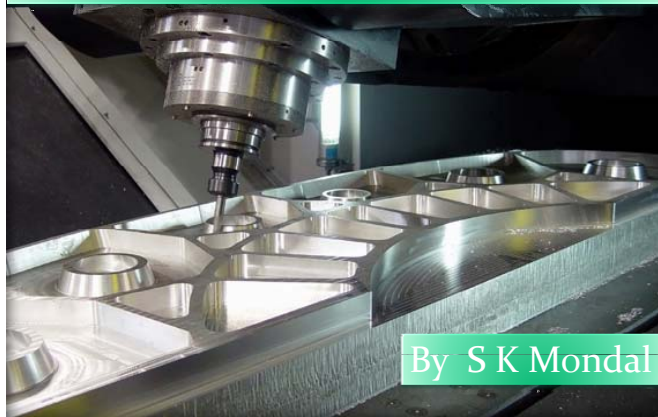
- (a) Drilling, reaming and grinding
- (b) Drilling, boring and grinding
- (c) Drilling, reaming and lapping
- (d) Drilling, reaming and electroplating

IAS - 2001

Which one of the following grinding wheels (with Grade, Grit and Bond) is suitable for cutter grinding?

- (a) K 60 vitrified
- (b) K 320 vitrified
- (c) T 60 resinoid
- (d) T 320 resinoid

NC, CNC & Robotics



By S K Mondal

What is NC/CNC?

- NC is an acronym for Numerical Control and CNC is an acronym for Computer Numerical Control.

What is the difference between NC and CNC ?

- The difference between NC and CNC is one of age and capability.
- The earliest NC machines performed limited functions and movements controlled by punched tape or punch cards.
- As the technology evolved, the machines were equipped with increasingly powerful microprocessors (computers) with the addition of these computers, NC machines become CNC machines.
- CNC machines have far more capability than their predecessor.

For-2015 (IES, GATE & PSUs)

contd.....

What is the difference between NC and CNC ?

- Some of the enhancements that came along with CNC include: Canned Cycles, Sub Programming, Cutter Compensation, Work coordinates, Coordinate system rotation, automatic corner rounding, chamfering, and B-spline interpolation.

Where did CNC get started?

- 1940 Jhon Parson developed first machine able to drill holes at specific coordinates programmed on punch cards.
- 1951 MIT developed servo-mechanism
- 1952 MIT developed first NC machines for milling.
- 1970 First CNC machines came into picture

Now-a-day's modified 1970's machines are used.

IAS - 1996

Assertion (A): The temperature control of an electric iron is an example of servomechanism.

Reason (R): It is an automatic control system.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Do all machines speak the same CNC language

- No, while there is fairly standard set of G and M codes, there is some variation in their application. For example a G0 or G00 command is universally regarded as the command for rapid travel. Some older machines do not have a G00 command. On these machines, rapid travel is commanded by using the F (feed) word address.

What is a "Conversational Control"

- CNC machine tool builders offer an option what is known as the conversational control. This control lets the operator/programmer use simple descriptive language to program the part. The control then displayed a graphical representation of the instructions so the operator/programmer can verify the tool path.

Are CNC machines faster than conventional machines?

- Yes, No, Sometimes. When it comes to making a single, simple part it is hard to beat a conventional mill or lathe. CNC machines move faster in rapid travel than conventional machines.

Are CNC machines more accurate than conventional machines?

- Yes, they can be. But like anything else it depends on who is running the machine, how well the machines has been maintained, quality of setup and so on.

GATE - 1994

CNC machines are more accurate than conventional machines because they have a high resolution encoder and digital read-outs for positioning.

True or false?

NC/CNC Machines-Advantages

- High Repeatability and Precision e.g. Aircraft parts
- Volume of production is very high
- Complex contours/surfaces need to be machined. E.g. Turbines
- Flexibility in job change, automatic tool settings, less scrap
- More safe, higher productivity, better quality
- Less paper work, faster prototype production, reduction in lead times

NC/CNC Machines-Disadvantages

- Costly setup, skilled operators
- Computers, programming knowledge required
- Maintenance is difficult

IES - 1999

Consider the following statements regarding numerically controlled machine tools:

1. They reduce non-productive time
 2. They reduce fixturing
 3. They reduce maintenance cost
- Which of these statements are correct?

- (a) 1, 2 and 3 (b) 1 and 2
(c) 2 and 3 (d) 1 and 3

IES - 1995

Consider the following characteristics of production jobs:

1. Processing of parts frequently in small lots
2. Need to accommodate design changes of products.
3. Low rate of metal removal
4. Need for holding close tolerances

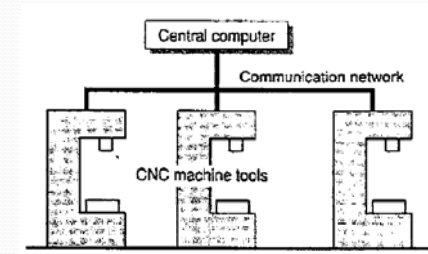
The characteristics which favour the choice of numerically controlled machines would include

- (a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

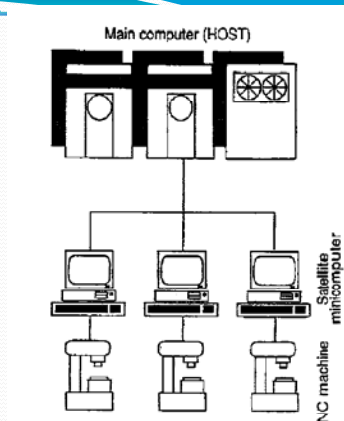
NC/CNC/DNC

- **Direct Numerical Control** is a system that uses a central computer to control several machines at the same time
- **Distributed Numerical Control (DNC)**: the central computer downloads complete programs to the CNC machines, which can be workstations or PCs, and can get the information for the machine operations.
- The speed of the system is increased, large files can be handled and the number of machine tools used is expanded.

Direct numerical control



DNC



IES - 2009

In which of the following machining manual part programming is done?

- (a) CNC machining (b) NC machining
(c) DNC machining (d) FMS machining

GATE - 1993

With reference to NC machine, which of the following statement is wrong?

- (a) Both closed-loop and open-loop control systems are used
(b) Paper tapes, floppy tapes and cassettes are used for data storage
(c) Digitizers may be used as interactive input devices
(d) Post processor is an item of hardware

IES - 2007

What are the main components of an NC machine?

1. Part program
2. Machine Control Unit
3. Servo motor

Select the correct answer using the code given below:

- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

JWM 2010

Consider the following components regarding numerical control system :

1. Programme of instructions
2. Machine control unit
3. Processing equipment

Which of these are correct ?

- (a) 1, 2 and 3 (b) 1 and 2 only
(c) 2 and 3 only (d) 1 and 3 only

IES - 2009

What is the purpose of satellite computers in Distributed Numerical Control machines?

- (a) To act as stand-by systems
(b) To share the processing of large-size NC programs
(c) To serve a group of NC machines
(d) To network with another DNC setup

IES - 1999

Consider the following components:

1. A dedicated computer
2. Bulk memory
3. Telecommunication lines

Which of these components are required for a DNC system?

- (a) 2 and 3 (b) 1 and 2
(c) 1, 2 and 3 (d) 1 and 3

JWM 2010

Consider the following advantages of DNC systems :

1. Time-sharing
2. Greater computational capability
3. Remote computer location

Which of the above is/are correct ?

- (a) 1 and 2 only (b) 2 and 3 only
(c) 2 only (d) 1, 2 and 3

IES – 2002

S-1

Match List I with List II and select the correct answer:

List I (NC machine tool systems)	List II (Features)
A. NC system	1. It has an integrated automatic tool changing unit and a component indexing device
B. CNC system	2. A number of machine tools are controlled by a computer. No tape reader, the part program is transmitted directly to the machine tool from the computer memory

IES – 2002 Contd..... From S-1

- C. DNC system 3. The controller consists of soft-wired computer and hard-wired logic Graphic display of tool path is also possible
- D. Machining centre 4. The instructions on tape is prepared in binary decimal form and operated by a series of coded instructions

Codes:	A	B	C	D		A	B	C	D
(a)	4	2	3	1	(b)	1	3	2	4
(c)	4	3	2	1	(d)	1	2	3	4

IAS-2011 main

Explain, at least two, characteristics each of NC, CNC and DNC.

[10-Marks]

Stepper Motor

- The stepper motor is special type of synchronous motor which is designed to rotate through a specific angle (Called step) for each electrical pulse received from the control unit.

IAS-2009 main

What is the function of stepper motor?

[2 – marks]

Basic CNC Principles

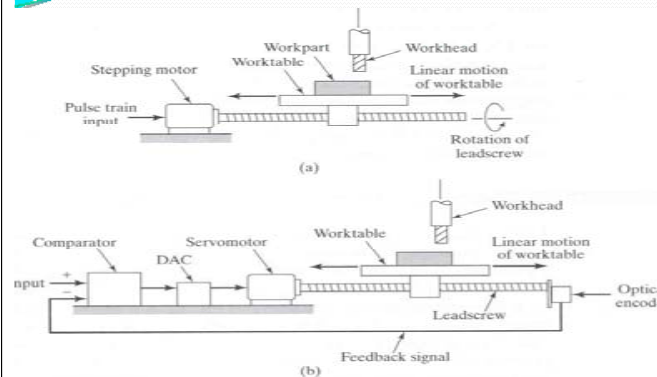


Figure 6.27 Two types of motion control in NC: (a) open loop and (b) closed loop.

IAS-2010 Main

Illustrate with the help of neat sketches the differences between open-loop and closed-loop control in NC system. Why is feedback not possible in open-loop control system ?

[22- Marks]

GATE - 2007

Which type of motor is NOT used in axis or spindle drives of CNC machine tools?

- (a) Induction motor
- (b) DC servo motor
- (c) Stepper motor
- (d) Linear servo motor

IES - 1994

Feed drives in CNC milling machines are provided by

- (a) Synchronous motors
- (b) Induction motors
- (c) Stepper motors
- (d) Servo-motors.

IES - 2002

In a CNC machine tool, encoder is used to sense and control

- (a) Table position
- (b) Table velocity
- (c) Spindle speed
- (d) Coolant flow

Basic Length Unit (BLU)

- In NC machine, the displacement length per one pulse output from machine is defined as a Basic Length Unit (BLU).
- In the CNC computer each bit (binary digit) represents 1 BLU.

Bit = BLU

- Example: If one pulse makes a servo motor rotate by one degree and the servo motor moves the table by 0.0001 mm, one BLU will be 0.0001 mm.
- The lead of a ball screw is related to the displacement unit of the machine tool table.



GATE - 1997

In a point to point control NC machine, the slides are positioned by an integrally mounted stepper motor drive. If the specification of the motor is $1^\circ/\text{pulse}$, and the pitch of the lead screw is 3.6 mm, what is the expected positioning accuracy?

- (a) $1\mu\text{m}$
- (b) $10\mu\text{m}$
- (c) $50\mu\text{m}$
- (d) $100\mu\text{m}$

GATE – 2007 (PI)

In a CNC machine feed drive, a stepper motor with step angle of 1.8° drives a lead screw with pitch of 2 mm. The Basic Length Unit (BLU) for this drive is

- (a) 10 microns
- (b) 20 microns
- (c) 40 microns
- (d) 100 microns

GATE – 2008 (PI)

A stepper motor has 150 steps. The output shaft of the motor is directly coupled to a lead screw of pitch 4 mm, which drives a table. If the frequency of pulse supply to the motor is 200 Hz, the speed of the table (in mm/min) is

- (a) 400
- (b) 320
- (c) 300
- (d) 280

Example

- A DC servomotor is coupled directly to a leadscrew which drives the table of an NC machine tool. A digital encoder, which emits 500 pulses per revolution, is mounted on the other end of the leadscrew. If the leadscrew pitch is 5 mm and the motor rotates at 600 rpm, calculate
 - (a) The linear velocity of the table
 - (b) The BLU of the NC system
 - (c) The frequency of pulses transmitted by the encoder.

IES 2011 Conventional

- The table of a CNC machine is driven by a Lead screw which is rotated by a DC servomotor. A digital encoder which emits 1000 pulses per second is mounted on the lead screw as a feedback device. If the lead screw pitch is 6 mm and motor rotates at 500 rpm, find

- Basic length Units of the system
- Linear velocity of the table.
- Frequency of pulses generated by the feedback device.

[5 Marks]

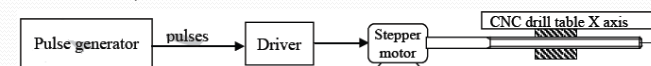
GATE – 2010 (PI)

For a 3 –axes CNC table, the slide along the vertical axis of the table is driven by a DC servo motor via a lead screw- nut mechanism. The lead screw has a pitch of 5 mm. This lead screw is fitted with a relative (incremental) circular encoder. The basic length unit (BLU) of the slide along the vertical axis of the table is 0.005 mm. When the table moves along the vertical axis by 9 mm, the corresponding number of pulses generated by the encoder is

- (a) 1400 (b) 1800 (c) 4200 (d) 9000

GATE – 2014(PI)

In an open loop, point-to-point controlled CNC drilling machine, a stepper motor, producing 200 angular steps per revolution, drives the table of a drilling machine by one angular step per each pulse generated by a pulse generator (shown in figure). Each angular step moves the table by one Basic Length Unit (BLU) along X axis with a lead screw having a pitch of 4 mm. If the frequency of pulse generator is doubled, the BLU will



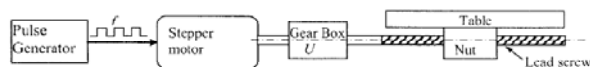
- (a) become double of previous value
 (b) become half of previous value
 (c) remain the same
 (d) become zero

Statement for Linked Answers questions: S-1

In the feed drive of a Point-to-Point open loop CNC drive, a stepper motor rotating at 200 steps/rev drives a table through a gear box and lead screw-nut mechanism (pitch = 4 mm, number of starts = 1).

The gear ratio = $\frac{\text{Output rotational speed}}{\text{Input rotational speed}}$ is given by $U = \frac{1}{4}$

The stepper motor (driven by voltage pulses from a pulse generator) executes 1 step/pulse of the pulse generator. The frequency of the pulse train from the pulse generator is $f = 10,000$ pulses per minute.



GATE – 2008 Q-1 (Statement in S-2)

The Basic Length Unit (BLU), i.e., the table movement corresponding to 1 pulse of the pulse generator, is

- (a) 0.5 microns (b) 5 microns
 (c) 50 microns (d) 500 microns

GATE – 2008 Q-2 (Statement in S-3)

A customer insists on a modification to change the BLU of the CNC drive to 10 microns without changing the table speed. The modification can be accomplished by

- (A) Changing U to $\frac{1}{2}$ and reducing f to $\frac{f}{2}$
 (B) Changing U to $\frac{1}{8}$ and increasing f to $2f$
 (C) Changing U to $\frac{1}{2}$ and keeping f unchanged
 (D) Keeping U unchanged and increasing f to $2f$

GATE – 2009 (PI)

The total angular movement (in degrees) of a lead-screw with a pitch of 5.0 mm to drive the work-table by a distance of 200 mm in a NC machine is

- (a) 14400 (b) 28800 (c) 57600 (d) 72000

GATE-2014 (PI)

Each axis of NC machine is driven by a stepper motor drive with a lead screw. The pitch of lead screw is p mm. The step angle of stepper motor per pulse input is α degrees/pulse. The ratio of gear drive in stepper motor drive is g (number of turns of the motor for each single turn of the lead screw). The number of pulses required to achieve a linear movement of x mm is

- (a) $\frac{\alpha g}{360 p} x$ (b) $\frac{360 g}{p} x$ (c) $\frac{g}{360 p} x$ (d) $\frac{360 g}{p \alpha} x$

IAS-2010 Main

In open-loop NC system the shaft of a stepping motor is connected directly to the lead screw x-axis of the machine table. The pitch of the lead screw is 3.0 mm. The number of step angles on the stepping motor is 200.

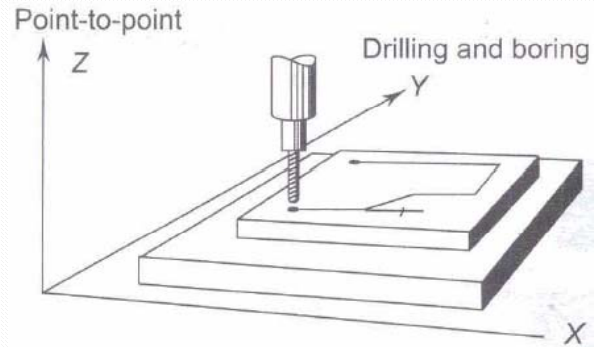
Determine how closely the position of the table can be controlled, assuming that there are no mechanical errors in the positioning system.

Also, what is the required frequency of the pulse train and the corresponding rotational speed of the stepping motor in order to drive the table at a travel rate of 100 mm/min?

[8- Marks]
 Rev.0

Control Systems possible in CNC Machine

- Point to point mode:



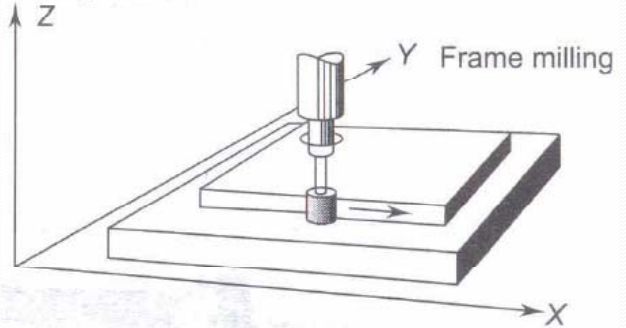
GATE - 1992

In a point-to-point type of NC system

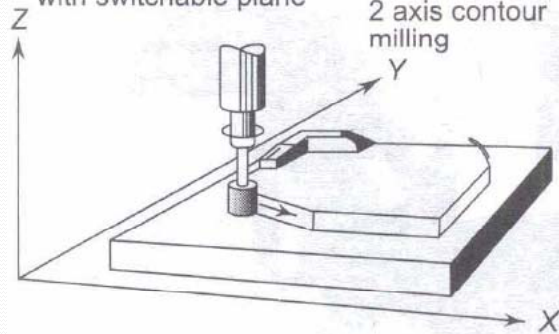
- Control of position and velocity of the tool is essential
- Control of only position of the tool is sufficient
- Control of only velocity of the tool is sufficient
- Neither position nor velocity need be controlled

Point-to-point straight line mode

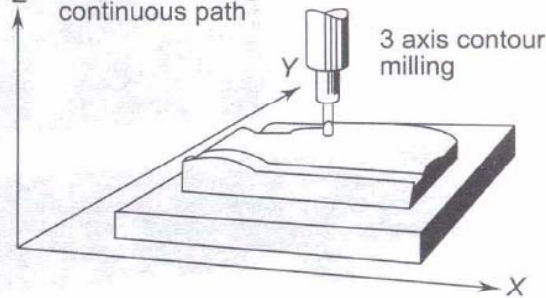
Point-to-point straight line



2 axis contouring with switchable plane



3 axis contouring continuous path



GATE - 2006

NC contouring is an example of

- Continuous path positioning
- Point-to-point positioning
- Absolute positioning
- Incremental positioning

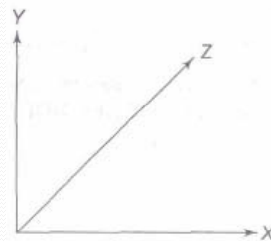
GATE-2005

Which among the NC operations given below are continuous path operations?

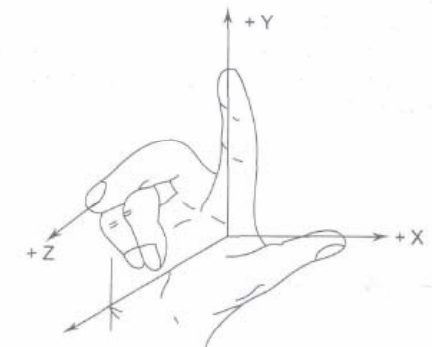
- | | |
|-----------------------------------|-----------------------------|
| Arc Welding (AW) | Milling (M) |
| Drilling (D) | Punching in Sheet Metal (P) |
| Laser Cutting of Sheet Metal (LC) | Spot Welding (SW) |
| (a) AW, LC and M | (b) AW, D, LC and M |
| (c) D, LC, P and SW | (d) D, LC, and SW |

Co-ordinate system

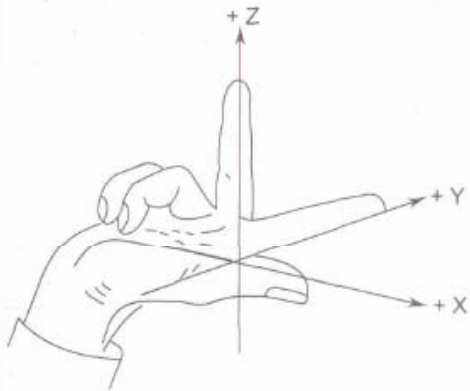
- All the machine tool use Cartesian Co-ordinate system.
- The first axis to be identified is the Z - axis, This is followed by X and Y axes respectively.



Right-hand Cartesian systems



(a) Axis designation for horizontal Z Rev.0



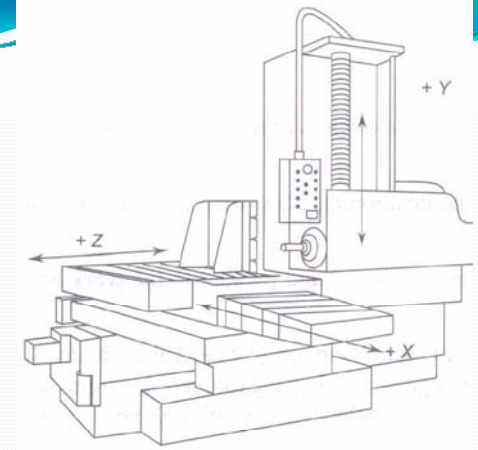
(b) Axis designation for vertical Z

IES - 2000

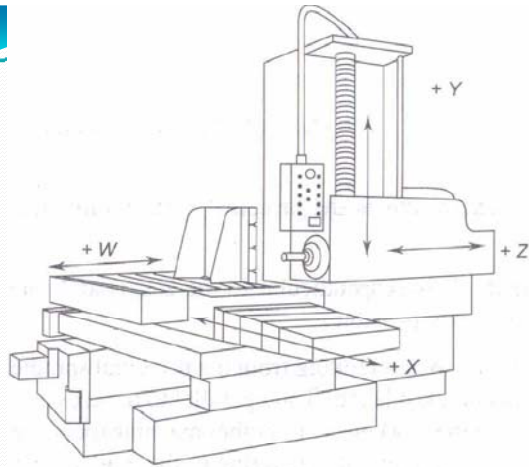
Assertion (A): The axis of an NC drilling machine spindle is denoted as z-axis.

Reason (R): In NC machine tool, the axis perpendicular to both x- and y-axis is designated as z-axis

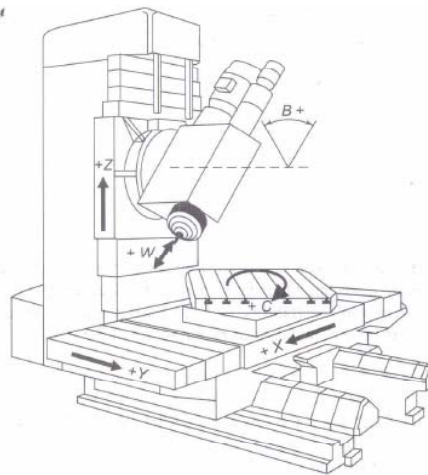
- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true



(a) Three-axis boring mill



(b) Four-axis boring mill



5 axes CNC vertical axis machining centre configuration

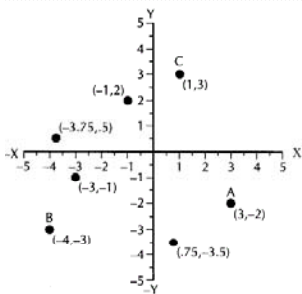
IES - 1996

Assertion (A): Numerically controlled machines having more than three axes do not exist.

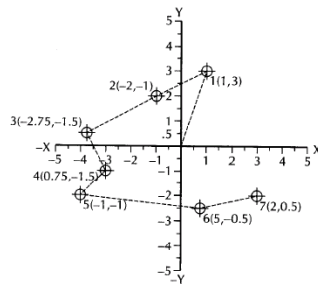
Reason (R): There are only three Cartesian coordinates namely x-y-z.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Absolute and Incremental Coordinate System

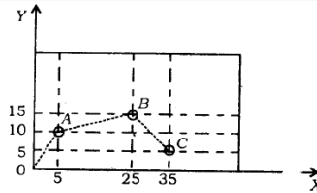


Absolute Coordinate System



Incremental Coordinate System

While part programming in CNC machines, the input of dimensional information for the tool path can be given in the absolute co-ordinate system or in incremental co-ordinate system. The above figure shows the route to be followed by the tool from O to C, i.e., O - A - B - C.



If incremental co-ordinates system is used, the co-ordinates of each point A, B and C are

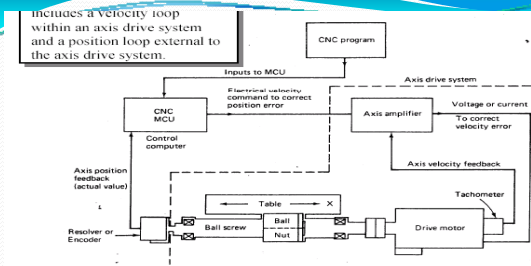
- (a) A: X 5.0, Y 10.0
B: X 20.0, Y 5.0
C: X 10.0, Y 10.0
- (b) A: X 5.0, Y 10.0
B: X 25, Y 15.0
C: X 35, Y 5.0
- (c) A: X 10.0, Y 5.0
B: X 15.0, Y 25.0
C: X 15.0, Y 35.0
- (d) A: X 10.0, Y 5.0
B: X 5.0, Y 20.0
C: X 10.0, Y 10.0

A CNC vertical milling machine has to cut a straight slot of 10 mm width and 2 mm depth by a cutter of 10 mm diameter between points (0, 0) and (100, 100) on the XY plane (dimensions in mm). The feed rate used for milling is 50 mm/min. Milling time for the slot (in seconds) is

- (a) 120 (b) 170 (c) 180 (d) 240

The following are the steps to be followed while developing the CNC part programs.

- Process planning
- Axes selection
- Tool selection
- Cutting process parameters planning
- Job and tool setup planning
- Machining path planning
- Part program writing
- Part program proving



- For a CNC machine control unit (MCU) decides cutting speed, feed, depth of cut, tool selection, coolant on off and tool paths. The MCU issues commands in form of numeric data to motors that position slides and tool accordingly.

Part Programming

- FANUC CONTROLL
- SIEMENS CONTROLL

CNC programming

Important things to know:

- Coordinate System
- Units, incremental or absolute positioning
- Coordinates: X,Y,Z, RX,RY,RZ
- Feed rate and spindle speed
- Coolant Control: On/Off, Flood, Mist
- Tool Control: Tool and tool parameters

For-2015 (IES, GATE & PSUs)

Programming Key Letters

- O - Program number (Used for program identification)
- N - Sequence number (Used for line identification)
- G - Preparatory function
- X - X axis designation
- Y - Y axis designation
- Z - Z axis designation
- R - Radius designation
- F - Feed rate designation
- S - Spindle speed designation
- H - Tool length offset designation
- D - Tool radius offset designation
- T - Tool Designation
- M - Miscellaneous function

Table of Important G codes

Code	Meaning	Format
G00	Rapid Transverse	N_G00 X__ Y__ Z__
G01	Linear Interpolation	N_G01 X__ Y__ Z__ F__
G02	Circular Interpolation, CW	N_G02 X__ Y__ Z__ R__ F__ N_G02 X__ Y__ Z__ I__ J__ K__ F__
G03	Circular Interpolation, CCW	N_G03 X__ Y__ Z__ R__ F__ N_G03 X__ Y__ Z__ I__ J__ K__ F__
G04	Dwell	N_G04P__
G17	XY Plane	
G18	XZ Plane	
G19	YZ Plane	

Table of Important G codes

Code	Meaning	Format
G20/G70	Inch Unit	
G21/G71	Metric Unit	
G28	Automatic Return to Reference Point	
G40	Cutter compensation cancel	
G41	Cutter compensation left	N__G41D__
G42	Cutter compensation right	N__G42D__
G43	Tool length compensation (plus)	N__G43H__

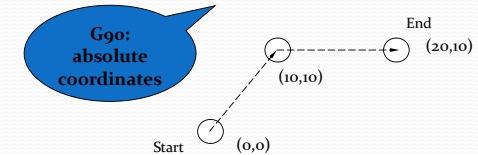
Table of Important G codes

Code	Meaning	Format
G44	Tool length compensation (minus)	N__G44H__
G49	Tool length compensation cancel	
G80	Cancel canned cycles	
G81	Drilling cycle	N__G81 Z__ R__ F__
G90	Absolute positioning	
G91	Incremental positioning	
G92	Absolute preset, change the datum position	N__G92X__Y__Z__

Rapid traverse: G00

- G00:
- to make the machine move at maximum speed.
- It is used for positioning motion.

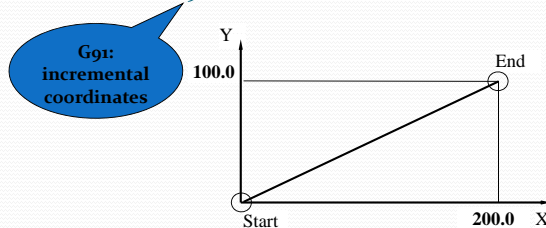
G90 G00 X20.0 Y10.0



Linear interpolation: G01

- G01:
- linear interpolation at feed speed.

G91 G01 X200.0 Y100.0 F200.0



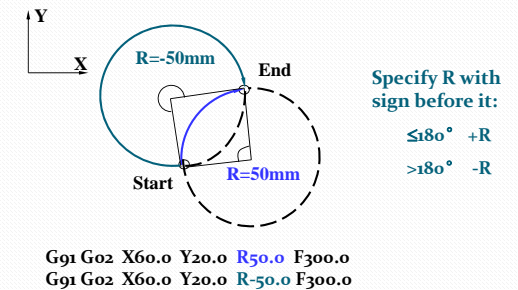
Circular interpolation: G02, G03

- G02, G03:
- For circular interpolation, the tool destination and the circle center are programmed in one block
- G02 is clockwise interpolation, G03 is counterclockwise interpolation

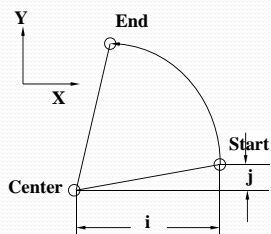
$$\begin{aligned}
 &G17 \begin{Bmatrix} G02 \\ G03 \end{Bmatrix} X _ Y _ \begin{Bmatrix} R \\ I _ J _ \end{Bmatrix} F _ ; \\
 &G18 \begin{Bmatrix} G02 \\ G03 \end{Bmatrix} X _ Z _ \begin{Bmatrix} R \\ I _ K _ \end{Bmatrix} F _ ; \\
 &G19 \begin{Bmatrix} G02 \\ G03 \end{Bmatrix} Y _ Z _ \begin{Bmatrix} R \\ J _ K _ \end{Bmatrix} F _ ;
 \end{aligned}$$

End point Circle center, radius

Circular interpolation: G02, G03



Circular interpolation: G02, G03



- Specify Center with I, J, K
- I, J, K are the incremental distance from the start of the arc;
- Viewing the start of arc as the origin, I, J, K have positive or negative signs.

Circular interpolation: G02, G03

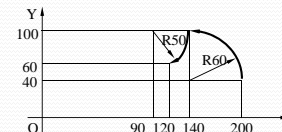
N0010 G92 X200.0 Y40.0 Z0 ;
N0020 G90 G03 X140.0 Y100.0 I-60.0 F300;
N0030 G02 X120.0 Y60.0 I-50.0 ;

Or

N0010 G92 X200.0 Y40.0 Z0 ;
N0020 G90 G03 X140.0 Y100.0 R60.0 F300;
N0030 G02 X120.0 Y60.0 R50.0 ;

G92:
To define working coordinate

G90:
absolute coordinates



Circular interpolation: G02, G03

Annotation for Circular Interpolation

- I0.0, J0.0, and K0.0 can be omitted.
- If X,Y,Z are all omitted in the program, that means start and end of arc are same points.
N0020 G02 I20.0 (a full circle)
- If I, J, K, and R all appears in circular interpolation instruction, R is valid and I, J, and K are invalid

GATE-2014

For the CNC part programming, match Group A with Group B:

Group A				Group B			
P: circular interpolation, counter clock wise				I: Go2			
Q: dwell				II: Go3			
R: circular interpolation, clock wise				III: Go4			
S: point to point counterling				IV: Goo			
P	Q	R	S	P	Q	R	S
(a) II	III	I	IV	(b) I	III	II	IV
(c) I	IV	II	III	(d) II	I	III	IV

GATE – 2007 (PI)

The interpolator in a CNC machine controls

- (a) Spindle Speed (b) Coolant flow
(c) Feed rate (d) Tool change

GATE - 2004

During the execution of a CNC part program block
N020 G02 X45.0 Y25.0 R5.0 the type of tool motion will be

- (a) Circular Interpolation – clockwise
(b) Circular Interpolation - counter clockwise
(c) Linear Interpolation
(d) Rapid feed

GATE - 2010

In a CNC program block, N002 G02 G91 X40 Z40..., G02 and G91 refer to

- (a) Circular interpolation in counterclockwise direction and incremental dimension
(b) Circular interpolation in counterclockwise direction and absolute dimension
(c) Circular interpolation in clockwise direction and incremental dimension
(d) Circular interpolation in clockwise direction and absolute dimension

IES - 2009

Interpolation in the controller refers to control of which one of the following in a CNC machine?

- (a) Loading/unloading of jobs on machine
(b) Loading/unloading of tools from the tool changer
(c) Axes of machine for contouring
(d) Coolant and miscellaneous functions on machine

GATE - 2001

In an NC machining operation, the tool has to be moved from point (5, 4) to point (7, 2) along a circular path with centre at (5, 2). Before starting the operation, the tool is at (5, 4). The correct G and M code for this motion is

- (a) N010 G03 X7.0 Y2.0 I5.0 J2.0
(b) N010 G02 X7.0 Y2.0 I5.0 J2.0
(c) N010 G01 X7.0 Y2.0 I5.0 J2.0
(d) N010 G00 X7.0 Y2.0 I5.0 J2.0

GATE - 2005

The tool of an NC machine has to move along a circular arc from (5, 5) to (10,10) while performing an operation. The centre of the arc is at (10, 5). Which one of the following NC tool path commands performs the above mentioned operation?

- (a) N010G02 X10 Y10 X5 Y5 R5
(b) N010G03 X10 Y10 X5 Y5 R5
(c) N010G01 X5 Y5 X10 Y10 R5
(d) N010G02 X5 Y5 X10 Y10 R5

GATE-2014 (PI)

A CNC instruction G91G01X30Y40F100 commands the movement of tool along the path at a feed rate of 100 mm/min (G91- incremental format and G01- linear interpolation). The feed rate of the tool (in mm/min) along the X axis will be _____

Tool Compensation

- Tool-Radius Compensation
 - Left hand G41
 - Right hand G42
 - Cancel tool-radius compensation G40
- Tool-Height Compensation
 - Positive G43
 - Negative G44
 - Cancel tool-height compensation G49

Tool-Radius Compensation

- Tool-radius compensations make it possible to program directly from the drawing, and thus eliminate the tool-offset calculation

G41 (G42) Dxx

- Dxx: the radius of tool to compensate is saved in a memory unit that is named Dxx
- G41/G42 is directly related with direction of tool movement and which side of part is cut.

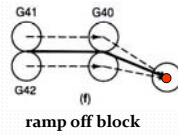


Cancel Tool Compensation: G40

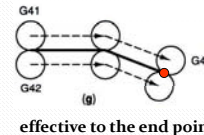
- Note the difference between two ways

N0060 G40 G01 X2.000 Y1.700 M02

N0060 G01 X2.000 Y1.700
N0070 G40 M02



ramp off block



effective to the end point

GATE - 2000

In finish machining of an island on a casting with CNC milling machine, an end mill with 10 mm diameter is employed. The corner points of the island are represented by (0, 0), (0, 30), (50, 30), and (50, 0). By applying cutter radius right compensation, the trajectory of the cutter will be

- (-5, 0), (-5, 35), (55, 35), (55, -5), (-5, -5)
- (0, -5), (55, -5), (55, 35), (-5, 35), (-5, -5)
- (5, 5), (5, 25), (45, 25), (45, 5), (5, 5)
- (5, 5), (45, 5), (45, 25), (5, 25), (5, 5)

GATE - 2014

For machining a rectangular island represented by coordinates P(0, 0), Q(100, 0), R(100, 50) and S(0, 50) on a casting using CNC milling machine, an end mill with a diameter of 16 mm is used. The trajectory of the cutter center to machine the island PQRS is

- (-8, -8), (108, -8), (108, 58), (-8, 58), (-8, -8)
- (8, 8), (94, 8), (94, 44), (8, 44), (8, 8)
- (-8, 8), (94, 0), (94, 44), (8, 44), (-8, 8)
- (0, 0), (100, 0), (100, 50), (50, 0), (0, 0)

Tool-Height Compensation

G43 (G44) Hxx

- Hxx: specified memory unit used to save height compensation of tool.
- Positive compensation (G43):
real position = specified position + value saved in Hxx
- Negative compensation (G44):
real position = specified position - value saved in Hxx

Tool-Height Compensation

- Example:

- N0010 G91 G00 X12.0 Y80.0
- N0020 G44 Z-32.0 H02;

G91:
incremental
coordinates

- If we put 0.5mm into H02,
- real position = -32.0 - 0.5 = -32.5

- Cancel tool-height compensation: G49

Table of Important M codes

- M00 Program stop
- M01 Optional program stop
- M03 Spindle on clockwise
- M04 Spindle on counterclockwise
- M05 Spindle stop
- M06 Tool change
- M08 Coolant on
- M09 Coolant off
- M10 Clamps on
- M11 Clamps off
- M02 or M30 Program stop, reset to start

For-2015 (IES, GATE & PSUs)

GATE - 2009

Match the following:

NC Code

P. M05

Q. G01

R. G04

S. G90

(a) P-2, Q-3, R-4, S-1

(c) P-3, Q-4, R-2, S-1

Definition

1. Absolute coordinate system

2. Dwell

3. Spindle stop

4. Linear interpolation

(b) P-3, Q-4, R-1, S-2

(d) P-4, Q-3, R-2, S-1

Rules for programming

Block Format

N135 G01 X1.0 Y1.0 Z0.125 F5

Sample Block

- Restrictions on CNC blocks
- Each may contain only one tool move
- Each may contain any number of non-tool move G-codes
- Each may contain only one feed rate
- Each may contain only one specified tool or spindle speed
- The block numbers should be sequential
- Both the program start flag and the program number must be independent of all other commands (on separate lines)
- The data within a block should follow the sequence shown in the above sample block

IES - 1993

A 'block' of information in N.C. machine program means

- (a) One row on tape
- (b) A word comprising several rows on tape
- (c) One complete instruction
- (d) One complete program for a job

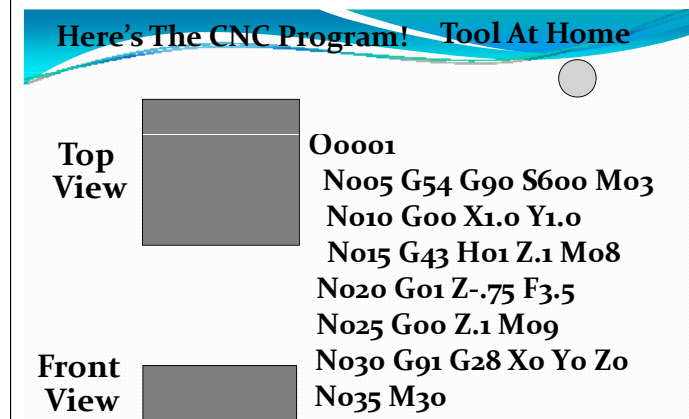
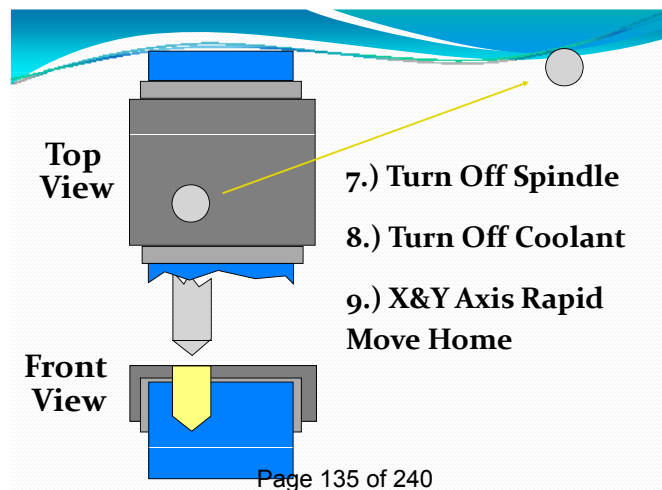
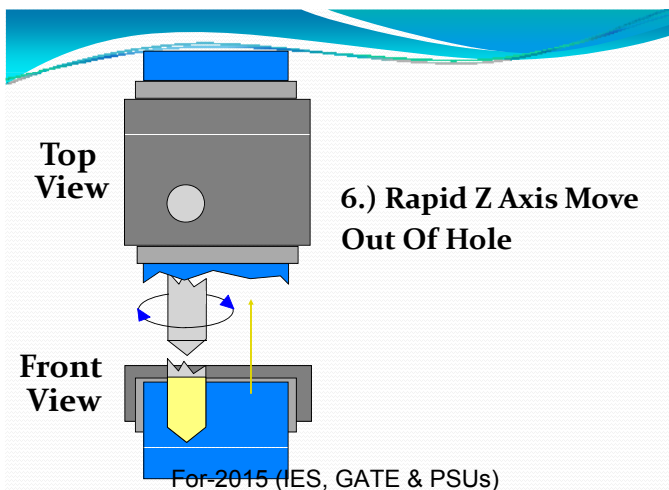
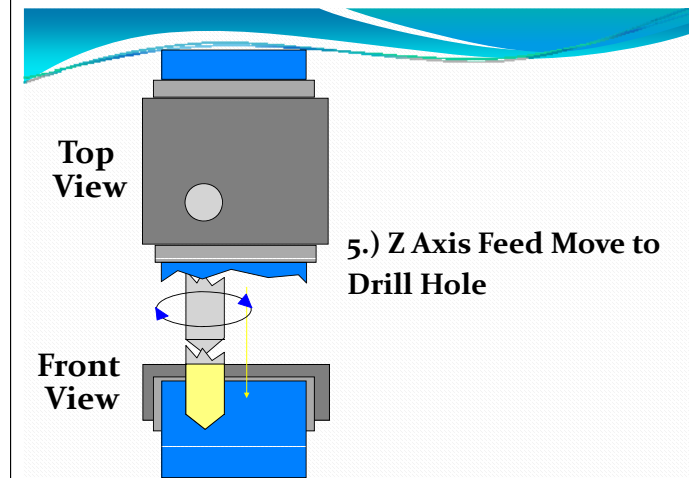
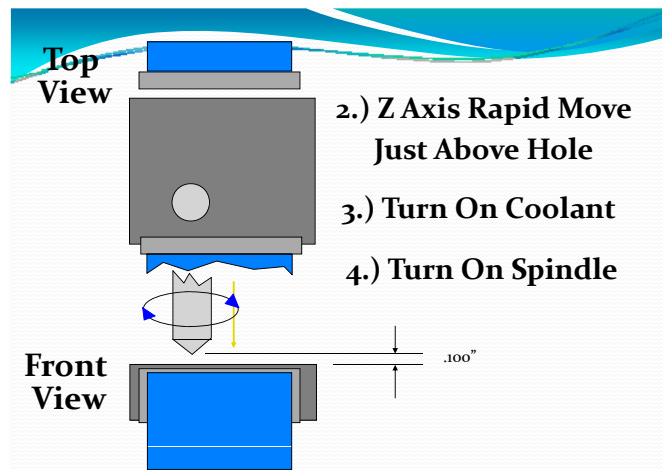
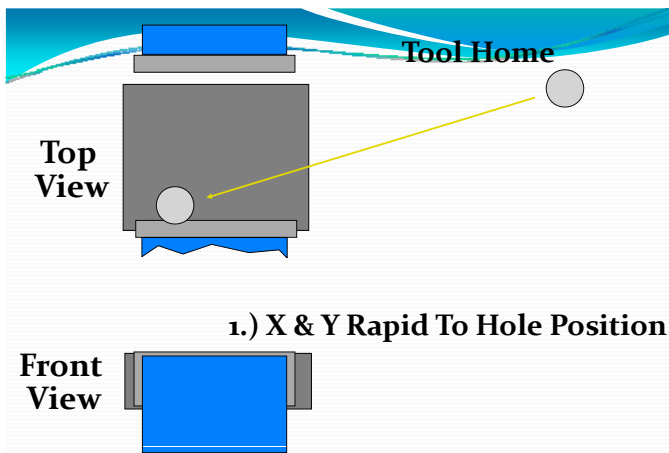
IES - 1996

In manual programming and tape preparation for a NC drilling machine, the spindle speed was coded as S 684 (using the magic-three code). The spindle speed in rpm will be

- (a) 684
- (b) 68.4
- (c) 840
- (d) 6840

Example of CNC Programming

- What Must Be Done To Drill A Hole On A CNC Vertical Milling Machine



Tool At Home

Top View



O0001

O0001

Number Assigned to this program

Front View



Tool At Home

Top View



O0001

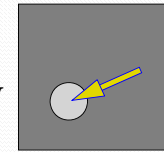
N005 G54 G90 S600 M03

N005 Sequence Number
G54 Fixture Offset
G90 Absolute Programming Mode
S600 Spindle Speed set to 600 RPM
M03 Spindle on in a Clockwise Direction

Front View



Top View



O0001

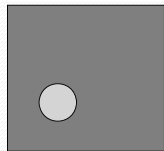
N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0

G00 Rapid Motion
X1.0 X Coordinate 1.0 in. from Zero
Y1.0 Y Coordinate 1.0 in. from Zero

Front View



Top View



O0001

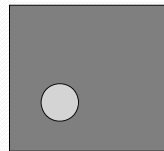
N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0
N015 G43 H01 Z.1 M08

G43 Tool Length Compensation
H01 Specifies Tool length compensation
Z.1 Z Coordinate .1 in. from Zero
M08 Flood Coolant On

Front View



Top View

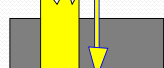


O0001

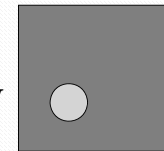
N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0
N015 G43 H01 Z.1 M08
N020 G01 Z-.75 F3.5

G01 Straight Line Cutting Motion
Z-.75 Z Coordinate -.75 in. from Zero
F3.5 Feed Rate set to 3.5 in/min.

Front View



Top View



O0001

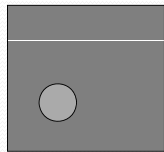
N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0
N015 G43 H01 Z.1 M08
N020 G01 Z-.75 F3.5
N025 G00 Z.1 M09

G00 Rapid Motion
Z.1 Z Coordinate .1 in. from Zero
M09 Coolant Off

Front View



Top View



O0001

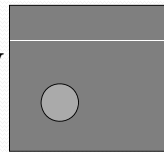
N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0
N015 G43 H01 Z.1 M08
N020 G01 Z-.75 F3.5
N025 G00 Z.1 M09
N030 G91 G28 X0 Y0 Z0

G91 Incremental Programming Mode
G28 Zero Return Command
X0, Y0, Z0 X, Y, & Z Coordinates at Zero

Front View



Top View



O0001

N005 G54 G90 S600 M03
N010 G00 X1.0 Y1.0
N015 G43 H01 Z.1 M08
N020 G01 Z-.75 F3.5
N025 G00 Z.1 M09
N030 G91 G28 X0 Y0 Z0
N035 M30

M30 End of Program

Front View



IES - 1995

Match List I with List II and select the correct answer using the codes given below the lists:

List I

(A function connected with NC m/c tool)

- A. Interpolation
- B. Parity check
- C. Preparatory function
- D. Point to point control

List II

(Associated parameter)

- 1. Tape preparation
- 2. Canned cycle
- 3. Drilling
- 4. Contouring
- 5. Turning

Code: A B C D

- (a) 4 1 2 3
- (c) 5 1 3 2

A B C D

- (b) 4 1 2 5
- (d) 1 4 3 2

Rev.0

IAS-2011 Main

In an NC drilling operation, the tool tip is at location (-100, 0, 100). The datum (0, 0, 0) is left hand lower corner on top surface of the workpiece, which is rectangular (300 mm x 300 mm x 1.5 mm thick). A thru' hole of 10 mm diameter is to be drilled in the centre of the workpiece. Using only rapid positioning and linear interpolation functions, write the program blocks, in absolute mode.

Assume permitted cutting speed = 32 m/min and feed rate = 150 mm/min. [10-Marks]

IFS 2011

In NC machine, what is the purpose of the parity check ? What is the function of Data Processing Unit (DPU) and Control Loop Unit (CLU) of MCU. How is Feed Rate Number (FRN) expressed ? What is indirect feedback ?

[10-marks]

APT Language

- APT (Automatically Programmed Tools)
- The APT language consists of many different types of statements made up of the following valid letters, numerals and punctuation marks.
- Letters: **ABCDEFGHIJKLMNOPQRSTUVWXYZ**
- Numerals: **0 1 2 3 4 5 6 7 8 9**
- / A slash divides a statement into two sections. eg., GO/PAST,
- , A comma is used as a separator between the elements in a statement generally to the right of the slash.
- = An equals is used for assigning an entity to a symbolic name, e.g., P1 = POINT/25,50,30.

Words

- The words to be used in the statements are built up from one to six letters or numerals with the first one being a letter. No special character is allowed in the words.

IES - 1998

Which of the following are the rules of programming NC machine tools in APT language?

1. Only capital letters are used
 2. A period is placed at the end of each statement
 3. Insertion of space does not affect the APT word
- Select the correct answer using the codes given below:
- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1 alone

The complete APT part program consists of the following four types of statements

- Geometry
- Motion
- Post processor
- Compilation control

Other Part Programming Languages

- **ADAPT** (ADaptation APT) was the first attempt to adapt APT programming system for smaller computers
- **AUTOSPOT** (AUTOMATIC Sytem for POSitioning Tools) was developed by IBM and first introduced in 1962
- **EXAPT** (EXtended subset of APT) was developed jointly in German in about 1964 by several universities to adapt APT for European use. It is compatible with APT and thus can use the same processor as APT
- **COMPACT** was developed by Manufacturing Data Systems, Inc. (MDSI)
- **SPLIT** (Sundstrand Processing Language Internally Translated) was developed by Sundstrand Corporation, intended for its own machine tools
- **MAPT** (Micro-APT) is a subset of APT, to be run on the microcomputers For-2015 (IES, GATE & PSUs)

APT Language

Additional statements:

- > MACHIN/DRILL, 2
- > COOLNT/
- For example: COOLNT/MIST COOLNT/FLOOD COOLNT/OFF
- > FEDRAT/
- > SPINDL/
- For example: SPINDL/ON SPINDL/1250, CCLW
- > TOOLNO/
- > TURRET/
- > END

APT Language

Other capabilities of APT, the macro facility, with use variable argument as in a FORTRAN subroutine, for example:

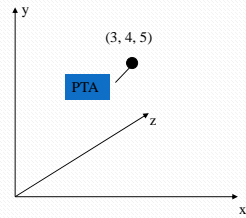
```
P0 = POINT/0.0, 0.3, 0.1
FROM/P0
CALL/DRILL, X=1.0, Y=1.0, Z=0.1, DEPTH=0.7
CALL/DRILL, X=2.0, Y=1.0, Z=0.1, DEPTH=0.7
GOTO/P0
```

when the definition of the macro DRILL is:

```
DRILL = MACRO/X, Y, Z, DEPTH
GOTO/X,Y,Z
GODLTA/0,0, -DEPTH
GODLTA/0,0, DEPTH
TARMAC
```

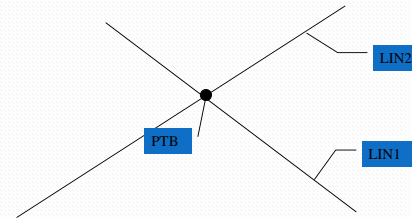

Point (POINT)

$$PTA = \text{POINT} / 3, 4, 5$$



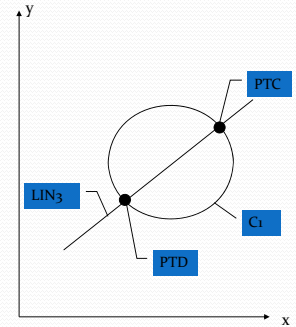
Point (POINT)

$$PTB = \text{POINT} / \text{INTOF}, \text{LIN1}, \text{LIN2}$$



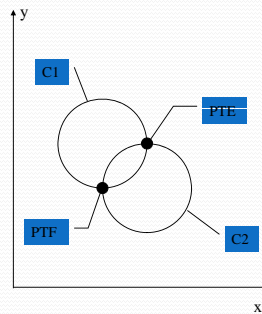
Point (POINT)

$$\begin{aligned} PTD &= \text{POINT} / \text{YSMALL}, \text{INTOF}, \text{LIN3}, \text{C1} \\ PTD &= \text{POINT} / \text{XSMALL}, \text{INTOF}, \text{LIN3}, \text{C1} \\ PTC &= \text{POINT} / \text{YLARGE}, \text{INTOF}, \text{LIN3}, \text{C1} \\ PTC &= \text{POINT} / \text{XLARGE}, \text{INTOF}, \text{LIN3}, \text{C1} \end{aligned}$$



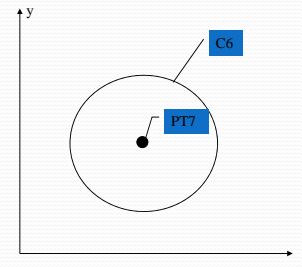
Point (POINT)

$$\begin{aligned} PTE &= \text{POINT} / \text{YLARGE}, \text{INTOF}, \text{C1}, \text{C2} \\ PTE &= \text{POINT} / \text{XLARGE}, \text{INTOF}, \text{C1}, \text{C2} \\ PTF &= \text{POINT} / \text{YSMALL}, \text{INTOF}, \text{C1}, \text{C2} \\ PTF &= \text{POINT} / \text{XSMALL}, \text{INTOF}, \text{C1}, \text{C2} \end{aligned}$$



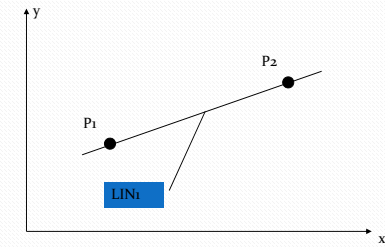
Point (POINT)

$$PT7 = \text{POINT} / \text{CENTER}, \text{C6}$$



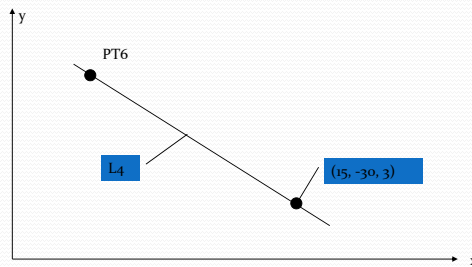
Line (LINE)

$$\text{LIN1} = \text{LINE} / P1, P2$$



Line (LINE)

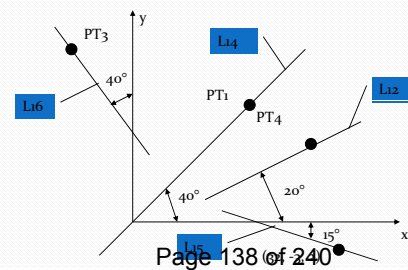
$$\text{LIN4} = \text{LINE} / \text{PT6}, 15, -30, 3$$



For-2015 (IES, GATE & PSUs)

Line (LINE)

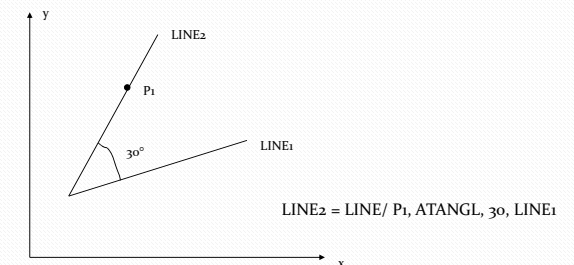
$$\begin{aligned} L12 &= \text{LINE} / \text{PT4}, \text{ATANGL}, 20, \text{XAXIS} \\ L14 &= \text{LINE} / \text{PT1}, \text{ATANGL}, 40 \\ L15 &= \text{LINE} / 32, -3, 2, \text{ATANGL}, -15, \text{XAXIS} \\ L16 &= \text{LINE} / \text{PT3}, \text{ATANGL}, 40, \text{YAXIS} \end{aligned}$$



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Line (LINE)

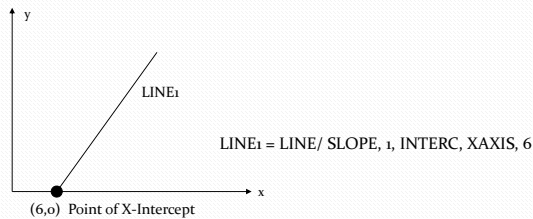
$$\text{LIN} = \text{LINE} / \text{POINT}, \text{ATANGL}, \text{ANGLE (in degrees)}, \text{LINE}$$



Rev.0

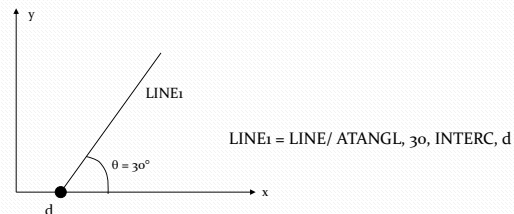
Line (LINE)

LIN = LINE/ SLOPE, SLOPE VALUE, INTERC, MODIFIER, d
where the slope value is y/x. The modifier options are [XAXIS, YAXIS], and d is the corresponding intercept value on the selected axis (i.e., modifier).



Line (LINE)

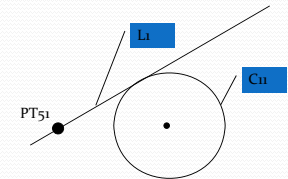
LIN = LINE/ ATANGL, DEGREES, INTERC, MODIFIER, d
The modifier options are [XAXIS, YAXIS], and d is the corresponding intercept value on the selected axis (i.e., modifier).



Line (LINE)

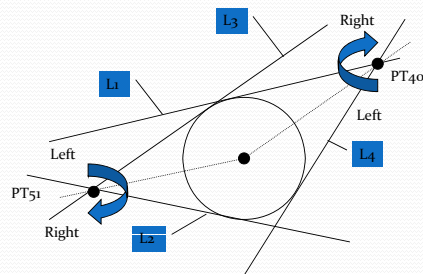
The **LEFT & RIGHT** modifier indicates whether the line is at the left or right tangent point, depending on how one looks at the circle from the point.

L1 = LINE/ PT51, LEFT, TANTO, C11



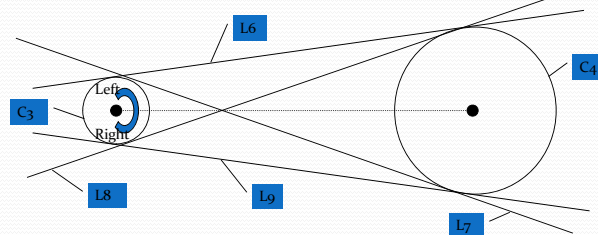
Line (LINE)

L2 = LINE/ PT51, RIGHT, TANTO, C11
L3 = LINE/ PT40, RIGHT, TANTO, C11
L4 = LINE/ PT40, LEFT, TANTO, C11



Line (LINE)

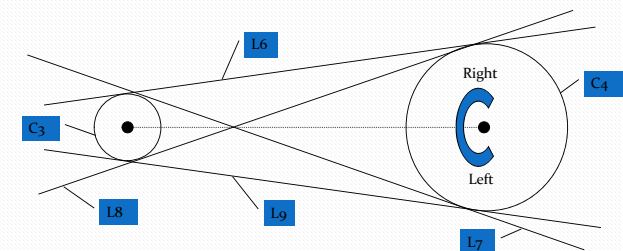
L6 = LINE/ LEFT, TANTO, C3, LEFT, TANTO, C4



The descriptive words **LEFT** and **RIGHT** are used by looking from the first circle written towards the second circle.

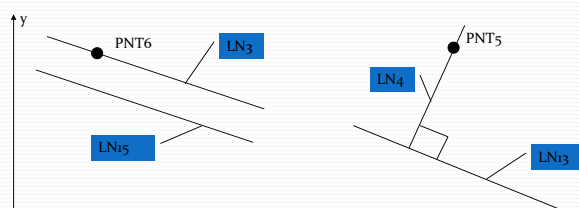
Line (LINE)

L6 = LINE/ RIGHT, TANTO, C4, RIGHT, TANTO, C3



Line (LINE)

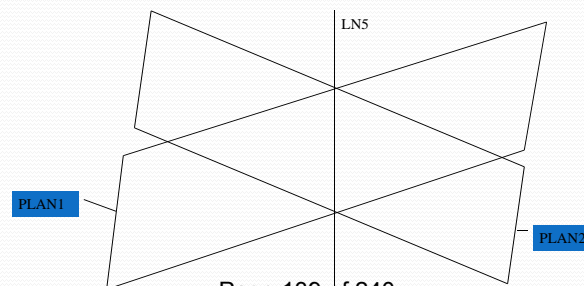
LN3 = LINE/ PNT6, PARLEL, LN15
LN4 = LINE/ PNT5, PERPTO, LN13



For-2015 (IES, GATE & PSUs)

Line

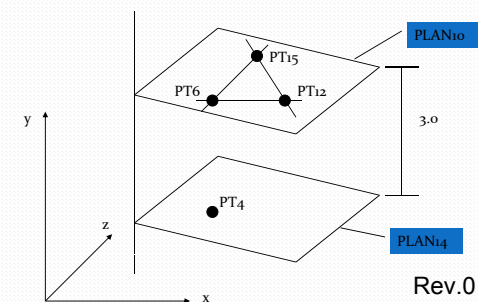
LN5 = LINE/ INTOF, PLAN1, PLAN2



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Plane (PLANE)

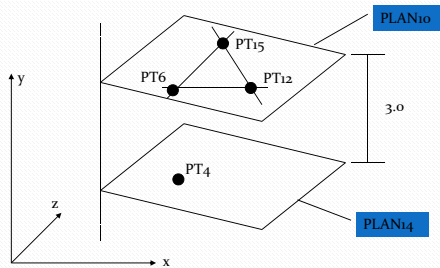
PLAN10 = PLANE/ PT6, PT12, PT15



Rev.0

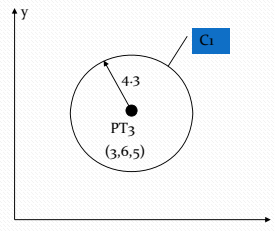
Plane (PLANE)

PLAN14 = PLANE/ PT4, PARLEL, PLAN10
 PLAN14 = PLANE/ PARLEL, PLAN10, YSMALL, 3.0



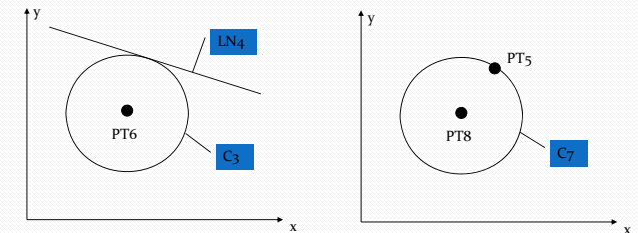
Circle (CIRCLE)

C1 = CIRCLE/ 3, 6, 5, 4.3
 C1 = CIRCLE/ CENTER, PT3, RADIUS, 4.3



Circle (CIRCLE)

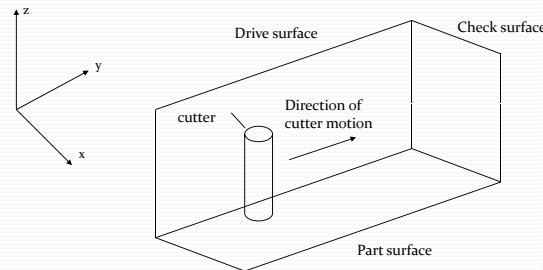
C3 = CIRCLE/ CENTER, PT6, TANTO, LN4
 C7 = CIRCLE/ CENTER, PT8, PT5



The Machining Plan

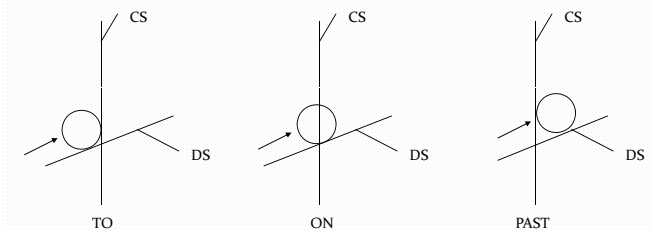
Contouring:

- **Part surface:** the surface on which the end of the tool is riding.
- **Drive surface:** the surface against which the edge of the tool rides.
- **Check surface:** a surface at which the current tool motion is to stop.



The Machining Plan

The Machining Plan

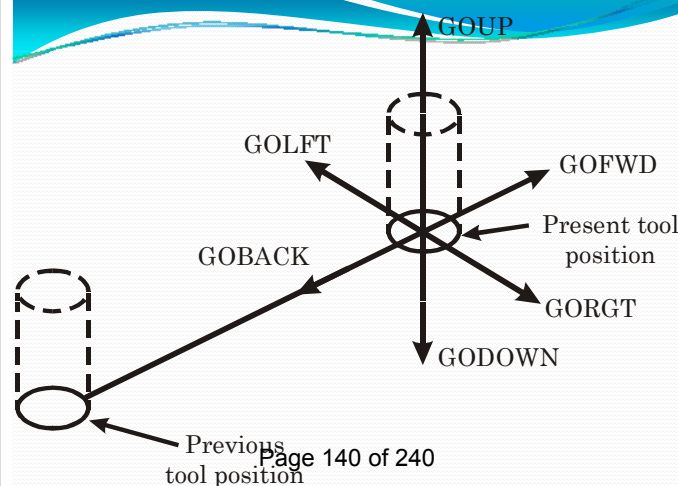


The Machining Plan

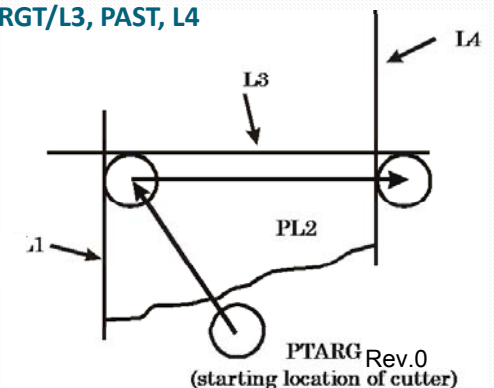
Motion commands:

- GOLFT/ : Move left along the drive surface
 GORGT/ : Move right along the drive surface
 GOUP/ : Move up along the drive surface
 GODOWN/ : Move down along the drive surface
 GOFWD/ : Move forward from a tangent position
 GOBACK/ : Move backward from a tangent position

For-2015 (IES, GATE & PSUs)



FROM/PTARG
 GO/TO, L1, TO, PL2, TO L3
 GORGT/L3, PAST, L4



Machining Specifications

Postprocessor commands for a particular machine tool are:

MACHIN/ : used to specify the machine tool and call the postprocessor for that tool:

MACHIN/ DRILL, 3

COOLNT/ : allows the coolant fluid to be turned on or off:

COOLNT/ MIST

COOLNT/ FLOOD

COOLNT/ OFF

COOLNT/ OFF

Machining Specifications

FEDRAT/ : specifies the feed rate for moving the tool along the part surface in inches per minute:

FEDRAT/ 4.5

SPINDL/ : gives the spindle rotation speed in revolutions per minute:

SPINDL/ 850

TURRET/ : can be used to call a specific tool from an automatic tool changer:

TURRET/ 11

TURRET/ 11

Machining Specifications

TOLERANCE SETTING: Nonlinear motion is accomplished in straight-line segments, and INTOL/ and OUTTOL/ statements dictate the number of straight-line segments to be generated.

INTOL/ 0.0015

OUTTOL/ 0.001

OUTTOL/ 0.001

Machining Specifications

PARTNO: identifies the part program and is inserted at the start of the program.

CLPRNT: indicates that a cutter location printout is desired.

CUTTER: specifies a cutter diameter for offset (rough versus finish cutting). If a milling cutter is 0.5 in. in diameter and we have

$$\text{CUTTER} / 0.6$$

then the tool will be offset from the finish cut by 0.05 in.

Machining Specifications

FINI: specifies the end of the program.

6

IES-2008

Name the four types of statements in a complete APT part program. Prepare part program for geometry description of the contour shown in the figure below:

[15-Marks]

For 2015 (IES, GATE & BSUs)

Answer:

PARTNO CONTOUR
MACHIN/MILL, 1
CLPRNT
UNITS/MM
P0 = POINT/0.0, 0.0, 0.0
P1 = POINT/110.0, 20.0, 0.0
P2 = POINT/20.0, 20.0, 0.0
P3 = POINT/90.0, 110.0, 0.0
P4 = POINT/20.0, 100.0, 0.0
P5 = POINT/50.0, 130.0, 0.0
L1 = LINE/P2, ATANGL, 90, XAXIS
L2 = LINE/P4, ANTNGL, 45, XAXIS
L3 = LINE/P5, ATANGL, 135, L2
L4 = LINE/P1, PERPTO, L3
L5 = LINE/P1, PERPTO, L4
C1=CIRCLE/CENTER, P3, RADIUS, 20.0
C2=CIRCLE/CENTER, P1, RADIUS, 20.0
PL1=PLANE/P1, P2, P3

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Contd....

CUTTER/25.0
TOLER/0.1
INTOL/0.05
OUTTOL/0.05
FEDRAT/200
SPINDL/500, CLW
COOLNT/ON
FROM/P0
GO/TO, L1, TO, PL1, TO, L5
GOLFT/L1, PAST, L2
GORGTL2, PAST, L3
GORGTL3, TANTO, C1
GOFWD/C1, PAST, L4
GOFWD/L4, PAST, C2
GORGTC2, PAST, L5
GORGTL5, PAST, L1

Rev.0

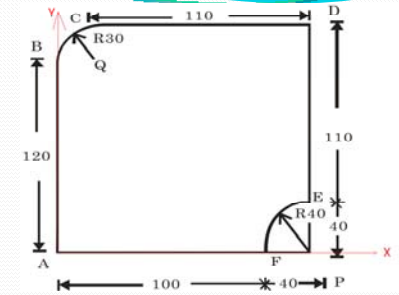
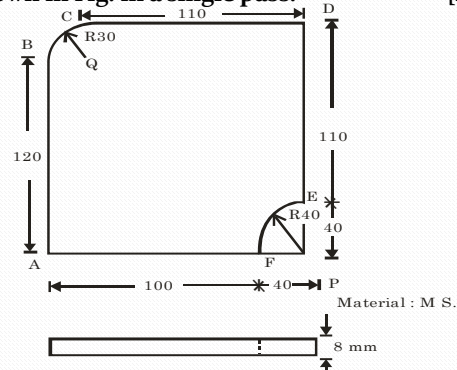
GORGT/L5, PAST, L1

Rev.0

RAPID
GOTO/P0
COOLNT/OFF
SPINDL/OFF
END
FINI

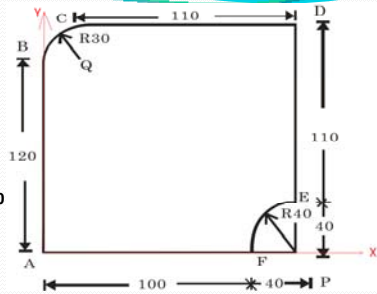
Contd....

IES-2007
Prepare part using APT language for milling the contour shown in Fig. in a single pass. [20-Marks]



Answer:

PARTNO CONTOUR
MACHIN/MILL, 2
CLPRNT
UNITS/MM
P0 = POINT/0.0, 0.0, 10.0
PTA = POINT/0.0, 0.0, 0.0
PTB = POINT/0.0, 120.0, 0.0
PTC = POINT/30.0, 150.0, 0.0
PTD = POINT/140.0, 150.0, 0.0
PTE = POINT/140.0, 40.0, 0.0
PTF = POINT/100.0, 0.0, 0.0
PTQ = POINT/30.0, 120.0, 0.0
PTP = POINT/140.0, 0.0, 0.0
LAB = LINE/PTA, PTB
LCD = LINE/PTC, PTD
LDE = LINE/PTD, PTE
LAF = LINE/PTA, PTF
CBC = CIRCLE/CENTRE, PTQ, RADIUS, 30.0
CEF = CIRCLE/CENTRE, PTP, RADIUS, 40.0
PL1=PLANE/PTA, PTB, PTC



CUTTER/25.0
TOLER/0.1
INTOL/0.05
OUTTOL/0.05
FEDRAT/200
SPINDL/500, CLW
COOLNT/ON
FROM/P0
GO/TO, LAB, TO, PL1, TO, LAF
GOLFT/LAB, TANTO, CBC
GOFWD/CBC, PAST, LCD
GORT/LCD, PAST, LDE
GORT/LDE, PAST, CEF
GORT/CEF, PAST, LAF
GORT/LAF, PAST, LAB

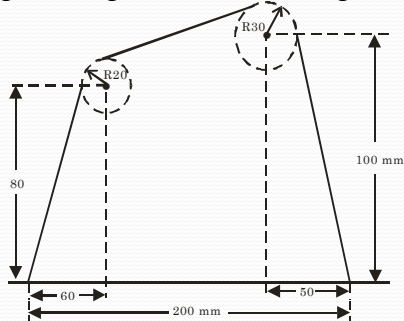
Contd....

RAPID
GOTO/P0
COOLNT/OFF
SPINDL/OFF
END
FINI

Contd....

IES-2006

Prepare part program to machine the contour shown in the figure using APT on CNC milling machine. [15-Marks]



For-2015 (IES, GATE & PSUs)
Material: MS Thickness: 8.0 mm

Answer:

PARTNO CONTOUR
MACHIN/MILL, 3
CLPRNT
UNITS/MM
P0 = POINT/0.0, 0.0, 10.0
P1 = POINT/0.0, 0.0, 0.0
P2 = POINT/60.0, 80.0, 0.0
P3 = POINT/150.0, 100.0, 0.0
P4 = POINT/200.0, 0.0, 0.0
C1 = CIRCLE/ CENTER, P2, RADIUS, 20
C2 = CIRCLE/CENTER, P3, RADIUS, 30
L1 = LINE/P1, LEFT, TANTO, C1
L2 = LINE/LEFT, TANTO, C1, LEFT, TANTO, C2
L3 = LINE/P4, RIGHT, TANTO, C2
L4 = LINE/P1, P4
PL1=PLANE/P1, P2, P3

Contd....

```
CUTTER/25.0
TOLER/0.1
INTOL/0.05
OUTTOL/0.05
COOLNT/ON
SPINDL/500, CLW
FEDRAT/200
FROM/P0
GO/TO, L1, TO, PL1, TO, L4
GOLFT/L1, TANTO, C1
GOFWD/C1, PAST, L2
GOFWD/L2, TANTO, C2
GOFWD/C2, PAST, L3
GOFWD/L3, PAST, L4
GORGTL4, PAST, L1
```

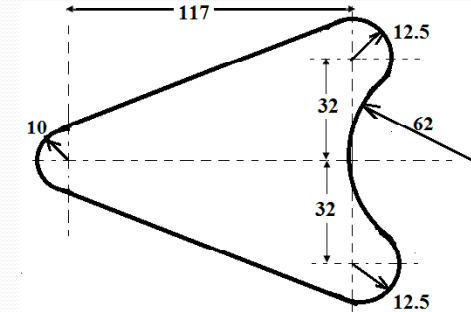
Contd....

```
RAPID
GOTO/P0
COOLNT/OFF
SPINDL/OFF
END
FINI
```

Home Work

Write a complete part program in APT for machining the product which is given in the diagram. Thickness of the workpiece is 6 mm. All dimensions are in mm.

[15]



PARTNO CONTOUR

MACHIN/MILL, 1

CLPRNT

UNITS/MM

P0 = POINT/-25.0,-25.0, 25.0

P1 = POINT/0.0, 0.0, 6.0

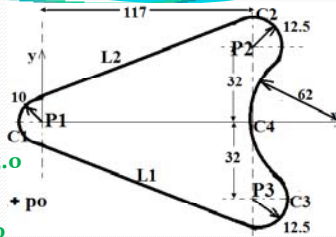
P2 = POINT/117.0, 32.0, 6.0

P3 = POINT/117.0, -32.0, 6.0

C1=CIRCLE/CENTER, P1, RADIUS, 10.0

C2=CIRCLE/CENTER, P2, RADIUS, 12.5

C3=CIRCLE/CENTER, P3, RADIUS, 12.5



```
L1 = LINE/RIGHT, TANTO, C1, RIGHT, TANTO, C3
L2 = LINE/LEFT, TANTO, C1, LEFT, TANTO, C2
C4=CIRCLE/XLARGE, OUT, C2, OUT, C3, RADIUS, 62
PL1=PLANE/P1, P2, P3
REMARK POSTPROCESSOR STATEMENT FOLLOW
CUTTER/50.0
TOLER/0.01
INTOL/0.05
OUTTOL/0.05
FEDRAT/200
SPINDL/1000, CLW
COOLNT/ON
```

REMARK MOTION STATEMENT FOLLOW

FROM/P0

GO/TO, L1, TO, PL1, TANTO, C1

GORGTL1, TANTO, C3

GOFWD/C3, TANTO, C4

GOFWD/C4, TANTO, C2

GOFWD/C2, PAST, L2

GOFWD/L2, TANTO, C1

GOFWD/C1, PAST, L1

RAPID

GOTO/P0

COOLNT/OFF

SPINDL/OFF

END

FINI

IES 2011 Conventional

State the method of defining line segment of cutter motion using APT program format.

[5 Marks]

IES - 1997

Which of the following are valid statements for point to point motion of the tool in APT language?

1. GO/TO/.....
2. GO DLTA/.....
3. GO/TO,

Select the correct answer using the codes given below:

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

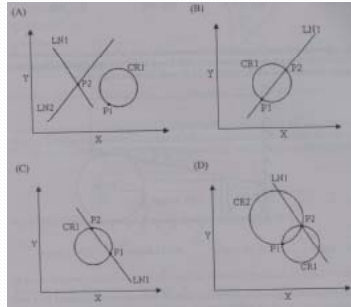
IES - 1995

In APT language, the cutter motion in incremental coordinate mode is addressed as

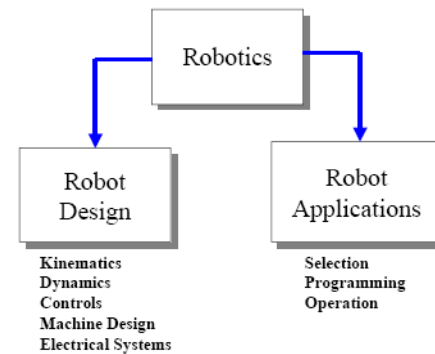
- (a) GO/TO/.....
(b) GO/TO.....
(c) GO DLTA/....
(d) GO FWD/...

GATE -2008 (PI)

Suppose point P_1 in APT programming is coded by statement $P_1 = \text{POINT/XSMALL, INTOF, LN1, CR1}$
The coded geometric situation without causing error is

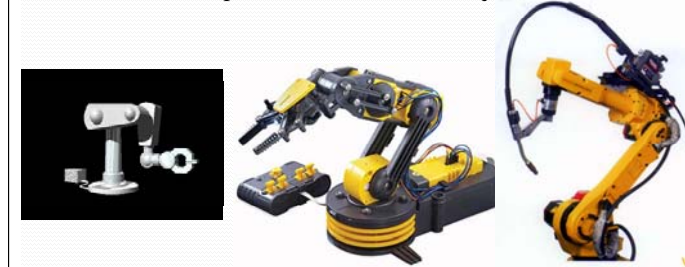


Robotics



What is an industrial robot?

A robot is a reprogrammable, multifunctional manipulator designed to handle material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks.



Advantages of Robots

- Robotics and automation can, in many situation, increase productivity, safety, efficiency, quality, and consistency of products
- Robots can work in hazardous environments
- Robots need no environmental comfort
- Robots work continuously without any humanity needs and illnesses
- Robots have repeatable precision at all times
- Robots can be much more accurate than humans, they may have mili or micro inch accuracy.
- Robots and their sensors can have capabilities beyond that of humans
- Robots can process multiple stimuli or tasks simultaneously, humans can only one.
- Robots replace human workers who can create economic problems

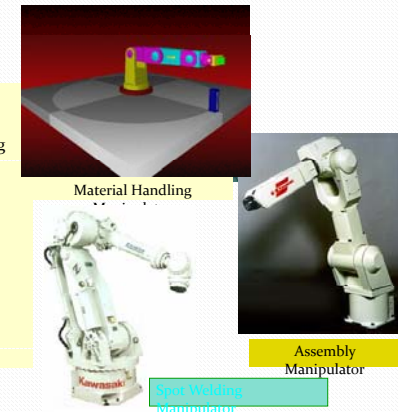
Disadvantages of Robots

- Robots lack capability to respond in emergencies, this can cause:
 - Inappropriate and wrong responses
 - A lack of decision-making power
 - A loss of power
 - Damage to the robot and other devices
 - Human injuries
- Robots may have limited capabilities in
 - Degrees of Freedom
 - Dexterity
 - Sensors
 - Vision systems
 - Real-time Response
- Robots are costly, due to
 - Initial cost of equipment
 - Installation Costs
 - Need for peripherals
 - Need for training
 - Need for Programming

What Can Robots Do?

Industrial Robots

- Material handling
- Material transfer
- Machine loading and/or unloading
- Spot welding
- Continuous arc welding
- Spray coating
- Assembly
- Inspection



Asimov's three laws of robotics

First law (Human safety):

- A robot may not injure a human being, or, through inaction, allow a human being to come to harm.

Second law (Robots are slaves):

- A robot must obey orders given it by human beings, except where such orders would conflict with the First Law.

Third law (Robot survival):

- A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

For-2015 (IES, GATE & PSUs)

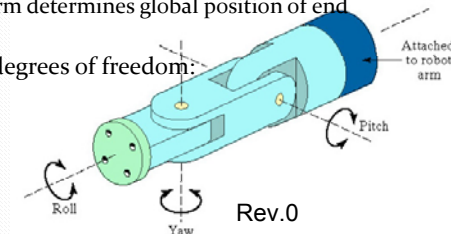
All robots have the following basic components:

- Manipulators:** the mechanical unit, often called the "arm," that does the actual work of the robot. It is composed of mechanical linkages and joints with actuators to drive the mechanism directly or indirectly through gears, chains, or ball screws.
- Feedback devices:** transducers that sense the positions of various linkages and joints and transmit this information to the controllers in either digital or analog Form.
- End effectors:** the "hand" or "gripper" portion of the robot, which attaches the end of the arm and perform the operations of the robot.
- Controller:** the brains of the system that direct the movements of the manipulator.
- Power supply**

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Wrist Configurations

- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
 - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
 - Roll
 - Pitch
 - Yaw



End Effectors

- The special tooling for a robot that enables it to perform a specific task
- Two types:
 - Grippers – to grasp and manipulate objects (e.g., parts) during work cycle
 - Tools – to perform a process, e.g., spot welding, spray painting



Grippers and Tools



Degrees of Freedom

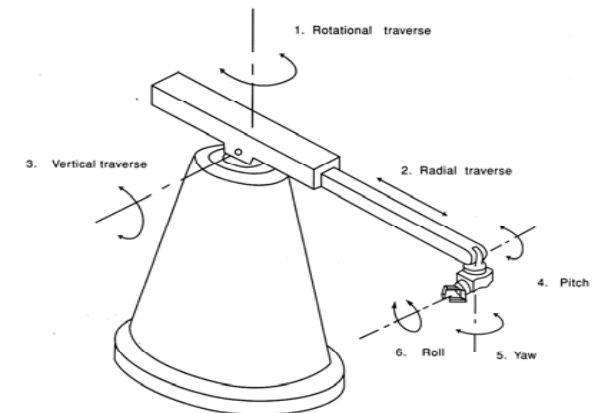
- The degree of freedom or grip of a robotic system can be compared to the way in which the human body moves.
- For each degree of freedom a joint is required.
- The degrees of freedom located in the arm define the configuration.
- Each of the five basic motion configurations utilizes three degrees of freedom in the arm.
- Three degrees of freedom located in the wrist give the end effector all the flexibility.

Degrees of Freedom (contd.)

- A total of six degrees of freedom is needed to locate a robot's hand at any point in its work space.
- Although six degrees of freedom are needed for maximum flexibility, most robot employee only three to five degrees of freedom.
- The more the degrees of freedom, the greater is the complexity of motions encountered.
- **The three degrees of freedom located in the arm of a robotic system are:**
 - **The rotational reverse:** is the movement of the arm assembly about a rotary axis, such as left-and-right swivel of the robot's arm about a base.

Degrees of Freedom (contd.)

- **The radial traverse:** is the extension and retraction of the arm or the in-and-out motion relative to the base.
- **The vertical traverse:** provides the up-and-down motion of the arm of the robotic system.
- **The three degrees of freedom located in the wrist, which bear the names of aeronautical terms, are**
 - **Pitch or bend:** is the up-and-down movement of the wrist.
 - **Yaw:** is the right-and-left movement of the wrist.
 - **Roll or swivel:** is the rotation of the hand.

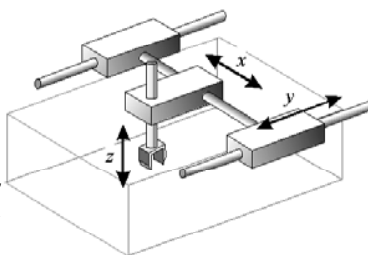


Six major degrees of freedom of a robotic system

Types of Robot

- **Cartesian or Gantry robot:**
- It's a robot whose arm has three prismatic joints, whose axes are coincident with a Cartesian coordinator.
- Used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding.

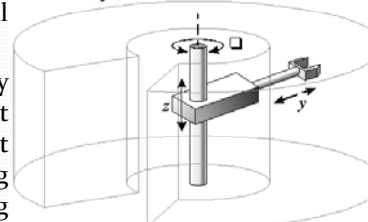
Cartesian Robot



Types of Robot

- **Cylindrical robot:**
- It's a robot whose axes form a cylindrical coordinate system.
- Used for assembly operations, handling at machine tools, spot welding, and handling at die casting machines.

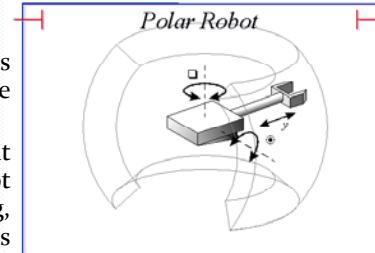
Cylindrical Robot



Types of Robot

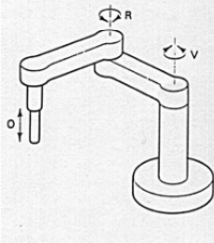
- **Spherical or Polar robot:**
- It's a robot whose axes form a polar coordinate system.
- Used for handling at machine tools, spot welding, diecasting, fettling machines, gas welding and arc welding.

Polar Robot



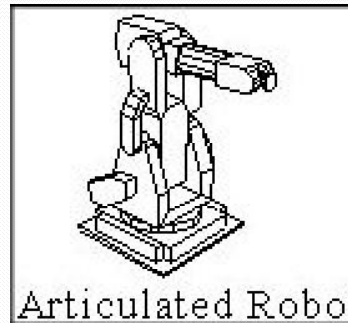
Types of Robot

- **SCARA robot**
- The SCARA acronym stands for Selective Compliant Assembly Robot Arm or Selective Compliant Articulated Robot Arm.
- It's a robot which has two parallel rotary joints to provide compliance in a plane
- Used for pick and place work, application of sealant, assembly operations and handling machine tools



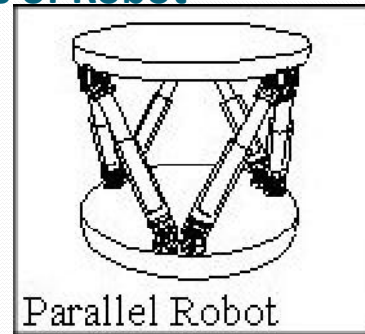
Types of Robot

- **Articulated or Revolute Robot:**
- It's a robot whose arm has at least three rotary joints.
- Used for assembly operations, die casting, fettling machines, gas welding, arc welding and spray painting.



Types of Robot

- **Parallel robot**
- One use is a mobile platform handling cockpit flight simulators. It's a robot whose arms have concurrent prismatic or rotary joints.



IES - 2012

The configuration of a robot using a telescoping arm that can be raised or lowered on a horizontal pivot mounted on a rotating base is called

- (a) Polar
- (b) Cylindrical
- (c) Cartesian coordinate
- (d) Jointed arm

Joint Drive System:

- Electric
 - Uses electric motors to actuate individual joints
 - Preferred drive system in today's robots
- Hydraulic
 - Uses hydraulic pistons and rotary vane actuators
 - Noted for their high power and lift capacity
- Pneumatic
 - Typically limited to smaller robots and simple material transfer applications

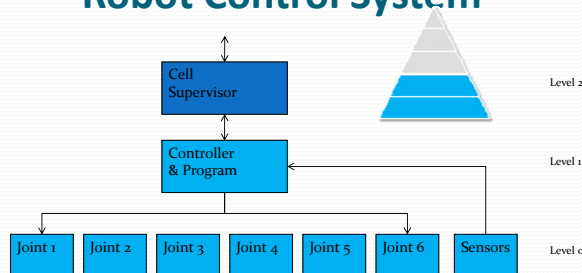


Robot Control Systems

- **Limited sequence control** – pick-and-place operations using mechanical stops to set positions
- **Playback with point-to-point control** – records work cycle as a sequence of points, then plays back the sequence during program execution
- **Playback with continuous path control** – greater memory capacity and/or interpolation capability to execute paths (in addition to points)
- **Intelligent control** – exhibits behavior that makes it seem intelligent, e.g., responds to sensor inputs, makes decisions, communicates with humans

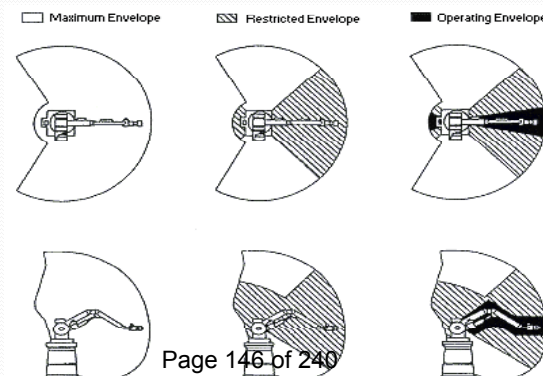


Robot Control System



For-2015 (IES, GATE & PSUs)

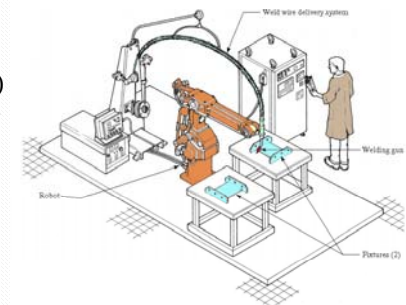
Working Envelope



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Robotic Arc-Welding Cell

- Robot performs flux-cored arc welding (FCAW) operation at one workstation while fitter changes parts at the other workstation



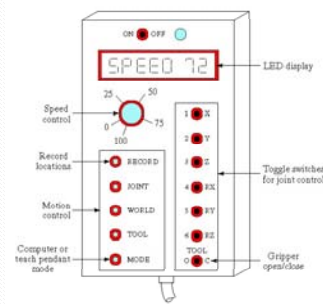
Rev.0

Robot Programming

- Leadthrough programming
 - Work cycle is taught to robot by moving the manipulator through the required motion cycle and simultaneously entering the program into controller memory for later playback
- Robot programming languages
 - Textual programming language to enter commands into robot controller
- Simulation and off-line programming
 - Program is prepared at a remote computer terminal and downloaded to robot controller for execution without need for leadthrough methods

Leadthrough Programming

1. Powered leadthrough
 - Common for point-to-point robots
 - Uses teach pendant
2. Manual leadthrough
 - Convenient for continuous path control robots
 - Human programmer physical moves manipulator



Leadthrough Programming Advantages

- Advantages:
 - Easily learned by shop personnel
 - Logical way to teach a robot
 - No computer programming
- Disadvantages:
 - Downtime during programming
 - Limited programming logic capability
 - Not compatible with supervisory control



IES 2011

Trajectory of a robot mean :

- (a) Path traced by the end effectors
- (b) Kinematics of Robot
- (c) Robot joints
- (d) Robot programming

IES 2010

Consider the following statements:

Good dynamic performance is usually difficult to achieve in robots which contain a rotary base because

1. Position, speed and acceleration of the other joints cause variations in the reflected torque and moment of inertia.
2. The moment of inertia reflected at the base depends upon the weight of the object being carried.
3. The moment of inertia reflected at the base also depends upon the distance between the base axis and the manipulated object.

Which of the above statements is/are correct?

- (a) 1, 2 and 3
- (b) 2 and 3 only
- (c) 1 only
- (d) 1 and 3 only

IES - 2006

Which one of the following is the third basic component of robots besides power supply and control (memory) console?

- (a) Software
- (b) Coaxial cable
- (c) Mechanical unit arm
- (d) Microcomputer

IES - 2000

Consider the following characteristics of a robot:

1. The tip of the robot arm moves from one point to another with its in-between path not being defined.
2. It can be used for drilling holes at difference points in a workpiece.
3. It can be used for V butt joint welding between two points.
4. The memory capacity required for its control unit is low.

Which of these are the characteristics associated with a point to point robot?

- (a) 1 and 2
- (b) 1, 3 and 4
- (c) 1, 2 and 4
- (d) 2, 3 and 4

CAD

Computer Aided Design (CAD): Used for creating the product database

- Geometric Modeling
- Engineering Analysis
- Design Review and Evaluation
- Automated Drafting

GATE-2013

In a CAD package, mirror image of a 2D point P(5,10) is to be obtained about a line which passes through the origin and makes an angle of 45° counterclockwise with the X-axis. The coordinates of the transformed point will be

- (a) (7.5, 5)
- (b) (10, 5)
- (c) (7.5, -5)
- (d) (10, -5)

GATE-2014

A robot arm PQ with end coordinates P(0, 0) and Q(2, 5) rotates counter clockwise about P in the XY plane by 90° .

The new coordinate pair of the end point Q is

- (a) (-2, 5) (b) (-5, 2)
(c) (-5, -2) (d) (2, -5)

CAM

Computer Aided Manufacturing (CAM):

- Computer Aided Process Planning (CAPP)
- Computerized material Resource Planning (MRP)
- NC part programming
- Robot Programming
- Computerized Scheduling
- Computerized process control
- Computerized Manufacturing Control by FMS
- Shop floor control
- Computer Aided Quality Control (CAQC)
- Computer Aided Inspection

IES - 2006

Which item best describes a CAM technology?

- (a) Geometric modeling (b) Documentation
(c) Drafting (d) Numerical control

ISRO-2011

In CAM, "Part programming" refers to

- (a) Generation of cutter location data
(b) On-line Inspection
(c) Machine Selection
(d) Tool Selection

Automation

- Automation is the process of following a predetermined sequence of operations with little or no human intervention, using specialized equipment and devices that perform and control the manufacturing process.

Why go for Automation?

1. Increased productivity
2. Reduced cost of labour
3. Improved quality
4. Reduced in-process inventory
5. Reduce Manufacturing time
6. Increased safety

There are three types of Automation

1. Fixed Automation
2. Programmable Automation
3. Flexible Automation

Automation

Fixed Automation

- It is also known as hard automation.
- Used to produce a standardized product.
- Used for very large quantity production of one or few marginally different components.
- Highly specialized tools, devices, equipment, special purpose machine tools, are utilized to produce a product.
- Very efficient, high production rate, low unit cost.

Automation

Programmable Automation

- Can change the design of the product or even change the product by changing the program.
- Used for the low quantity production of large number of different components.
- Equipment are designed to be flexible or programmable.
- Used for batch production.

Automation

Flexible Automation

- It is also known as FMS, and uses CAD/CAM
- Produce different products on the same equipment in any order or mix.

IES - 2012

Programmable automation is suitable for

- (a) Low production volume and large varieties of parts
(b) Low production volume and small varieties of parts
(c) High production volume and small varieties of parts
(d) High production volume and large varieties of parts

What is an FMS?

- A **flexible manufacturing system** (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes.
- Two categories of flexibility
 - **Machine flexibility**, covers the system's ability to be changed to produce new product types, and ability to change the order of operations executed on a part.
 - **Routing flexibility**, which consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes, such as in volume, capacity, or capability.

FMS Components

- Most FMS systems comprise of three main systems
 - Work machines (typically automated CNC machines) that perform a series of operations;
 - An integrated material transport system and a computer that controls the flow of materials, tools, and information (e.g. machining data and machine malfunctions) throughout the system;
 - Auxiliary work stations for loading and unloading, cleaning, inspection, etc.

FMS Goals

- Reduction in manufacturing cost by lowering direct labor cost and minimizing scrap, re-work, and material wastage.
- Less skilled labor required.
- Reduction in work-in-process inventory by eliminating the need for batch processing.
- Reduction in production lead time permitting manufacturers to respond more quickly to the variability of market demand.
- Better process control resulting in consistent quality.

Advantages of FMS

- Faster, lower- cost changes from one part to another which will improve capital utilization
- Lower direct labor cost, due to the reduction in number of workers
- Reduced inventory, due to the planning and programming precision
- Consistent and better quality, due to the automated control
- Lower cost/unit of output, due to the greater productivity using the same number of workers
- Savings from the indirect labor, from reduced errors, rework, repairs and rejects

Disadvantages of FMS

- Limited ability to adapt to changes in product or product mix (e.g., machines are of limited capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
- Substantial pre-planning activity
- Expensive, costing millions of dollars
- Technological problems of exact component positioning and precise timing necessary to process a component
- Sophisticated manufacturing systems

IES - 1996

Which of the following pairs are correctly matched?

1. CNC machine..... Post processor
 2. Machining centre....Tool magazine
 3. DNC..... FMS
- (a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

IES - 2006

Flexible manufacturing allows for:

- (a) Tool design and production
- (b) Automated design
- (c) Quick and inexpensive product change
- (d) Quality control

IES - 2004

Consider the following characteristics:

1. Single machine tool
2. Manual materials handling system
3. Computer control
4. Random sequencing of parts to machines

Which of the above characteristics are associated with flexible manufacturing system?

- (a) 1, 2 and 3 (b) 1 and 2
(c) 3 and 4 (d) 2, 3 and 4

IES - 2012

Rank order clustering as applied to manufacturing automation is

- (a) A technique of identifying process sequence in production of a component
- (b) A just in time (JIT) method
- (c) An approach of grouping the machines into cells in an FMS system
- (d) A tool to generate bill of materials

Reference Book

- **CAD/CAM: Computer-Aided Design and Manufacturing** By Groover
- **CNC Machines** By B. S. Pabla, M. Adithan
- **Machine tool design and numerical control** - By Mehta
- **Computer Control Of Manu. Systems** By Koren

IFS -2011

Prepare a flow diagram for writing the computer programme in FORTRAN for Pulse MIG welding process.

[10-marks]

Need for Unconventional Processes

- New materials having high strength and hardness, such as nimonic alloys and alloys with alloying elements such as tungsten, molybdenum, and columbium are difficult to machine by the traditional methods.
- By conventional machining the MRR reduces with an increase in the work material hardness.
- Need for development of non-traditional machining processes which utilize other methods such as electrochemical processes for the material removal.

Need for Unconventional Processes

- Complex shapes.
- A very high accuracy is desired besides the complexity of the surface to be machined.

In Unconventional Machining

- Different forms of energy directly applied to the workpiece to have shape transformation or material removal from work surface.
- No chips, No lay pattern on work surface, no direct physical contact between the tool and the workpiece .
- The tool material does not have to be harder than the work material.
- Tool forces do not increase as the work material gets harder.
- Economic metal removal rate does not decrease as the work material gets harder.

Classification of NTMM

The Non-traditional Machining Methods are classified according to the major energy sources employed in machining.

1. **Thermal Energy Methods**
2. **Electro - Chemical Energy Method**
3. **Chemical Energy Methods**
4. **Mechanical Energy Methods**

1. Thermal Energy Methods

- Electrical discharge machining (EDM)
- Laser beam Machining (LBM)
- Plasma Arc Machining (PAM)
- Electron Beam Machining(EBM)
- Ion Beam Machining (IBM)

2. Electro - Chemical Energy Method

- Electro-Chemical Machining (ECM)
- Electro-Chemical grinding (ECG)
- Electro-Chemical Honing (ECH)
- Electro-Chemical Deburring (ECD)

3. Chemical Energy Methods

These methods involve controlled etching of the workpiece material in contact with a chemical solution.

- Chemical Machining Method (CHM).

4. Mechanical Energy Methods

- Ultra Sonic Machining (USM)
- Abrasive Jet Machining (AJM)
- Water Jet Machining (WJM)

GATE-2014

The process utilizing mainly thermal energy for removing material is

- (a) Ultrasonic Machining
- (b) Electrochemical Machining
- (c) Abrasive Jet Machining
- (d) Laser Beam Machining

Some Observations

- EDM has the lowest specific power requirement and can achieve sufficient accuracy.
- ECM has the highest metal removal rate, MRR.
- USM and AJM have low MRR and combined with high tool wear, are used for non-metal cutting.
- LBM and EBM have high penetration rates with low MRR and, therefore, are commonly used for micro drilling, sheet cutting, and welding.
- CHM is used for manufacturing PCB and other shallow components.
- PAM can be used for clean, rapid cuts and profiles in almost all plates upto 20 cm thick with 5° to 10° taper.

Shapes Cutting Capability

The various NTMM have some special shape cutting capability as given below:

1. Micro-machining and Drilling : LBM and EBM
2. Cavity sinking and standard Hole Drilling: EDM and USM
3. Fine hole drilling and Contour Machining: ECM
4. Clean, rapid Cuts and Profiles: PAM
5. Shallow Pocketing: AJM

GATE-2014

The following four unconventional machining processes are available in a shop floor. The most appropriate one to drill a hole of square cross section of 6 mm × 6 mm and 25 mm deep is

- (a) Abrasive Jet Machining
- (b) Plasma Arc Machining
- (c) Laser Beam Machining
- (d) Electro Discharge Machining

Limitations of NTMM

- Expensive set up, low MRR and skilled labour required.
- The limitation of electrical machining methods is that the work material must be an electrical conductor. Also, consumption of electrical energy is very large.
- The NTMM which have not been proved commercially economical are: USM, AJM, CHM, EBM and PAM.

IES - 2012

Which of the following processes has very high material removal rate efficiency?

- (a) Electron beam machining
- (b) Electrochemical machining
- (c) Electro discharge machining
- (d) Plasma arc machining

GATE - 2006

Arrange the processes in the increasing order of their maximum material removal rate.

- Electrochemical Machining (ECM)
Ultrasonic Machining (USM)
Electron Beam Machining (EBM)
Laser Beam Machining (LBM) and
Electric Discharge Machining (EDM)
- (a) USM, LBM, EBM, EDM, ECM
 - (b) EBM, LBM, USM, ECM, EDM
 - (c) LBM, EBM, USM, ECM, EDM
 - (d) LBM, EBM, USM, EDM, ECM

IES - 2007

Consider the following statements in relation to the unconventional machining processes:

1. Different forms of energy directly applied to the piece to have shape transformation or material removal from work surface.
 2. Relative motion between the work and the tool is essential.
 3. Cutting tool is not in physical contact with work piece.
- (a) 1 and 2 only (b) 1, 2 and 3 only
(c) 2 and 3 only (d) 1 and 3 only

IES - 2009

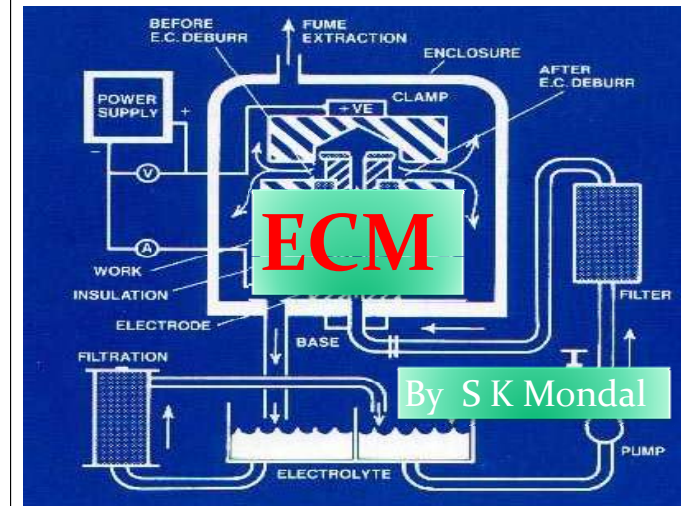
Which one of the following statements is correct in respect of unconventional machining processes?

- (a) The cutting tool is in direct contact with the job
- (b) The tool material needs to be harder than the job material
- (c) The tool is never in contact with the job
- (d) There has to be a relative motion between the tool and the job

IAS - 2002

Match List I (Processes) with List II (Tolerances obtained) and select the correct answer using the codes given below the Lists:

List I (Processes)				List II (Tolerances obtained)					
A.	Plasma Arc machining			1.	7.5 microns				
B.	Laser Beam machining			2.	25 microns				
C.	Abrasive Jet machining			3.	50 microns				
D.	Ultrasonic machining			4.	125 microns				
Codes:	A	B	C	D	A	B	C	D	
(a)	4	1	3	2	(b)	3	2	4	1
(c)	4	2	3	1	(d)	3	1	4	2



Electrochemical Machining

- Electrochemical machining is the reverse of electro plating
- The work-piece is made the anode, which is placed in close proximity to an electrode (cathode), and a high-amperage direct current is passed between them through an electrolyte, such as salt water, flowing in the anode-cathode gap.
- Metal is removed by anodic dissolution and is carried away in the form of a hydroxide in the electrolyte for recycling or recovery.
- MRR in ECM depends on atomic weight of work material

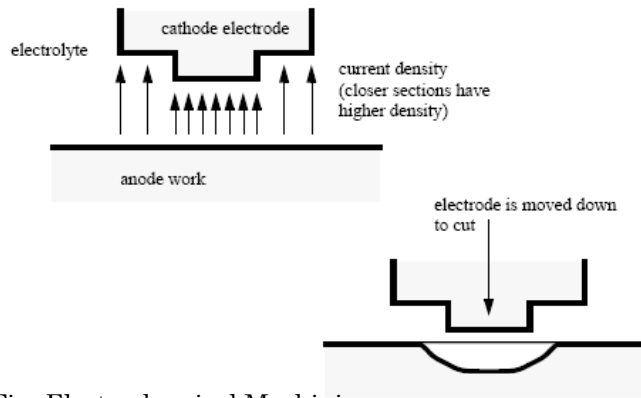
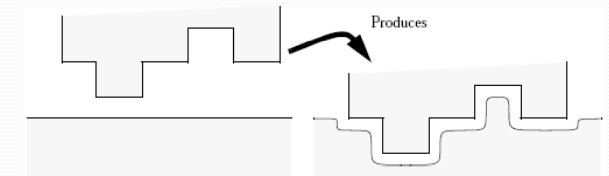


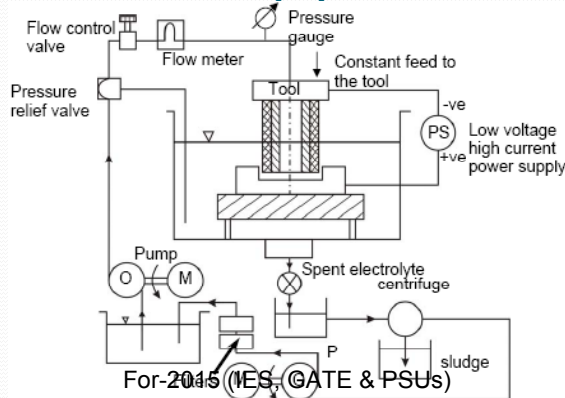
Fig- Electrochemical Machining process

Electrochemical Machining

- Variation in the current density will result in work taking the electrodes shape.
- The electrode is fed with a constant velocity, and the electrolyte is fed through the tool.



ECM Equipment



ECM Equipment

- Supply Voltage 2 to 35 V DC and Current 500 to 40,000 A
- The tool-to-work gap needs to be maintained at a very small value 0.1 to 0.25 mm. A servo drive is provided on the tool axis for this purpose.
- The electrolyte needs to be pumped through this gap at high pressures ranging from 0.70 to 3.00 MPa. This introduces a large amount of load on the machine, because of the large working areas involved. Hence the machine structure will have to be made rigid to withstand such forces.

ECM Equipment

- The electrolyte consists of the metal debris removed from the anode, which will have to be filtered before it is re-pumped into the system.
- Also a large amount of heat is generated during the electrolysis, which heats up the electrolyte, and hence it needs to be cooled.

Electrolyte

The electrolyte is so chosen that the anode (workpiece) is dissolved but no deposition takes place on the cathode (tool).

Properties electrolyte should be

1. High electrical conductivity
2. Low viscosity
3. High specific heat
4. Chemical stability
5. Resistance to formation of passivating film on workpiece surface
6. Non-corrosive and non-toxic
7. Inexpensive and readily available

Alloy	Electrolyte
Iron based	Chloride solutions in water (mostly 20% NaCl)
Ni based	HCl or mixture of brine and H_2SO_4
Ti based	10% hydrofluoric acid + 10% HCl + 10% HNO_3
Co-Cr-W based	NaCl
WC based	strong alkaline solutions

For ECM of steel NaCl is used as the electrolyte.

Tool

The properties of tool materials should be:

1. High electrical and thermal conductivity
 2. Easy machinability
 3. Good stiffness
 4. High corrosion resistance
- **Tool materials:** Copper, brass, bronze, Al, Stainless Steel, Cupro nickel, etc.
 - Material wear / Tool wear: Infinite

Advantages

1. Complex three-dimensional surfaces can be machined accurately. Good for low machinability or complicated shapes.
2. As ECM leads to atomic level dissolution, the surface finish is excellent (R_a 0.2 to 0.6 μm) with almost stress free machined surface and without any thermal damage.
3. The tool wear is practically nil which results in a large number of components produced per tool.
4. MRR is highest (1600 mm^3/min) among NTMM and comparable with conventional machining.

Disadvantages

1. Use of corrosive media as electrolytes makes it difficult to handle.
2. Sharp interior edges and corners (< 0.2 mm radius) are difficult to produce.
3. Very expensive machine.
4. Forces are large with this method because of fluid pumping forces.
5. Very high specific energy consumption (about 150 times that required for conventional processes),
6. Not applicable with electrically non-conducting materials and jobs with very small dimensions
7. Lower fatigue strength

Applications

- Any electrically conductive work material irrespective of their hardness, strength or even thermal properties.
- The machining surface can be situated at any inaccessible.
- Shape application – blind complex cavities, curved surfaces, through cutting, large through cavities.
- It is used for the machining of the gas turbine blades.
- Die sinking
- Profiling and contouring
- Trepanning
- Grinding
- Drilling
- Micro-machining

ISRO-2009

The machining process in which the work piece is dissolved into an electrolyte solution is called

- (a) Electro-chemical machining
- (b) Ultrasonic machining
- (c) Electro-discharge machining
- (d) Laser machining

PSU

ECM cannot be undertaken for

- (a) steel
- (b) Nickel based superalloy
- (c) Al_2O_3
- (d) Titanium alloy

PSU

Commercial ECM is carried out at a combination of

- (a) low voltage high current
- (b) low current low voltage
- (c) high current high voltage
- (d) low current low voltage

IAS-2011 Main

What is the principle of electro-chemical machining (ECM)?

What are the advantages and disadvantages of ECM over conventional drilling?

Comment on the surface finish and the accuracy of the ECM.

[20-Marks]

ECM Calculations

Faraday's laws state that,

$$m = \frac{ItE}{F}$$

Where

m = weight (g) of a material

I = current (A)

t = time (sec)

E = gram equivalent weight of the material

F = constant of proportionality – Faraday (96,500 coulombs)

ECM Calculations

$$\bullet \text{MRR} = \frac{EI}{F} \quad \text{g/s} = \frac{AI}{F \cdot V} \quad \text{g/s}$$

If you put E = equivalent weight in CGS i.e. g/mole

I in Ampere (A)

$F = 96500$ coulomb/mole i.e. As/mole

The MRR will be in g/s

ECM Calculations

\Rightarrow If ρ in kg/m^3 then

$$= \rho \times \frac{1000 \text{ g}}{(100)^3 \text{ cm}^3} = \rho \times 10^{-3} \text{ g/cm}^3$$

And then put to above formula

$$\text{MRR} = \frac{E \cdot I}{F \cdot \rho} = \frac{AI}{FV\rho} = x \text{ cm}^3/\text{s}$$

$$= x \times \frac{(10\text{mm})^3}{\left(\frac{1}{60}\right) \text{ min}} = x \times 60 \times 1000 \text{ mm}^3/\text{min}$$

ECM Calculations

- MRR for pure metal

$$\frac{AI}{\rho VF} \left(\frac{\text{cm}^3}{\text{sec}} \right) = \frac{EI}{\rho F} \left(\frac{\text{cm}^3}{\text{sec}} \right)$$

- MRR for Alloy

$$\frac{E_{eq} I}{\rho_{eq} F} \left(\frac{\text{cm}^3}{\text{sec}} \right)$$

$$\frac{100}{\rho_{eq}} = \sum_i \left(\frac{x_i}{\rho_i} \right) \quad \text{and} \quad \frac{100}{E_{eq}} = \sum_i \left(\frac{x_i v_i}{A_i} \right)$$

GATE-2014

The principle of material removal in Electro-chemical machining is

- Fick's law
- Faraday's laws
- Kirchhoff's laws
- Ohm's law

Example

Using ECM remove $5 \text{ cm}^3/\text{min}$ from an iron workpiece, what current is required?

Atomic weight of iron 56, density 7.8 g/cm^3 valency, 2

GATE-2008 (PI)

In an electro chemical machining (ECM) operation, a square hole of dimensions $5 \text{ mm} \times 5 \text{ mm}$ is drilled in a block of copper. The current used is 5000 A. Atomic weight of copper is 63 and valency of dissolution is 1. Faraday's constant is 96500 coulomb. The material removal rate (in g/s) is

- 0.326
- 3.260
- 3.15×10^3
- 3.15×10^5

GATE – 2011 (PI)

While removing material from iron (atomic weight = 56, valency = 2 and density = 7.8 g/cc) by electrochemical machining, a metal removal rate of 2 cc/min is desired. The current (in A) required for achieving this material removal rate is

- 896.07
- 14.93
- 448.03
- 53764.29

Example

Calculate the material removal rate and the electrode feed rate in the electrochemical machining of an iron surface that is 25 mm × 25 mm in cross-section using NaCl in water as electrolyte. The gap between the tool and the workpiece is 0.25 mm. The supply voltage is 12 V DC. The specific resistance of the electrolyte is 3 Ω cm

For iron, Valency, $Z = 2$

Atomic weight, $A = 55.85$

Density, $= 7860 \text{ kg/m}^3$

Example (GATE-2009)

Electrochemical machining is performed to remove material from an iron surface of 20 mm × 20 mm under the following conditions:

Inter electrode gap = 0.2 mm

Supply Voltage (DC) = 12 V

Specific resistance of electrolyte = 2 Ω cm

Atomic weight of Iron = 55.85

Valency of Iron = 2

Faraday's constant = 96540 Coulombs

The material removal rate (in g/s) is

GATE-2013

During the electrochemical machining (ECM) of iron (atomic weight = 56, valency = 2) at current of 1000 A with 90% current efficiency, the material removal rate was observed to be 0.26 gm/s. If Titanium (atomic weight = 48, valency = 3) is machined by the ECM process at the current of 2000 A with 90% current efficiency, the expected material removal rate in gm/s will be

(a) 0.11 (b) 0.23 (c) 0.30 (d) 0.52

Example

Composition of a Nickel super-alloy is as follows:

Ni = 70.0%, Cr = 20.0%, Fe = 5.0% and rest Titanium

Calculate rate of dissolution if the area of the tool is 1500 mm² and a current of 1000 A is being passed through the cell. Assume dissolution to take place at lowest valency of the elements.

$A_{Ni} = 58.71$	$\rho_{Ni} = 8.9$	$v_{Ni} = 2$
$A_{Cr} = 51.99$	$\rho_{Cr} = 7.19$	$v_{Cr} = 2$
$A_{Fe} = 55.85$	$\rho_{Fe} = 7.86$	$v_{Fe} = 2$
$A_{Ti} = 47.9$	$\rho_{Ti} = 4.51$	$v_{Ti} = 3$

GATE - 2008

A researcher conducts electrochemical machining (ECM) on a binary alloy (density 6000 kg/m³) of iron (atomic weight 56, valency 2) and metal P (atomic weight 24, valency 4). Faraday's constant = 96500 coulomb/mole. Volumetric material removal rate of the alloy is 50 mm³/s at a current of 2000 A. The percentage of the metal P in the alloy is closest to

(a) 40 (b) 25 (c) 15 (d) 79

Flow analysis

- To calculate the fluid flow required, match the heat generated to the heat absorbed by the electrolyte.

The heat generated in the gap, H is given by

$$H = I^2 \times R$$

Heat absorbed by the electrolyte, H_e is

$$H_e = q \rho_e c_e (\theta_B - \theta_o)$$

- Neglecting all the heat losses

$$I^2 R = q \rho_e c_e (\theta_B - \theta_o)$$

Example

The electrochemical machining of an iron surface that is 25 mm × 25 mm in cross-section using NaCl in water as electrolyte. The gap between the tool and the workpiece is 0.25 mm. The supply voltage is 12 V DC. The specific resistance of the electrolyte is 3 Ω cm.

Estimate the electrolyte flow rate. Specific heat of the electrolyte is given as 0.997 cal/g°C. The ambient temperature is 35°C and the electrolyte boiling temperature, is 95°C.

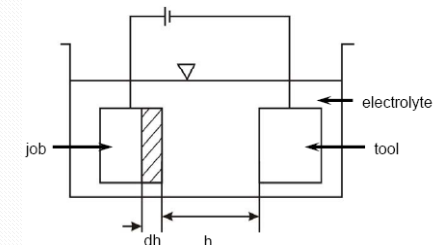
Density, $= 7860 \text{ kg/m}^3$

Overtoltage

- If the total over voltage at the anode and the cathode is ΔV and the applied voltage is V , the current I is given by,

$$I = \frac{V - \Delta V}{R}$$

Dynamics of Electrochemical Machining



- Schematic representation of the ECM process with no feed to the tool

Rev.0

Example

In ECM operation of pure iron an equilibrium gap of 2 mm is to be kept. Determine supply voltage, if the total overvoltage is 2.5 V. The resistivity of the electrolyte is 50 Ω -mm and the set feed rate is 0.25 mm/min.

GATE – 2007 (PI)

Which one of the following process conditions leads to higher MRR in ECM process?

- (a) higher current, larger atomic weight
- (b) higher valency, lower current
- (c) lower atomic weight, lower valency
- (d) higher valency, lower atomic weight

GATE – 2012 (PI) Linked S-1

In an EDM process using RC relaxation circuit, a 12 mm diameter through hole is made in a steel plate of 50 mm thickness using a graphite tool and kerosene as dielectric. Assume discharge time to be negligible. Machining is carried out under the following conditions:

Resistance	40 Ω
Capacitance	20 μ F
Supply voltage	220 V
Discharge voltage	110 V

The time for one cycle, in milliseconds, is

- (a) 0.55 (b) 0.32 (c) 0.89 (d) 0.24

GATE – 2012 (PI) Linked S-2

In an EDM process using RC relaxation circuit, a 12 mm diameter through hole is made in a steel plate of 50 mm thickness using a graphite tool and kerosene as dielectric. Assume discharge time to be negligible. Machining is carried out under the following conditions:

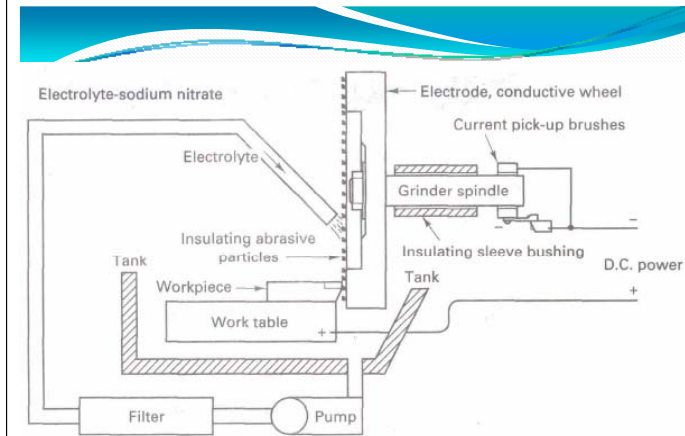
Resistance	40 Ω
Capacitance	20 μ F
Supply voltage	220 V
Discharge voltage	110 V

Average power input (in kW) is

- (a) 0.373 (b) 0.137 (c) 0.218 (d) 0.500

Electrochemical Grinding (ECG)

- In ECG, the tool electrode is a rotating, metal bonded, diamond grit grinding wheel.
- As the electric current flows between the workpiece and the wheel, through the electrolyte, the surface metal is changed to a metal oxide, which is ground away by the abrasives. As the oxide film is removed, new surface metal is oxidized and removed.
- ECG is a low-voltage high-current electrical process.
- The purpose of the abrasive is to increase the efficiency of the ECG process and permit the continuance of the process.
- The abrasive particles are always nonconductive material such as aluminum oxide, diamond, or borazon (CBN). Thus they act as an insulating spacer maintaining a separation of from 0.012 to 0.050 mm between the electrodes.



Equipment setup and electrical circuit for electrochemical grinding.

Electrochemical Grinding (ECG)

- The process is used for shaping and sharpening carbide cutting tools, which cause high wear rates on expensive diamond wheels in normal grinding. Electrochemical grinding greatly reduces this wheel wear.
- Fragile parts (honeycomb structures), surgical needles, and tips of assembled turbine blades have been ECG-processed successfully.
- The lack of heat damage, burrs, and residual stresses is very beneficial, particularly when coupled with MRRs that are competitive with conventional grinding but with far less wheel wear.

For-2015 (IES, GATE & PSUs)

IES - 2000

Consider the following statements:

In electrochemical grinding,

1. A rubber bonded alumina grinding wheel acts as the cathode and the workplace as the anode.
2. A copper bonded alumina grinding wheel acts as the cathode and the work piece as the anode.
3. Metal removal takes place due to the pressure applied by the grinding wheel.
4. Metal removal takes place due to electrolysis.

Which of these statements are correct?

- (a) 1 and 3 (b) 2 and 4
(c) 2 and 3 (d) 1 and 4

Other Electrochemical processes

- Electrochemical polishing
- Electrochemical hole-drilling
- Electrochemical Deburring

GATE - 2001

In ECM, the material removal is due to

- (a) Corrosion
- (b) Erosion
- (c) Fusion
- (d) Ion displacement

GATE - 1997

Selection electrolyte for ECM is as follows:

- (a) Non-passivating electrolyte for stock removal and passivating electrolyte for finish control
- (b) Passivating electrolyte for stock removal and non-passivating electrolyte for finish control
- (c) Selection of electrolyte is dependent on current density
- (d) Electrolyte selection is based on tool- work electrodes

GATE - 1992

The two main criteria for selecting the electrolyte in Electrochemical Machining (ECM) is that the electrolyte should

- (a) Be chemically stable
- (b) Not allow dissolution of cathode material
- (c) Not allow dissolution of anode material
- (d) Have high electrical conductivity

GATE - 1997

Inter electrode gap in ECG is controlled by

- (a) Controlling the pressure of electrolyte flow
- (b) Controlling the applied static load
- (c) Controlling the size of diamond particle in the wheel
- (d) Controlling the texture of the work piece

IES - 2002

Assertion (A): In ECM, the shape of the cavity is the mirror image of the tool, but unlike EDM, the tool wear in ECM is less.

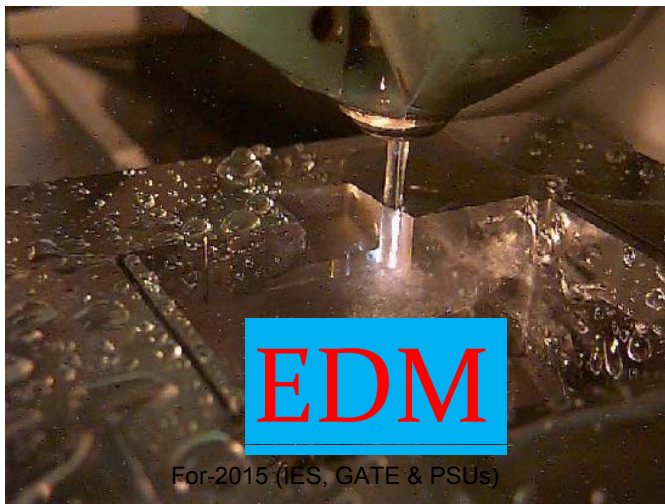
Reason (R): The tool in ECM is a cathode.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES - 1997

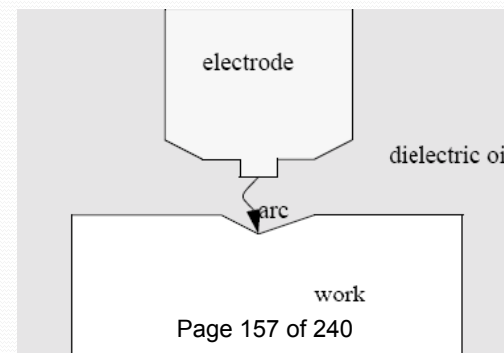
Which one of the following processes does not cause tool wear?

- (a) Ultrasonic machining
- (b) Electrochemical machining
- (c) Electric discharge machining
- (d) Anode mechanical machining



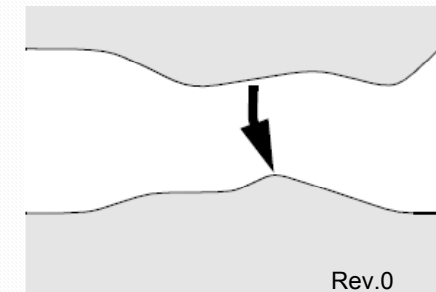
Physical Principle

- Basic process



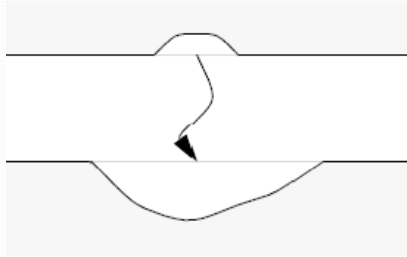
Physical Principle

- An arc jumps between two points along the path of least resistance.



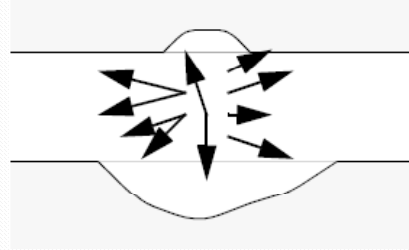
Physical Principle

- The energy of the arc is so concentrated that it causes the electrode, and the work to melt. But the electrode material is chosen so that it melts less.



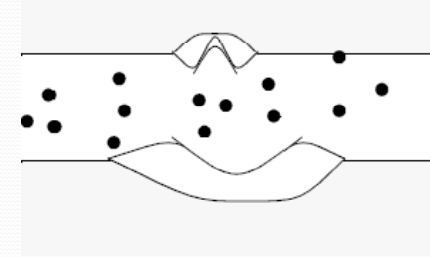
Physical Principle

- The metal and dielectric fluid is partly vaporized, causing sudden expansion.



Physical Principle

- The blast from the expanding vapors knocks some molten particles loose, and the remaining molten metal hardens.



Characteristics of EDM

- Mechanics of material removal** - melting and evaporation aided by cavitation.
- The process is based on melting temperature, not hardness, so some very hard materials can be machined this way.
- The arc that jumps heats the metal, and about 1 to 10% of the molten metal goes into the fluid. The melted metal then recast layer is about 1 to 30 μm thick, and is generally hard and rough.
- The electrode workpiece gap is in the range of 10 μm to 100 μm .

Characteristics of EDM

- Uses Voltage of 60 to 300 V to give a transient arc lasting from 0.1 μs to 8 ms.
- Typical cycle time is 20 ms or less, up to millions of cycles may be required for completion of the part.
- Rotating the wire in an orbital direction will,
 - Increase accuracy in form and surface finish
 - Decrease electrode wear
- Surface finish obtained 0.25 μm

EDM Tool

Prime requirements EDM tool Material

- It should be electrically conductive.
- It should have good machinability, thus allowing easy manufacture of complex shapes.
- It should have low erosion rate or good work to tool wear ratio.
- It should have low electrical resistance.
- It should have high melting point.
- It should have high electron emission.

EDM Tool

The usual choices for tool (electrode) materials are

- Copper,
- brass,
- alloys of zinc and tin,
- hardened plain carbon steel,
- copper tungsten,
- silver tungsten,
- tungsten carbide,
- copper graphite, and graphite.

Wear Ratio

- One major drawback of EDM is the wear that occurs on the electrode at each spark. Tool wear is given in terms of wear ratio which is defined as,

$$\text{Wear ratio} = \frac{\text{Volume of metal removed work}}{\text{Volume of metal removed tool}}$$

- Wear ratio for brass electrode is 1: 1. For most other metallic electrodes, it is about 3: 1 or 4: 1.
- With graphite (with the highest melting point, 3500°C), the wear ratio may range from 5: 1 up to 50: 1.

Servo-Mechanism

- The gap between the tool and work has a critical importance. As the workpiece is machined, this gap tends to increase. For optimum machining efficiency, this gap should be maintained constant. This is done by servo- mechanism which controls the movement of the electrode.

Dielectric Fluid

- Fluid is used to act as a dielectric, and to help carry away debris.
- If the fluid is pumped through and out the end of the electrode, particles will push out, and mainly collect at the edges. They will lower the dielectric resistance, resulting in more arcs. As a result the holes will be conical.
- If fluid is vacuum pumped into the electrode tip, straight holes will result.
- **Quite often kerosene-based oil.**
- The dielectric fluid is circulated through the tool at a pressure of 0.35 N/m² or less. To free it from eroded metal particles, it is circulated through a filter.

IES 2011 Conventional

Discuss the effects of insufficient dielectric and electrolyte circulation in the inter-electrode gap on the Electric Discharge machining and Electro Chemical Machining process respectively. [5 Marks]

Relaxation circuit

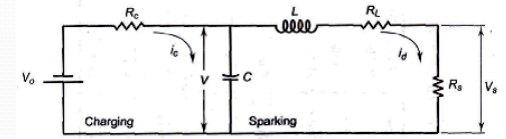


Fig-Relaxation circuit used for generating the pulses in EDM process

$$V_c = V_0 \left(1 - e^{-\frac{t}{R_0 C}}\right)$$

The time constant, τ of the circuit is given by

$$\tau = R_0 \times C$$

Charging current can then be specified by

$$i_c = \frac{V_0}{R_0} e^{-\frac{t}{\tau}}$$

For maximum power

$$V_c = 0.72 \times V_0$$

Advantages

1. Hardness, toughness or brittleness of the material poses no problems. Due to this EDM can be used for machining materials that are too hard or brittle to be machined by conventional methods.
2. The method does not leave any chips or burrs on the work piece.
3. Cutting forces are virtually zero, so very delicate and fine work can be done.
4. The process dimension repeatability and surface finish obtained in finishing are extremely good.
5. The characteristic surface obtained, which is made up of craters, helps in better oil retention. This improves die life.
6. Because the forces between the tool and the workpiece and virtually zero, very delicate work can be done.

Disadvantages

1. Only electrically conductive materials can be machined by EDM. Thus non - metallic, such as plastics, ceramics or glass, cannot be machined by EDM.
2. Electrode wear and over-cut are serious problems.
3. A re-hardened, highly stressed zone is produced on the work surface by the heat generated during machining. This brittle layer can cause serious problems when the part is put into service.
4. Perfectly square corners cannot be made by EDM.
5. High specific energy consumption (about 50 times that in conventional machining)
6. MRR is quite low

Applications

- EDM can be used for machining any material that is electrically conductive, thus including metals, alloys and most carbides.
- EDM is widely used for machining burr free intricate shapes, narrow slots and blind cavities etc., for example, sinking of dies for moulding, die casting, plastic moulding, wire drawing, compacting, cold heading, forging, extrusion and press tools.

Applications

- EDM is particularly useful when dealing with internal cuts that are hard to get tools into. Machining tends to work best with external cuts.
- Almost any geometry (negative of tool geometry) can be generated on a workpiece if a suitable tool can be fabricated (the use of punch as a tool to machine its own mating die is commonly employed in EDM method).

Applications

- The method is also employed for blanking parts from sheets, cutting off rods of materials, flat or form grinding and sharpening of tools, cutters and broaches.
- **In EDM method, small holes, about 0.13 mm, in diameter and as deep as 20mm diameters can be drilled with virtually no bending or drifting of hole.** Due to this, EDM is particularly useful for machining of small holes, orifices or slots in diesel-fuel injection nozzles, or in aircraft engines, air brake valves and so on.

IES 2009 Conventional

- i. What is the principle of metal removal in EDM process?
- ii. Describe the process with the help of sketch.
- iii. List advantages and limitations of the system.

[15 marks]

GATE - 1994

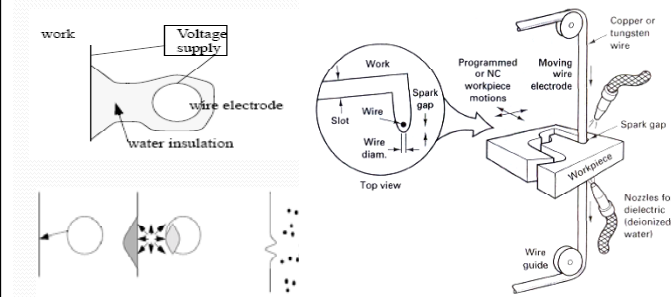
Electric discharge machining is more efficient process than Electrochemical machining for producing large non-circular holes.

The above statement is

- (a) True
- (b) False
- (c) Cant say
- (d) Insufficient data

Wire EDM

- Wire EDM is a special form of EDM wherein the electrode is a continuously moving conductive wire.
- A thin wire of brass, tungsten, or copper is used as an electrode.
- The electrode wire is typically made with a 0.05 to 0.25-mm diameter, which is wire electrode wound between the two spools.
- **Deionized water is used as the dielectric.**



Wire EDM

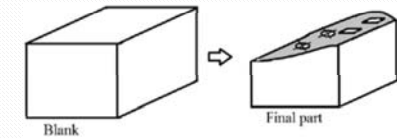
- This process is much faster than electrode EDM.
- This process is widely used for the manufacture of punches, dies, and stripper plates, with modern machines capable of cutting die relief, intricate openings, tight radius contours, and corners routinely.



- Geometrically accurate but moderately finished straight toothed metallic spur gears, both external and internal type, can be produced by wire type Electro discharge Machining (EDM).

GATE-2014 (PI)

Find the correct combination of manufacturing processes to produce the part, shown in figure, from a blank (holes shown are with square and circular cross-sections)



- (a) Drilling and milling on column and knee type universal milling machine
- (b) Die-sinking and CNC Wire-cut EDM process
- (c) Die-sinking and CNC drilling
- (d) CNC Wire-cut EDM process only

Electric Discharge Grinding (EDG)

- EDG is similar to EDM except that the electrode is a rotating wheel (usually graphite).
- Positively charged work pieces are immersed in or flooded by a dielectric fluid and fed past the negatively charged wheel by servo-controlled machine table.
- Metal is removed by intermittent high frequency electrical discharges passing through the gap between wheel and workpiece.
- Each spark discharge melts or vaporizes a small amount of metal from the workpiece surface, producing a small crater at the discharge site, as in EDM.

For-2015 (IES, GATE & PSUs)

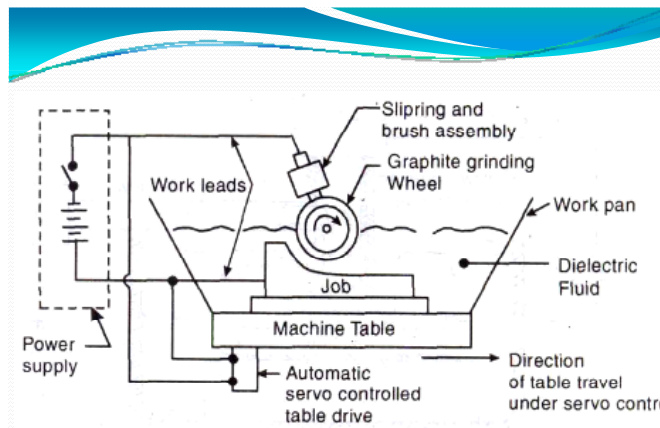


Fig- Electric Discharge Grinding (EDG)

Electric Discharge Grinding (EDG)

- The spark gap is normally held at 0.013 to 0.076 mm
 - The graphite wheel is rotated at 0.5 to 3 m/s
- The method can be used for**
1. External cylindrical grinding, internal grinding and surface grinding.
 2. Grinding carbide and steel at the same time without wheel loading.
 3. Grinding thin sections where abrasive wheel pressures might cause distortion.
 4. Grinding brittle materials or fragile parts where abrasive materials might cause fracturing.

Rev9.

IES - 2012

Statement (I): In Electro Discharge Machining (EDM) process, tool is made cathode and work piece anode

Statement (II): In this process if both electrodes are made of same material, greatest erosion takes place upon anode

(a) Both Statement (I) and Statement (II) are individually true and Statement (II) is the correct explanation of Statement (I)

(b) Both Statement (I) and Statement (II) are individually true but Statement (II) is not the correct explanation of Statement (I)

(c) Statement (I) is true but Statement (II) is false

(d) Statement (I) is false but Statement (II) is true

GATE - 2004

The mechanism of material removal in EDM process is

- (a) Melting and Evaporation
- (b) Melting and Corrosion
- (c) Erosion and Cavitation
- (d) Cavitation and Evaporation

GATE - 2003

As tool and work are not in contact in EDM process

- (a) No relative motion occurs between them
- (b) No wear of tool occurs
- (c) No power is consumed during metal cutting
- (d) No force between tool and work occurs

GATE - 1999

In Electro-Discharge Machining (EDM), the tool is made of

- (a) Copper
- (b) High Speed Steel
- (c) Cast Iron
- (d) Plain Carbon Steel

GATE-2010 (PI)

Keeping all other parameters unchanged, the tool wear in electrical discharge machining (EDM) would be less if the tool material has

- (a) high thermal conductivity and high specific heat
- (b) high thermal conductivity and low specific heat
- (c) low thermal conductivity and low specific heat
- (d) low thermal conductivity and high specific heat

GATE - 2007

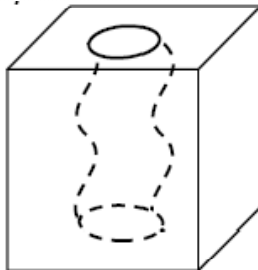
In electro discharge machining (EDM), if the thermal conductivity of tool is high and the specific heat of work piece is low, then the tool wear rate and material removal rate are expected to be respectively

- (a) High and high
- (b) Low and low
- (c) High and low
- (d) Low and high

GATE - 2005

A zigzag cavity in a block of high strength alloy is to be finish machined. This can be carried out by using

- (a) Electric discharge machining
- (b) Electro-chemical machining
- (c) Laser beam machining
- (d) Abrasive flow machining



IES - 2005

Which of the following is/are used as low wearing tool material(s) in electric discharge machining?

- (a) Copper and brass
- (b) Aluminium and graphite
- (c) Silver tungsten and copper tungsten
- (d) Cast iron

GATE- 2000

Deep hole drilling of small diameter, say 0.2 mm is done with EDM by selecting the tool material as

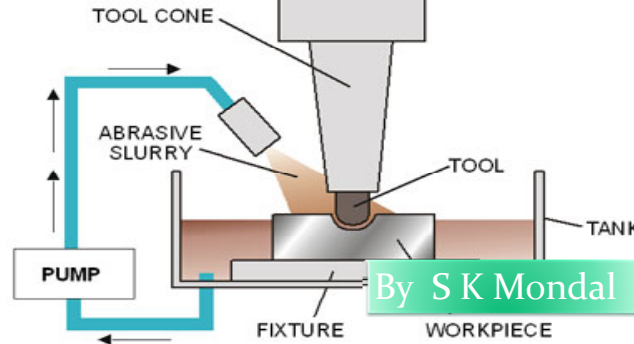
- (a) Copper wire
- (b) Tungsten wire
- (c) Brass wire
- (d) Tungsten carbide

GATE – 2009 (PI)

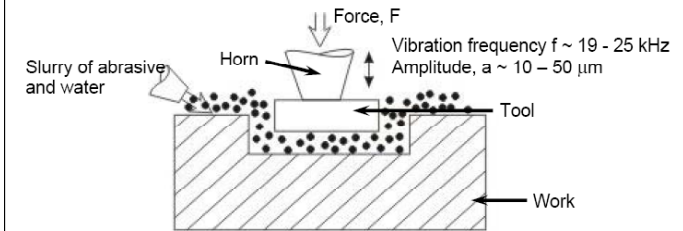
A titanium sheet of 5.0 mm thickness is cut by wire – cut EDM process using a wire of 1.0 mm diameter. A uniform spark gap of 0.5 mm on both sides of the wire is maintained during cutting operation. If the feed rate of the wire into the sheet is 20 mm/min, the material removal rate (in mm³/min) will be

- (a) 150 (b) 200 (c) 300 (d) 400

Ultrasonic Machining



Ultrasonic Machining

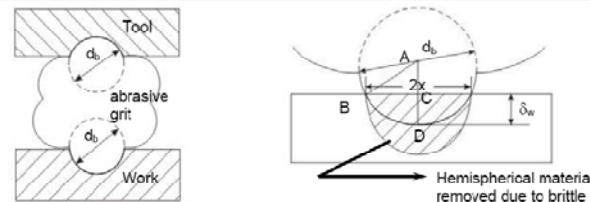


Ultrasonic Machining

- In ultrasonic machining, a tool of desired shape vibrates at an ultrasonic frequency (19 ~ 25 kHz) with an amplitude of around 15 ~ 50 μm over the workpiece.
- Generally the tool is pressed downward with a feed force, F. Between the tool and workpiece, the machining zone is flooded with hard abrasive particles generally in the form of water based slurry.
- As the tool vibrates over the workpiece, the abrasive particles act as the indenters and indent both the work material and the tool. The abrasive particles, as they indent, the work material, would remove the same, particularly if the work material is brittle, due to crack initiation, propagation and brittle fracture of the material.

Ultrasonic Machining

- USM is mainly used for machining brittle materials {which are poor conductors of electricity and thus cannot be processed by Electrochemical and Electro-discharge machining (ECM and EDM)}.



Ultrasonic Machining

- At full indentation, the indentation depth in the work material is characterized by δ_w . Due to the indentation, as the work material is brittle, brittle fracture takes place leading to hemi-spherical fracture of diameter '2x' under the contact zone.
- If at any moment of time, there are an average 'n' of grits and the tool is vibrating at a frequency 'f' then material removal rate can be expressed as

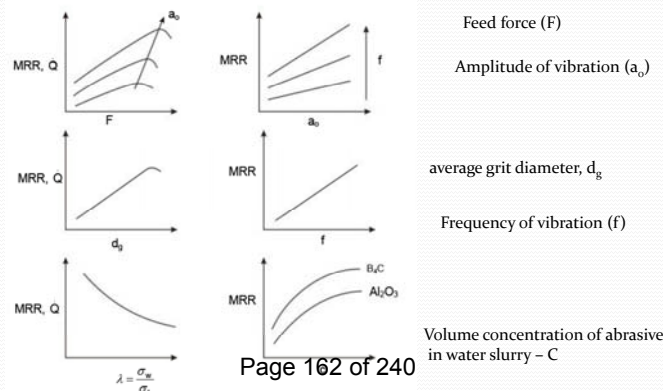
$$MRR_w = \frac{2}{3} \pi (\delta_w d_b)^{3/2} n f$$

Process Parameters

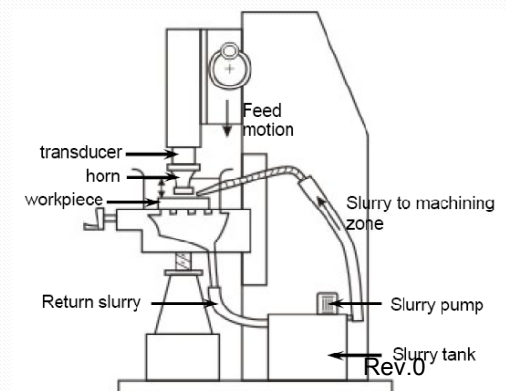
- Amplitude of vibration (a_o) – 15 – 50 μm
- Frequency of vibration (f) – 19 – 25 kHz
- Feed force (F) – related to tool dimensions
- Feed pressure (p)
- Abrasive size – 15 μm – 150 μm
- Abrasive material – Al_2O_3
 - SiC
 - B_4C
 - Boronsilicarbide
 - Diamond

For-2015 (IIT, GATE & PSUs)

Effect of machining parameters on MRR



Ultrasonic Machine



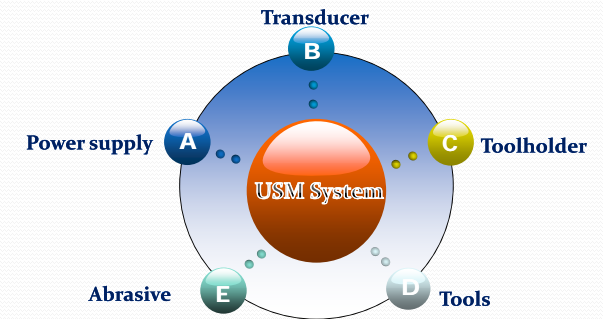
Ultrasonic Machine

- The basic mechanical structure of an USM is very similar to a drill press.
- It has additional features to carry out USM of brittle work material.
- The workpiece is mounted on a vice, which can be located at the desired position under the tool using a 2 axis table.
- The table can further be lowered or raised to accommodate work of different thickness.
- Slurry delivery and return system

Ultrasonic Machine

- Feed mechanism to provide a downward feed force on the tool during machining
- The transducer, which generates the ultrasonic vibration
- The horn or concentrator, which mechanically amplifies the vibration to the required amplitude of 15 – 50 μm and accommodates the tool at its tip.

Subsystems of USM



Transducer

- The ultrasonic vibrations are produced by the transducer. The transducer is driven by suitable signal generator followed by power amplifier. The transducer for USM works on the following principle
 - Piezoelectric effect
 - Magnetostrictive effect
 - Electrostrictive effect
- Magnetostrictive transducers are most popular and robust amongst all.

GATE -2010 (PI)

Ultrasonic machines, used in material removal processes, require ultrasonic transducers. The transducers work on different working principles. One of the working principles of such ultrasonic transducers is based on

- | | |
|----------------------------|---------------------------|
| (a) eddy current effect | (b) Seebeck effect |
| (c) piezo-resistive effect | (d) piezo-electric effect |

Tool holder or Horn

- Its function is to increase the tool vibration amplitude and to match the vibrator to the acoustic load.
- It must be constructed of a material with good acoustic properties and be highly resistant to fatigue cracking.
- Monel and titanium have good acoustic properties and are often used together with stainless steel, which is cheaper.

Tool

- Tools should be constructed from relatively ductile materials.
- The harder the tool material, the faster its wear rate will be.

Limitations

- Low MRR
- Rather high tool wear
- Low depth of hole

Applications

- Used for machining hard and brittle metallic alloys, semiconductors, glass, ceramics, carbides etc.
- Used for machining round, square, irregular shaped holes and surface impressions.
- Machining, wire drawing, punching or small blanking dies.

Note

- The following material is generally machined by USM
 - (i) Glass
 - (ii) Silicon
 - (iii) Germanium
- Tool in USM is generally made of Steel

GATE - 1994

Ultrasonic machining is about the best process for making holes in glass which are comparable in size with the thickness of the sheet.

The above statement is

- (a) True
- (b) False
- (c) Cant say
- (d) Insufficient data

IES 2011

USM has good machining performance for :

- (a) Al
- (b) Steel
- (c) Super alloys
- (d) Refractory material

GATE - 1993

In ultrasonic machining process, the material removal rate will be higher for materials with

- (a) Higher toughness
- (b) Higher ductility
- (c) Lower toughness
- (d) Higher fracture strain

GATE - 1992

In Ultrasonic Machining (USM) the material removal rate would

- (a) Increase
- (b) Decrease
- (c) Increase and then decrease
- (d) decrease and then increase

with increasing mean grain diameter of the abrasive material.

IES - 2009

By which one of the following processes the metering holes in injector nozzles of diesel engines can be suitably made?

- (a) Ultrasonic machining
- (b) Abrasive jet machining
- (c) Electron beam machining
- (d) Chemical machining

IES - 2006

During ultrasonic machining, the metal removal is achieved by

- (a) High frequency eddy currents
- (b) high frequency sound waves
- (c) Hammering action of abrasive particles
- (d) Rubbing action between tool and workpiece

IAS - 1996

During ultrasonic machining, the metal removal is affected by the

- (a) Hammering action of abrasive particles
- (b) Rubbing action between tool and workpiece
- (c) High frequency sound waves
- (d) High frequency eddy currents

Chemical Machining

- Chemicals are used to dissolve material
- Masks are used to control attack
- Most common use is circuit boards and plates for printing.
- Cutting speed of 0.0025-0.1 mm/minute – very slow

Chemical Machining

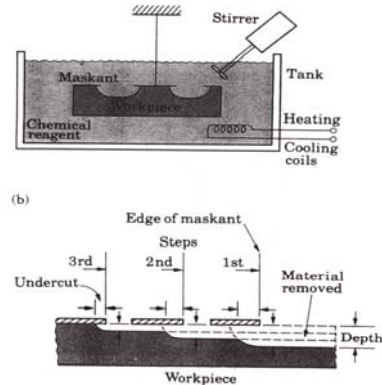
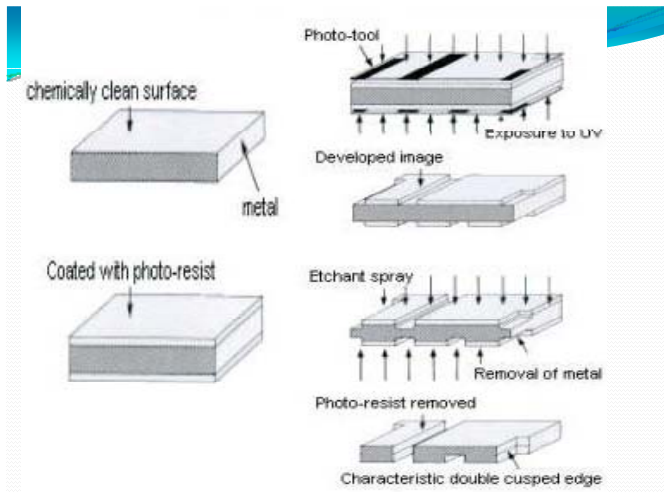
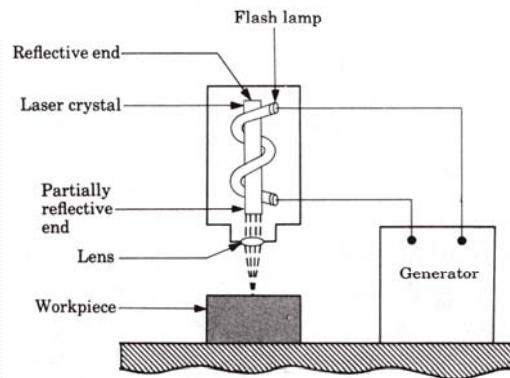


Photo-Chemical Machining

- PCM is a material removal process using chemicals (etchants) to produce high precision parts.
- This process is also known as Photo Etching, Chemical Blanking and Photo Chemical Milling.
- Coat both sides of the plate with photoresist. (photoresist is a polymer that adheres to the metal when exposed to UV light).
- Spray metal with etchant or dip it in hot acidic solution to etch all material other than part covered with photoresist (1-15 min.).
- Rinse the plate to ensure photoresist and etchant removal.



Laser Beam Machining



Laser Beam Machining

- Direct laser beam against surface of workpiece, as in laser welding
- Successive pulses from laser gun vaporize tiny bits of workpiece
- Location of laser beam controlled by computer
- Workpiece need not be conductive
- Cuts are tapered
- Gotta trap overshoot from laser beam

Laser Beam Machining

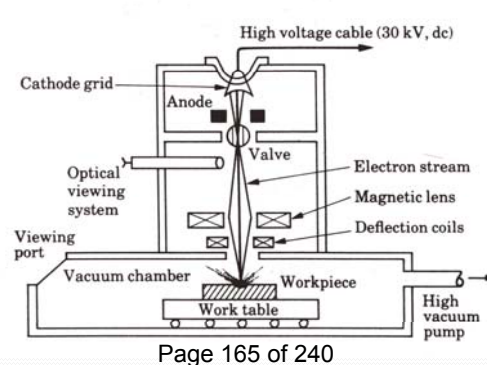
- Produces large remelt zone
- Can produce holes as small as 0.0005 mm diameter
- Can produce deep holes
- Used to produce cooling holes in blades/vanes for jet engines

Electron Beam Machining

- Workpiece placed in vacuum chamber
- High-voltage electron beam directed toward workpiece
- Energy of electron beam melts/ vaporizes selected region of workpiece
- Electron beam moved by deflection coils
- Similar process to EB welding

For-2015 (IES, GATE & PSUs)

Electron Beam Machining



IFS-2011

Write the advantages, limitations and applications of electron beam machining. What is the safety problem connected with EBM?

[5-Marks]

Rev.0

Plasma Arc Cutting

- Plasma is a stream of ionized gas
- Typical temperatures are very high
- Same process as plasma welding, without filler metal
- Torch movement controlled by computer
- Power requirements depend on material being cut, plus depth of cut
- Recast layer is deeper than with other processes

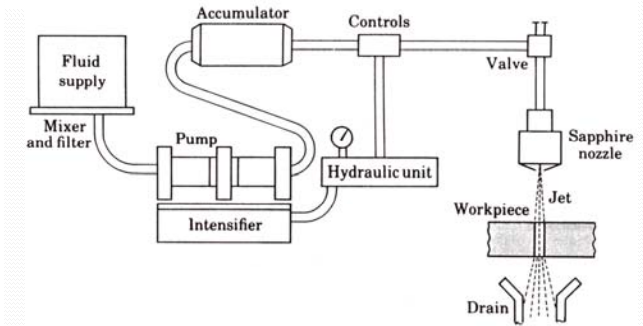
316

Water Jet Machining

- Narrow jet of water directed, at high pressure and velocity, against surface of workpiece
- Jet of water erodes surface of workpiece, thereby cutting workpiece
- Computer control to achieve shape

317

Water Jet Machining



318

Abrasive Jet Machining (Dry)

- It is similar to sand blasting, except that a very narrow jet of gas and abrasive particles achieves localized cutting.
- It removes material through the eroding action of a high velocity stream of abrasive-laden gas.
- The gas is first compressed and mixed with the abrasive powder in a mixing chamber and passed through outlet nozzle.
- Computer is used to position the jet.
- Gas Pressure about 7 atm
- Velocity of jet about 300 m/s
- Jet Diameter 0.12 mm to 1.25 mm
- Abrasive used: Al_2O_3 , SiC with particle size 10 to 50 μm
- Tool (nozzle) material – tungsten carbide or sapphire
- Tool (nozzle) Life – about 30 hours

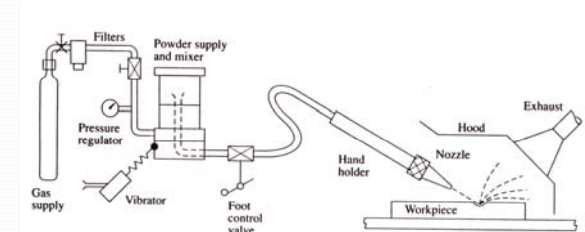
319

GATE-2013 (PI)

In water jet machining, the water jet is issued through a 0.3 mm diameter orifice at a pressure of 400 MPa. The density of water is 1000 kg/m^3 . The coefficient of discharge is 1.0. Neglecting all losses during water jet formation through the orifice, the power of the water jet in KW is

- (a) 25.3 (b) 50.6 (c) 75.9 (d) 101.2

Abrasive Jet Machining



321

Advantages of AJM

- Can be used in any material, conductive, non-conductive, ductile or brittle
- Good dimensional accuracy ($\pm 0.05 \text{ mm}$)
- Good Surface finish – 0.25 to 1.25 μm
- Due to cooling action of gas stream no thermal damage on the work surface
- Due to negligible force delicate workpiece can be machined. For-2015 (IES, GATE & PSUs)

Disadvantages of AJM

- Low MRR
- Possibility of stray cutting
- Embedding of abrasive particles in soft workpiece
- Dust control needed

Application of AJM

- Cutting and drilling on metal foils and thin sections of ceramics and glass
- Intricate holes in electronic components such as resistor paths in insulation
- Engraving of characters on toughened glass automobile windows
- Cleaning, polishing and deburring the surface

GATE -2012 Same Q in GATE-2012 (PI)

In abrasive jet machining, as the distance between the nozzle tip and the work surface increases, the material removal rate

- (a) increases continuously.
- (b) decreases continuously.
- (c) decreases, becomes stable and then increases.
- (d) increases, becomes stable and then decreases.

GATE-2014 (PI)

A hard ceramic marble, having density (ρ) of 3000 kg/m³ and diameter (d) of 0.025 m, is dropped accidentally from a static weather balloon at a height of 1 km above the roof of a greenhouse. The flow stress of roof material (σ) is 2.5 GPa. The marble hits and creates an indentation on the roof. Assume that the principle of creation of indentation is the same as that in case of abrasive jet machining (AJM). The acceleration due to gravity (g) is 10 m/s². If V is the velocity, in m/s, of the marble at the time it hits the greenhouse, the indentation depth $\left(\delta = 1000 \times \sqrt{\frac{\rho}{6\sigma}} \times d \times V \right)$, in mm, is.....

IAS-2011 Main

State the mechanism of cutting by abrasive jet.

What are the advantages and disadvantages of AJM ? Mention two applications.

[10-Marks]

IFS-2011

What are the disadvantages of abrasive jet machining?
Write some of its applications.

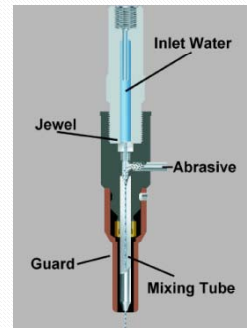
[5-Marks]

Abrasive WJ Cutting

- Used to cut much harder materials
- Water is not used directly to cut material as in Pure, instead water is used to accelerate abrasive particles which do the cutting
- 80-mesh garnet (sandpaper) is typically used though 50 and 120-mesh is also used
- Standoff distance between mixing tube and workpart is typically 0.010-0.200 – important to keep to a minimum to keep a good surface finish

Abrasive WJ Cutting

- Evolution of mixing tube technology
- Standard Tungsten Carbide lasts 4-6 hours (not used much anymore)
- Premium Composite Carbide lasts 100-150 hours
- Consumables include water, abrasive, orifice and mixing tube



GATE - 1992

Match the following components with the appropriate machining processes:

Component	Process
(A) Square hole in a high strength alloy	(1) Milling
(B) Square hole in a ceramic component	(2) Drilling
(C) Blind holes in a die	(3) ECM
(D) Turbine blade profile on high strength alloy	(4) Jig boring
	(5) EDM
	(6) USM

Codes:	A	B	C	D	A	B	C	D	
(a)	4	1	2	3	(b)	5	6	1	3
(c)	4	2	3	1	(d)	6	1	2	4

GATE 2011

Match the following non – traditional machining processes with the corresponding material removal mechanism:

Machining process	Mechanism of material removal
P. Chemical machining	1. Erosion
Q. Electro – chemical machining	2. Corrosive reaction
R. Electro – discharge machining	3. Ion displacement
S. Ultrasonic machining	4. Fusion and vaporization

- (a) P – 2, Q – 3, R – 4, S – 1 (b) P – 2, Q – 4, R – 3, S – 1
(c) P – 3, Q – 2, R – 4, S – 1 (d) P – 2, Q – 3, R – 1, S – 4

GATE - 2007

Match the most suitable manufacturing processes for the following parts.

Parts	Manufacturing Processes
P. Computer chip	1. Electrochemical Machining
Q. Metal forming dies and moulds	2. Ultrasonic Machining
R. Turbine blade	3. Electro-discharge Machining
S. Glass	4. Photochemical Machining

Codes:	P	Q	R	S	P	Q	R	S	
(a)	4	3	1	2	(b)	4	3	2	1
(c)	3	1	4	2	(d)	1	2	4	3

GATE - 1998

List I

- (A) ECM
(B) EDM
(C) USM
(D) LBM

List II

- (1) Plastic shear
(2) Erosion/Brittle fracture
(3) Corrosive reaction
(4) Melting and vaporization
(5) Ion displacement
(6) Plastic shear and ion displacement

Codes:	A	B	C	D		A	B	C	D
(a)	4	1	2	3	(b)	5	4	2	4
(c)	4	2	1	3	(d)	3	1	2	4

IES - 2008

Match List-I with List-II and select the correct answer using the code given below the lists:

List-I

(Unconventional machining process)

- A. Electro polishing
B. Electrochemical machining
C. Abrasive jet machining
D. Electrical discharge machining

List-II

(Basic process)

1. Thermal
2. Mechanical
3. Electrochemical
4. Chemical

Code:A	B	C	D		A	B	C	D	
(a)	4	3	2	1	(b)	2	1	4	3
(c)	4	1	2	3	(d)	2	3	4	1

IES – 1998, ISRO-2009

Match List-I (Machining process) with List-II (Associated medium) and select the correct answer using the codes given below the lists:

List-I

- A. Ultrasonic machining
B. EDM
C. ECM
D. EBM

List-II

1. Kerosene
2. Abrasive slurry
3. Vacuum
4. Salt solution

Code:A	B	C	D		A	B	C	D	
(a)	2	3	4	1	(b)	2	1	4	3
(c)	4	1	2	3	(d)	4	3	2	1

IES - 2005

Match List I (Machining Process) with List II (Application) and select the correct answer using the code given below the Lists:

List I

- A. EDM 1. Holes & cavities in hard & brittle materials
B. LBM 2. Micro-drilling & micro-welding of materials
C. USM 3. Shaping of hard metals or reshaping of cemented carbide tools
D. ECM 4. Shaping of cemented carbide dies and punches

Codes:	A	B	C	D		A	B	C	D
(a)	4	1	2	3	(b)	3	2	1	4
(c)	4	2	1	3	(d)	3	1	2	4

IES - 2003

Match List I (Materials) with List II (Machining) and select the correct answer using the codes given below the Lists:

List I

(Materials)

- A. Machining of conducting materials
B. Ruby rod
C. Electrolyte
D. Abrasive slurry

List II

(Machining)

1. ECM
2. EDM
3. USM
4. LBM

Codes:	A	B	C	D		A	B	C	D
(a)	4	2	1	3	(b)	4	2	3	1
(c)	2	4	3	1	(d)	2	4	1	3

IES - 2003

Assertion (A): Water jet machining uses high pressure and high velocity water stream which acts like a saw and cuts a narrow groove in the material.

Reason (R): The force required for cutting is generated from sudden change in the momentum of the water stream.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS - 2002

Which one of the following pairs is NOT correctly matched?

(Unconventional machining method)

- (a) Electric discharge : Machining of electrically conductive materials
(b) Laser beam : Micromachining
(c) Plasma arc : Faster cutting of hard materials
(d) Electron beam : Faster metal removal rate

For-2015 (IES, GATE & PSUs)

IAS - 1999

Match List I (Unconventional machining process) with List II (Typical application) and select the correct answer using the codes given below the lists:

List I

- A. Electro discharge machining
B. Electro chemical machining
C. Ultrasonic machining
D. Laser beam machining

List II

1. Drilling micro holes in very hard metals
2. Drilling holes in glass
3. Die sinking
4. Machining contours

Codes:	A	B	C	D	A	B	C	D	
(a)	4	2	3	1	(b)	3	4	1	2
(c)	4	3	2	1	(d)	3	4	2	1

IES - 2004

Match List I (Machining processes) with List II (Operating media) and select the correct answer using the codes given below the Lists:

List I

- A. Abrasive jet machining
B. Electron beam machining
C. Electro-chemical machining
D. Electro-discharge machining

List II

1. Dielectric
2. Electrolyte
3. Abrasive slurry
4. Vacuum
5. Air

Codes:	A	B	C	D		A	B	C	D
(a)	5	4	2	1	(b)	4	5	2	1
(c)	4	2	3	5	(d)	2	5	3	4

Rev.0

IES - 1999

Match List-I with List-II and select the correct answer using the codes given below the Lists:

List-I

- A. Die sinking
- B. Debarring
- C. Fine hole drilling (thin materials)
- D. Cutting/sharpening hard materials

List-II

- 1. Abrasive jet machining
- 2. Laser beam machining
- 3. EDM
- 4. Ultrasonic machining
- 5. Electrochemical grinding

Code:	A	B	C	D	A	B	C	D
(a)	3	5	4	1	(b)	2	4	1
(c)	3	1	2	5	(d)	4	5	1

GATE - 2004

Typical machining operations are to be performed on hard-to-machine materials by using the processes listed below. Choose the best set of Operation-Process combinations

Operation

- P. Debarring (internal surface)
- Q. Die sinking
- R. Fine hole drilling in thin sheets
- S. Tool sharpening

Process

- 1. Plasma Arc Machining
- 2. Abrasive Flow Machining
- 3. Electric Discharge Machining
- 4. Ultrasonic Machining
- 5. Laser beam Machining
- 6. Electrochemical Grinding

- (a) P-1 Q-5 R-3 S-4
- (b) P-1 Q-4 R-1 S-2
- (c) P-5 Q-1 R-2 S-6
- (d) P-2 Q-3 R-5 S-6

Basic Concepts (Structure of Solids)

Crystal Structure of materials

- FCC: Ni, Cu, Ag, Pt, Au, Pb, Al (soft)
- BCC: V, Mo, Ta, W (hard material)
- HCP: Mg, Zn
- Cobalt HCP < 420°C, FCC > 420°C
- Chromium HCP < 20°C, BCC > 20°C
- Glass- Amorphous
- BCC-Ferrite or α iron & δ -ferrite or δ -iron
- FCC- Austenite or γ -iron

GATE 2011

The crystal structure of austenite is

- body centered cubic
- face centered cubic
- hexagonal closed packed
- body centered tetragonal

IES 2011

Match List –I with List –II and select the correct answer using the code given below the lists :

List –I	List –II
A. Alpha iron	1. FCC
B. Zinc	2. BCC
C. Glass	3. HCP
D. Copper	4. Amorphous

Codes

A	B	C	D	A	B	C	D
(a) 1	4	3	2	(b) 2	4	3	1
(c) 1	3	4	2	(d) 2	3	4	1

IES-2003

Match List-I (Crystal Structure) with List-II (Example) and select the correct answer using the codes given below the Lists:

List-I (Crystal Structure)	List-II (Example)
A. Simple Cubic	1. Zinc
B. Body-centered Cubic	2. Copper
C. Face-centered Cubic	3. Alpha iron at room temperature
D. Hexagonal Close Packed	4. Manganese

Codes:	A	B	C	D	A	B	C	D	
(a)	4	3	1	2	(b)	4	3	2	1
(c)	3	4	2	1	(d)	3	4	1	2

IES-1998

Match List-I with List-II and select the correct answer using the codes given below the lists:

List-I (Material)	List-II (Structure)
A. Charcoal	1. F.C.C
B. Graphite	2. H.C.P
C. Chromium	3. Amorphous
D. Copper	4. B.C.C

Code:	A	B	C	D		A	B	C	D
(a)	3	2	1	4	(b)	3	2	4	1
(c)	2	3	4	1	(d)	2	3	1	4

IES-2001

Match List-I (Name of the Element) with List-II (Crystal Structure) and select the correct answer using the codes given below the lists:

List I	List II
A. Fluorspar	1. Body-centered cubic
B. Alpha-Iron	2. Hexagonal closed packed
C. Silver	3. Simple cubic
D. Zinc	4. Face-centered cubic

Codes:	A	B	C	D		A	B	C	D
(a)	3	2	4	1	(b)	4	1	3	2
(c)	4	2	3	1	(d)	3	1	4	2

IES-2006

Match List-I (Element) with List-II (Crystal Structure) and select the correct answer using the code given below the Lists:

List - I	List - II
A. Alpha Iron	1.Hexagonal closed packed
B. Copper	2.Body-centred cubic
C. Zinc	3.Amorphous
D. Glass	4.Face-centred cubic

Codes:	A	B	C	D		A	B	C	D
(a)	2	3	1	4	(b)	1	4	2	3
(c)	2	4	1	3	(d)	1	3	2	4

Plastic deformation

Following the elastic deformation, material undergoes plastic deformation.

- Also characterized by relation between stress and strain at constant strain rate and temperature.
- Microscopically, it involves breaking atomic bonds, moving atoms, then restoration of bonds.
- Stress-Strain relation here is complex because of atomic plane movement, dislocation movement, and the obstacles they encounter.
- Crystalline solids deform by processes – **slip and twinning** in particular directions.

- Amorphous solids deform by viscous flow mechanism without any directionality.
- Because of the complexity involved, theory of plasticity neglects the following effects:
 - Anelastic strain, which is time dependent recoverable strain.
 - Hysteresis behavior resulting from loading and unloading of material.
 - Bauschinger effect – dependence of yield stress on loading path and direction.
- Equations relating stress and strain are called *constitutive equations*.

Contd...

- A true stress-strain curve is called *flow curve* as it gives the stress required to cause the material to flow plastically to certain strain.
- Because of the complexity involved, there have been many stress-strain relations proposed.

$$\sigma = f(n, \epsilon, T, \text{microstructure})$$

$$\sigma = K\epsilon^n \quad \text{Strain hardening exponent, } n = 0.1 - 0.5$$

$$\sigma = K\dot{\epsilon}^m \quad \text{Strain - rate sensitivity, } m = 0.4 - 0.9$$

$$\sigma = K(\epsilon_0 + \epsilon)^n \quad \text{Strain from previous work - } \epsilon_0$$

$$\sigma = \sigma_0 + K\epsilon^n \quad \text{Yield strength - } \sigma_0$$

Slip

- Slip is the prominent mechanism of plastic deformation in metals.
- It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes.
- In physical words it is analogous to a deck of cards when it is pushed from one end.
- Slip occurs when shear stress applied exceeds a critical value.
- During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same.
- Steps observable under microscope as straight lines are called slip lines.

Twinning

- The second important mechanism of plastic deformation is twinning.
- It results when a portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way.
- The twinned portion of the crystal is a mirror image of the parent crystal. The plane of symmetry is called twinning plane.
- Each atom in the twinned region moves by a homogeneous shear a distance proportional to its distance from the twin plane.
- The lattice strains involved in twinning are small, usually in order of fraction of inter-atomic distance, thus resulting in very small gross plastic deformation.

Contd...

- The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.
- Twinning generally occurs when slip is restricted, because the stress necessary for twinning is usually higher than that for slip.
- Thus, some HCP metals with limited number of slip systems may preferably twin.
- Also, BCC metals twin at low temperatures because slip is difficult.
- Of course, twinning and slip may occur sequentially or even concurrently in some cases.

IES 2007

What is the movement of block of atoms along certain crystallographic planes and directions, termed as?

- Glide
- Twinning
- Slip
- Jog

IES-2005

The B.C.C. and H.C.P. metals undergo plastic deformation by:

- Slip
- Twinning
- Edge dislocation
- Twinning in combination with slip

IES-1998

Assertion (A): Plastic deformation in metals and alloys is a permanent deformation under load. This property is useful in obtaining products by cold rolling.

Reason (R): Plastic or permanent deformation in metal or alloy is caused by movement or dislocations.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is not the correct explanation of A
- A is true but R is false
- A is false but R is true

Atomic Structure

- Atoms consist of a relatively dense nucleus composed of positively charged protons and neutral particles of nearly identical mass, known as neutrons.
- Surrounding the nucleus are the negatively charged electrons, which have only $1/1839$ times the mass of a neutron and appear in numbers equal to the protons, to maintain a net charge balance.
- The light electrons that surround the nucleus play a far more significant role in determining material properties.
- Again, experiments reveal that the electrons are arranged in a characteristic structure consisting of shells and subshells, each possessing a distinctive energy. Upon absorbing a small amount of energy, an electron can jump to a higher-energy shell farther from the nucleus.

- The reverse jump can also occur with the concurrent release of a distinct amount, or quantum, of energy.
- The number of electrons surrounding the nucleus of a neutral atom is called the atomic number.
- More important, however, are those electrons in the outermost shell or subshell, known as valence electrons.
- These are influential in determining chemical properties, electrical conductivity, some mechanical properties, the nature of interatomic bonding, atom size, and optical characteristics.

Atomic Bonds

- General characteristics of materials joined by **ionic bonds** include moderate to high strength, high hardness, brittleness, high melting point, and low electrical conductivity.
- A second type of primary bond is the **covalent type**.
- Like the ionic bond, the covalent bond tends to produce materials with high strength and high melting point.
- Atom movement within the framework material (plastic deformation) requires the breaking of discrete bonds, thereby making the material characteristically brittle.
- Electrical conductivity depends on bond strength, ranging from conductive tin (weak covalent bonding), through semiconducting silicon and germanium, to insulating diamond (carbon).
- Engineering materials possessing ionic or covalent bonds tend to be ceramic (refractories or abrasives) or polymeric in nature.

Contd...

- A third type of primary bond can form when a complete outer shell cannot be formed by either electron transfer or electron sharing. This bond is known as the **metallic bond**.
- If there are only a few valence electrons (one, two, or three) in each of the atoms in an aggregate, these electrons can easily be removed while the remainder are held firmly to the nucleus.
- These *highly-mobile*, "free" electrons account for the high electrical and thermal conductivity values as well as the opaque property (free electrons can absorb the discrete energies of light radiation) observed in metals.
- Moreover, they provide the "cement" required for the positive-negative-positive attractions that result in bonding.
- Bond strength, and therefore material strength, varies over a wide range.

Contd...

- More significant, however, is the observation that the positive ions can move within the structure without the breaking of discrete bonds. Materials bonded by metallic bonds can therefore be deformed by atom-movement mechanisms and produce a deformed material that is every bit as strong as the original.
- This phenomenon is the basis of metal plasticity, ductility, and many of the shaping processes used in the fabrication of metal products.

IES-2008

Assertion (A): Elements are classified into metals and non-metals on the basis of their atomic weights.

Reason (R): The valence electron structures contribute to the primary bonding between the atoms to form aggregates.

- Both A and R are true and R is the correct explanation of A
- Both A and R are true but R is NOT the correct explanation of A
- A is true but R is false
- A is false but R is true

IES-2003

Assertion (A): Unlike in the case of ionic bonds, the co-ordination numbers for covalently bonded atoms are not controlled by the radii ratio.

Reason (R): A covalent bond has a specific direction of bonding in space.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

IES 2011

Solid material chemical bonds are :

- Ionic, molecular and fusion
- Covalent, fusion and fission
- Ionic, covalent and molecular
- Fission, molecular and ionic

Development of a grain structure

- When a metal solidifies, a small particle of solid forms from the liquid with a lattice structure characteristic of the given material.
- This particle then acts like a *seed or nucleus* and grows as other atoms in the vicinity attach themselves. The basic crystalline unit is repeated throughout space.
- In actual solidification, many nuclei form independently at various locations throughout the liquid and have random orientations with respect to one another. Each then grows until it begins to interfere with its neighbours.
- Since adjacent lattice structures have different alignments or orientations, growth cannot produce a single continuous structure.

- The small, continuous volumes of solid are known as crystals or grains, and the surfaces that divide them (i.e., the surfaces of crystalline discontinuity) are known as **grain boundaries**.
- The process by which a grain structure is produced Upon solidification is one of nucleation and growth.
- Grains are the smallest of the structural units in a metal that are observable with ordinary light microscopy.
- The atoms in the grain boundaries are more loosely bonded and tend to react with the chemical more readily than those that are part of the grain interior.

- The number and size of the grains in a metal vary with the rate of nucleation and the rate of growth.
- The greater the nucleation rate, the smaller the resulting grains. Conversely, the greater the rate of growth, the larger the grain.
- Because the resulting grain structure will influence certain mechanical and physical properties, it is an important property for an engineer to both control and specify. One means of specification is through the ASTM (American Society for Testing and Materials) grain size number, defined as:

$$N = 2^{n-1}$$

where N is the number of grains per square inch visible in a prepared specimen at 100X and n is the ASTM grain-size number. Low ASTM numbers mean a few massive grains; high numbers refer to materials with many small grains.

IES-2002

Chemicals attack atoms within grain boundaries preferentially because they have

- Lower energy than those in the grains
- Higher energy than those in the grains
- Higher number of atoms than in the grains
- Lower number of atoms than in the grains

Fracture of metals

- If the plastic deformation of a metal is extended too far, the metal may ultimately fracture.
- These types of fractures are known as ductile fractures, noting that the initial response to the applied load was one of plastic deformation.
- Another possibility, however, is where fracture precedes plastic deformation, occurring in a sudden, catastrophic manner, and propagating rapidly through the material. These fractures, known as brittle fractures, are most common with metals having the **bcc or hcp** crystal structures.
- Whether the fracture is ductile or brittle, however, often depends on the specific conditions of material, temperature, state of stress, and rate of loading.
- Fracture strength depends only on the basic crystal structure.

GATE-2010

The material property which depends only on the basic crystal structure is

- Fatigue strength
- Work hardening
- Fracture strength
- Elastic constant

IES-1992

Which of the following statement is true about brittle fracture?

- High temperature and low strain rates favour brittle fracture
- Many metal with HCP crystal structure commonly show brittle fracture
- Brittle fracture is always preceded by noise
- Cup and cone formation is characteristic for brittle materials

Cold working, recrystallization and hot working

- During deformation, a portion of the deformation energy becomes stored within the material in the form of additional dislocations and increased grain boundary surface area. If a deformed polycrystalline metal is subsequently heated to a high-enough temperature, the material will seek to lower its energy. New, equiaxed (spherical-shaped) crystals will nucleate and grow out of the original structure. This process of reducing the internal energy through the formation of new crystals is known as **recrystallization**.
- The temperature at which recrystallization takes place is different for each metal and also varies with the amount of prior deformation.

Contd...

- The greater the amount of prior deformation, the more stored energy, and the lower the recrystallization temperature. However, there is a lower limit below which recrystallization will not take place in a reasonable amount of time.
- This temperature can often be estimated by taking 0.4 times the melting point of the metal when the melting point is expressed in an absolute temperature scale.
- This is also the temperature at which atomic diffusion (atom movement within the solid) becomes significant, indicating that diffusion is an important mechanism in recrystallization.

- When metals are plastically deformed below their recrystallization temperature, the process is called **cold working**.
- The metal strain hardens and the structure consists of distorted grains. If the deformation is continued, the metal may fracture. Therefore, we find it common practice to recrystallize material after certain amounts of cold work.
- Ductility is restored, and the material is ready for further deformation.
- The heating process is known as a recrystallization anneal and enables deformation to be carried out to great lengths without the danger of fracture.

- If metals are deformed at temperatures sufficiently above the recrystallization, the process is known as **hot working**.
- Deformation and recrystallization can take place simultaneously, and large deformations are possible.
- Since a recrystallized grain structure is constantly forming, the final product will not exhibit strain hardening.

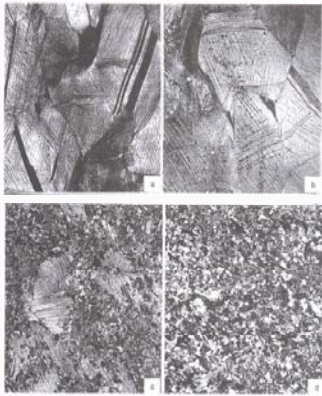


Fig. Recrystallization of 70-30 brass: (a) cold-worked 33%; (b) heated at 580°C (1075°F) for 3 seconds, (c) 4 seconds, and (d) 8 seconds

Plastic deformation in polycrystalline metals

- Gross plastic deformation of a polycrystalline specimen corresponds to the comparable distortion of the individual grains by means of **slip**. Although some grains may be oriented favourably for slip, yielding cannot occur unless the unfavourably oriented neighbouring grains can also slip.
- Thus in a polycrystalline aggregate, individual grains provide a mutual geometrical constraint on one other, and this precludes plastic deformation at low applied stresses.
- That is to initiate plastic deformation, polycrystalline metals require higher stresses than for equivalent single crystals, where stress depends on orientation of the crystal.
- Much of this increase is attributed to geometrical reasons.

Contd...

- Slip in polycrystalline material involves generation, movement and (re-)arrangement of dislocations.
- The second important mechanism of plastic deformation is **twinning**. It results when a portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, symmetrical way.
- The twinned portion of the crystal is a mirror image of the parent crystal. The plane of symmetry is called twinning plane.

Crystalline Materials

Crystalline material and Crystal Structures

Stable crystal structure satisfies

- The crystals are electrically neutral.
- The ion-ion repulsion is minimized.
- The ions or atoms in crystals are packed as closely as possible under the constraints of specific bonding.
- The free energy of the system becomes minimum

Crystal Structures

- All solid materials are made of atoms/molecules, which are arranged in specific order in some materials, called *crystalline solids*. Otherwise *non-crystalline* or *amorphous solids*.
- Groups of atoms/molecules specifically arranged – crystal.
- Lattice* is used to represent a three-dimensional periodic array of points coinciding with atom positions.
- Unit cell* is smallest repeatable entity that can be used to completely represent a crystal structure. It is the building block of crystal structure

Unit cell

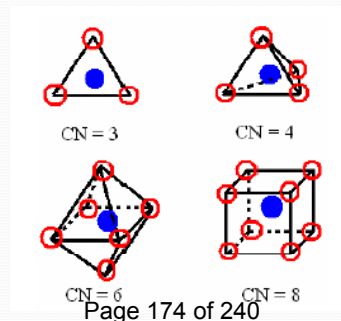
It is characterized by:

- Type of atom and their radii, R
- Cell dimensions (Lattice spacing a , b and c) in terms of R and angle between the axis
- a^* , b^* , c^* - lattice distances in reciprocal lattice, α^* , β^* , γ^* - angles in reciprocal lattice
- Number of atoms per unit cell, n
- Coordination number (CN)– closest neighbors to an atom
- Atomic packing factor, APF

For-2015 (IES, GATE & PSUs)

Contd...

Most common unit cells – Face-centered cubic, Body-centered cubic and Hexagonal.

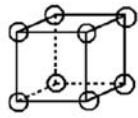


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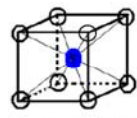
Common Crystal Structures

Unit Cell	N	CN	a/R	APF
Simple Cubic	1	6	2	0.52
Body-Centered Cubic	2	8	$4/\sqrt{3}$	0.68
Face-Centered Cubic	4	12	$4/\sqrt{2}$	0.74
Hexagonal Close Packed	6	12		0.74

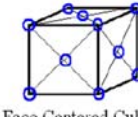
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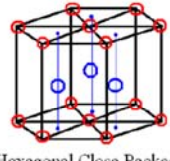
Simple Cubic



Body Centered Cubic



Face Centered Cubic



Hexagonal Close Packed

Fig. Different Unit Cell

Crystal Structure of materials

- FCC: Ni, Cu, Ag, Pt, Au, Pb, Al (soft)
- BCC: V, Mo, Ta, W (hard material)
- HCP: Mg, Zn
- Cobalt HCP < 420°C, FCC > 420°C
- Chromium HCP < 20°C, BCC > 20°C
- Glass- Amorphous
- BCC-Ferrite or α iron & δ -ferrite or δ -iron
- FCC- Austenite or γ -iron

IAS 2009 main

Show that in a hexagonal close-packed structure, atomic packing factor is 0.74. Take dimension $c = 1.633a$.

10

IES 2010

Assertion (A): Most of the materials exist in single crystal.

Reason (R): Sugar is a single crystal material.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is NOT the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

IES-2008

In the atomic hard-sphere model of the crystal structure of Copper, what is the edge length of unit cell?

- (a) $2 \times$ Atomic radius
 (b) $(4/\sqrt{3}) \times$ Atomic radius
 (c) $(2\sqrt{2}) \times$ Atomic radius
 (d) $\sqrt{2} \times$ Atomic radius

IES-2003

The coordination number for FCC crystal structure is

- (a) 4
 (b) 8
 (c) 12
 (d) 16

GATE-2009

The effective number of lattice points in the unit cell of simple cubic, body centered cubic, and face centered cubic space lattices, respectively, are

- (a) 1, 2, 2
 (b) 1, 2, 4
 (c) 2, 3, 4
 (d) 2, 4, 4

IES-2004

Assuming atoms to be perfect spheres, what is the value of the highest possible atomic packing factor (APF) in metals?

- (a) 0.95
 (b) 0.74
 (c) 0.66
 (d) 0.5

IES-2000

Atomic packing factor (APF) in the case of copper crystal is

- (a) 0.52
 (b) 0.68
 (c) 0.74
 (d) 1.633

IES-1999

Match List-I (Crystal structure) with List-II (Atomic packing factor) and select the correct answer using the codes given below the Lists:

List-I

- A. Simple cubic
- B. Body-centered cubic
- C. Face-centered cubic
- D. Hexagonal close packed

Codes:

A	B	C	D	A	B	C	D
(a) 3	4	2	1	(b) 4	3	2	1
(c) 3	4	1	2	(d) 4	3	1	2

List-II

- 1. 74%
- 2. 74%
- 3. 52%
- 4. 68%

IES 2007

Which one of the following is the correct ascending order of packing density for the given crystal structures of metals?

- (a) Simple cubic – Face centred cubic – Body centred cubic
- (b) Body centred cubic - Simple cubic - Face centred cubic
- (c) Simple cubic - Body centred cubic - Face centred cubic
- (d) Body centred cubic - Face centred cubic - Simple cubic

IES-2005

Consider the following statements about FCC and HCP crystal structure:

- Both have same coordination number and atomic packing fraction.
- Both represent closely packed crystal structures.
- Both structures are generated by stacking of close packed planes on top of one another, but only the stacking sequence is different.

Which of the statements given above are correct?

- (a) 1 and 2
- (b) 2 and 3
- (c) 1, 2 and 3
- (d) 1 and 3

Formula for a lattice constant

$$a = \left(\frac{nM}{\rho N} \right)^{1/3}$$

[Where n = no of atoms per cell, M = Atomic weight, N = Avogadro's number, ρ = Density of Metal]

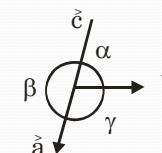
IES-2004

A metal has FCC structure. Suppose its atomic weight and atomic radius is A and r respectively. Let N denotes Avogadro's number. What is the density of the material?

- (a) $\frac{A}{2\sqrt{2}r^3 N}$
- (b) $\frac{A}{4\sqrt{2}r^3 N}$
- (c) $\frac{A}{8\sqrt{2}r^3 N}$
- (d) $\frac{A}{16\sqrt{2}r^3 N}$

Bravis Lattice and unit cell

- Total six lattice parameters $\vec{a}, \vec{b}, \vec{c}$ along the three crystal axes, and α, β, γ three, crystal angles.



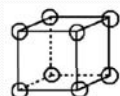
- There are seven lattice systems

Note: Total 7 lattice system but total 14 Bravais lattice

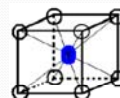
1. Cubic

- $a = b = c$
- $\alpha = \beta = \gamma = 90^\circ$

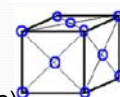
- Simple Cubic (SC) = 1 atom



- Body centered cubic (BCC) = 2 atom



- Face centered cubic (FCC) = 4 atom

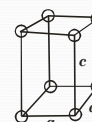


For-2015 (IES, GATE & PSUs)

2. Tetragonal

- $a = b \neq c$
- $\alpha = \beta = \gamma$

- Simple tetragonal (ST)



- Body centered tetragonal (BCT)



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IES-2001

Which one of the following pairs of axis lengths (a, b, c) and inter-axial angles (α, β, γ) represents the tetragonal crystal system?

- (a) $a = b = c; \alpha = \beta = \gamma = 90^\circ$
- (b) $a = b \neq c; \alpha = \beta = \gamma = 90^\circ$
- (c) $a \neq b \neq c; \alpha = \beta = \gamma = 90^\circ$
- (d) $a = b = c; \alpha = \beta = \gamma \neq 90^\circ$

Rev.0

IES-2006

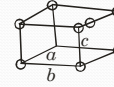
In Zinc Blende structure, each atom is surrounded by four atoms of the opposite kind which are located at the corners of which one of the following?

- Tetrahedron
- Hexahedron
- Cube
- Orthorhombic

3. Orthorhombic

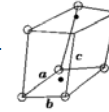
- $a \neq b \neq c$
- $\alpha = \beta = \gamma = 90^\circ$

1. Simple orthorhombic (SO) →



2. Body centered orthorhombic (BCO)
3. Face centered orthorhombic (FCO)

4. End centered orthorhombic (ECO) →



4. Rhombohedral

- $a = b = c$
- $\alpha = \beta = \gamma \neq 90^\circ$

(i) Simple Rhombohedral (Sr)

IES 2007

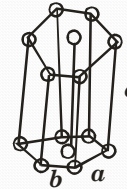
For a Rhombohedral space lattice, which one of the following is correct?

- $\alpha = \beta = \gamma = 90^\circ$
- $\alpha = \beta = \gamma \neq 90^\circ$
- $\alpha = \gamma = 90^\circ \neq \beta$
- $\alpha \neq \beta \neq \gamma \neq 90^\circ$

5. Hexagonal

- $a = b \neq c$
- $\alpha = \beta = 90^\circ$
- $\gamma = 120^\circ$

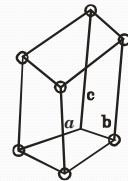
(i) Simple Hexagonal (Sh)



6. Monoclinic

- $a \neq b \neq c$
- $\alpha = \beta = 90^\circ \neq \gamma$

1. Simple Monoclinic (Sm) →

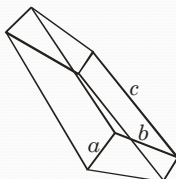


2. End centered monoclinic (ECM)

7. Triclinic

- $a \neq b \neq c$
- $\alpha \neq \beta \neq \gamma$

1. Simple Triclinic (Stri)



For-2015 (IES, GATE & PSUs)

IES 2011

In a triclinic unit cell :

- $\alpha = \beta = \gamma = 90^\circ$
- $\alpha = \beta = 90^\circ, \gamma = 120^\circ$
- $\alpha = \beta = 90^\circ \neq \gamma$
- $\alpha \neq \beta \neq \gamma \neq 90^\circ$

IES-2006

Which one of the following pairs is not correctly matched?

Space Lattice Relation between Atomic radius r and Edge element a

- Simple cubic structure : $a^2 = 4r^2$
- Body-centred cubic structure: $3a^2 = 16r^2$
- Triclinic: $2a^2 = 3r^2$
- Face-centred cubic structure: $a^2 = 8r^2$

Miller indices

- A system of notation is required to identify particular direction(s) or plane(s) to characterize the arrangement of atoms in a unit cell
- Formulas involving Miller indices are very similar to related formulas from analytical geometry – simple to use
- Use of reciprocals avoids the complication of infinite intercepts
- Specifying dimensions in unit cell terms means that the same label can be applied to any plane with a similar stacking pattern, regardless of the crystal class of the crystal. Plane (111) always steps the same way regardless of crystal system.

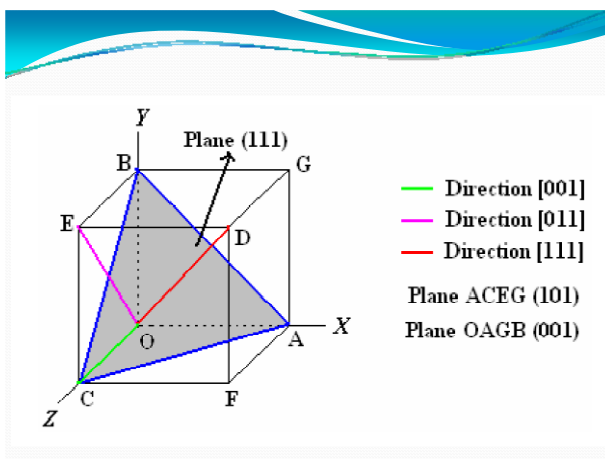
Miller indices – Direction

- A vector of convenient length is placed parallel to the required direction
- The length of the vector projection on each of three axes are measured *in terms of unit cell dimensions*
- These three numbers are made to smallest integer values, known as indices, by multiplying or dividing by a common factor
- The three indices are enclosed in square brackets, $[uvw]$
- A family of directions is represented by $\langle uvw \rangle$

Miller indices – Plane

- Determine the intercepts of the plane along the crystallographic axes, *in terms of unit cell dimensions*. If plane is passing through origin, there is a need to construct a plane parallel to original plane
- Take the reciprocals of these intercept numbers
- Clear fractions
- Reduce to set of smallest integers
- The three indices are enclosed in parenthesis, (hkl) .
- A family of planes is represented by $\{hkl\}$

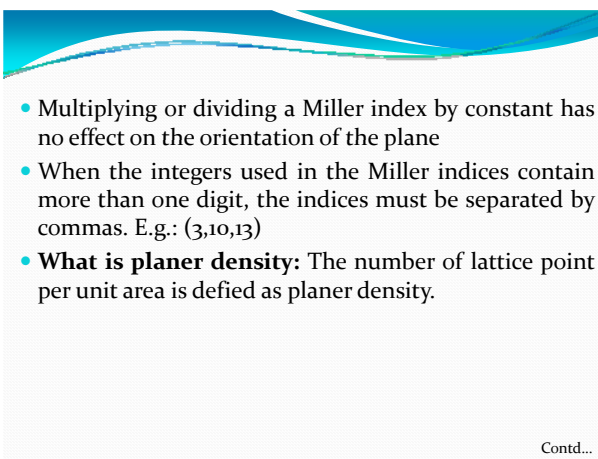
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Miller indices – Useful Conventions

- If a plane is parallel to an axis, its intercept is at infinity and its Miller index will be zero
- Never alter negative numbers. This implies symmetry that the crystal may not have! Use bar over the number to represent negative numbers.
- A plane or direction of family is not necessarily parallel to other planes or directions in the same family
- The smaller the Miller index, more nearly parallel the plane to that axis, and vice versa

Contd...

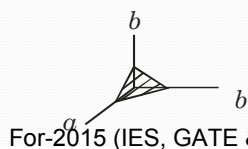


- Multiplying or dividing a Miller index by constant has no effect on the orientation of the plane
- When the integers used in the Miller indices contain more than one digit, the indices must be separated by commas. E.g.: (3,10,13)
- **What is planer density:** The number of lattice point per unit area is defied as planer density.

Contd...

Miller Indices (hkl)

- Step-I: Find the intercepts of a plane along the crystal axes a, b, c and express the intercepts in units of crystal parameter a, b, c respectively.
- Step-II: Find the reciprocal of the intercepts.
- Step-III: Reduce the reciprocals to the three smallest integer (h, k, l) keeping the ratios same.
- Step-IV: Enclose these integer into same parameters (h, k, l)



For-2015 (IES, GATE & PSUs)

Example: Find the miller indices of a plane that makes intercepts in the units of lattice parameters of 1 and 2 on a and b respectively. The plane is parallel to c axis.

Solution:

	a	b	c
Intercepts	1	2	∞
Take reciprocals	1	$\frac{1}{2}$	0
Reduce to reciprocals	2	1	0

Hence millers Indices are (210)

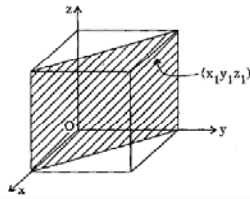
IAS 2009 Main

In an orthogonal crystal structure with lattice parameters $a \neq b \neq c$, draw the direction $[2 \bar{1} 2]$.

10

IES 2010

Miller indices (x, y, z) for the hatched plane in the above unit cell are represented as



- (a) (100)
- (b) (110)
- (c) (111)
- (d) (101)

IES-2006

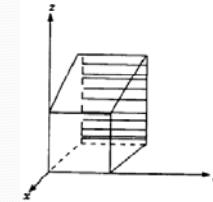
What is the planar density of (100) plane in FCC (face-centred cubic) crystal with unit cell side a equal to?

- (a) $\frac{1.484}{a^2}$
- (b) $\frac{2}{a^2}$
- (c) $\frac{1}{a^2}$
- (d) $\frac{\sqrt{2}}{a^2}$

IES-1999

The set of Miller indices of the plane shown in the given figure is

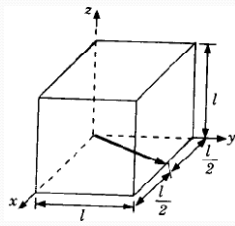
- (a) $(\bar{1} 0 0)$
- (b) $(1 0 0)$
- (c) $(1 0 1)$
- (d) $(1 1 0)$



IES-1998

A unit cell of a crystal is shown in the given figure. The Miller indices of the direction (arrow) shown in the figure is

- (a) $[0 1 2]$
- (b) $[0 2 1]$
- (c) $[2 1 0]$
- (d) $[2 0 1]$



Useful Conventions for a cubic crystal

- $[uvw]$ is normal to (hkl) if $u = h, v = k, w = l$.
E.g.: $(111) \perp [111]$
- $[uvw]$ is parallel to (hkl) if $hu + kv + lw = 0$
- Two planes $(h_1k_1l_1)$ and $(h_2k_2l_2)$ are normal if $h_1h_2 + k_1k_2 + l_1l_2 = 0$
- Two directions $(u_1v_1w_1)$ and $(u_2v_2w_2)$ are normal if $u_1u_2 + v_1v_2 + w_1w_2 = 0$

Contd...

Inter Planar distance between family of planes $\{hkl\}$

$$d_{(hkl)} = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

Angles between two planes is given by

$$\cos \theta = \frac{h_1h_2 + k_1k_2 + l_1l_2}{\sqrt{h_1^2 + k_1^2 + l_1^2} \times \sqrt{h_2^2 + k_2^2 + l_2^2}}$$

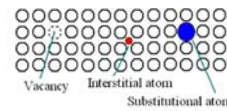
Crystal Defects

- The assumption of perfectly arranged atoms in a solid may not valid i.e. atomic order must have been disturbed.
- Disordered atomic region is called *defect* or *imperfection*.
- Based on geometry, defects are: Point defects (zero-D), Line defects (1-D) or Dislocations, Interfacial defects (2-D) and Bulk or Volume defects (3-D).

For-2015 (IES, GATE & PSUs)

Point defects

- Point defects are of zero-dimensional i.e. atomic disorder is restricted to point-like regions.
- Thermodynamically stable compared with other kind of defects.



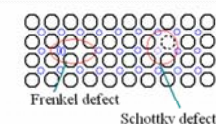
- Fraction of vacancy sites can be given as follows: $\frac{n}{N} = e^{-Q/RT}$

[Where n is the number of vacant sites in N lattice positions, k is gas or Boltzmann's constant, T is absolute temperature in kelvin, and Q is the energy required to move an atom from the interior of a crystal to its surface.]

Contd...

- It is clear from the equation that there is an exponential increase in number of vacancies with temperature. When the density of vacancies becomes relatively large, there is a possibility for them to cluster together and form voids.

- In **ionic crystals**, defects can form on the condition of charge neutrality. Two possibilities are:



Rev.0

IES-1998; 1999

Assertion (A): Carbon forms interstitial solid solution when added to iron.

Reason (R): The atomic radius of carbon atom is much smaller than that of iron.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-1992

Which of the following is a point imperfection?

- 1. Vacancy
 - 2. Interstitialcy
 - 3. Frenkel imperfection
 - 4. Schottky imperfection
- (a) 1 and 2 only (b) 2 and 3 only
- (c) 2, 3 and 4 only (d) 1, 2, 3 and 4

IES-2009

Which one of the following defects is 'Schottky defect'?

- (a) Vacancy defect
- (b) Compositional defect
- (c) Interstitial defects
- (d) Surface defect

Line defects

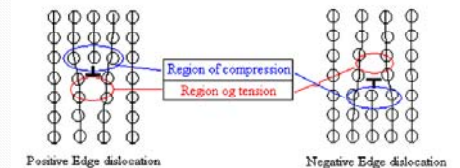
- Line defects or Dislocations are abrupt change in atomic order along a line.
- They occur if an incomplete plane inserted between perfect planes of atoms or when vacancies are aligned in a line.
- A dislocation is the defect responsible for the phenomenon of slip, by which most metals deform plastically.
- Dislocations occur in high densities (10^8 - 10^{10} m^{-2}), and are intimately connected to almost all mechanical properties which are in fact structure-sensitive.
- Dislocation form during plastic deformation, solidification or due to thermal stresses arising from rapid cooling.

Burger's vector

- A dislocation is characterized by Burger's vector, b .
- It is unique to a dislocation, and usually have the direction of close pack lattice direction. It is also the slip direction of a dislocation.
- It represents the magnitude and direction of distortion associated with that particular dislocation.
- Two limiting cases of dislocations, **edge and screw**, are characterized by Burger's vector perpendicular to the dislocation line (t) and Burger's vector parallel to the dislocation line respectively. Ordinary dislocation is of mixed character of edge and screw type.

Line defects - Edge dislocation

- It is also called as Taylor-Orowan dislocation.
- It will have regions of compressive and tensile stresses on either side of the plane containing dislocation.



Contd...

- A pure edge dislocation can glide or slip in a direction perpendicular to its length i.e. along its Burger's vector in the slip plane (made of b and t vectors), on which dislocation moves by slip while conserving number of atoms in the incomplete plane.
- It may move vertically by a process known as **climb**, if diffusion of atoms or vacancies can take place at appropriate rate.
- Atoms are added to the incomplete plane for negative climb i.e. the incomplete plane increases in extent downwards, and vice versa.
- Thus climb motion is considered as non-conservative, the movement by climb is controlled by diffusion process.

For-2015 (IES, GATE & PSUs)

Contd...

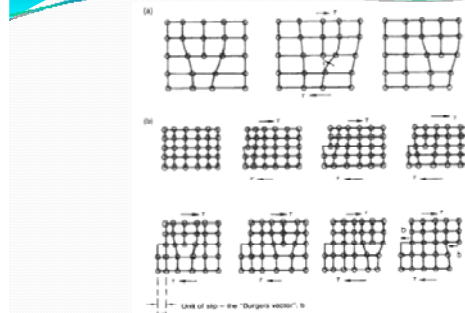
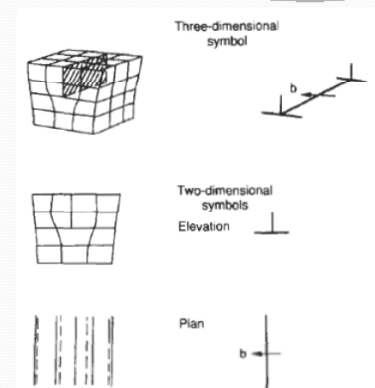


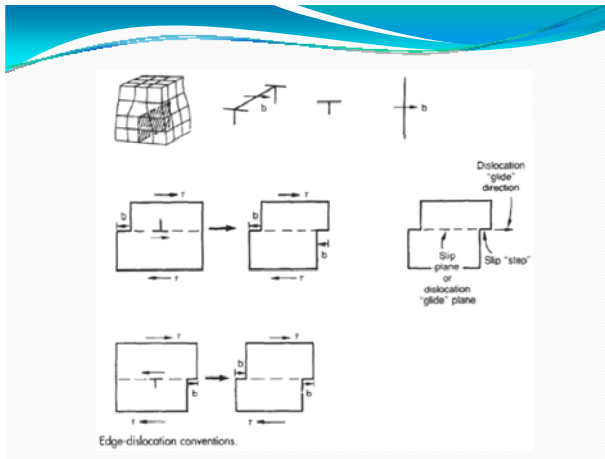
Fig. 9.4. (a) Shows how an edge dislocation moves through a crystal. (b) Shows a complete sequence for the introduction of a dislocation into a crystal from the left-hand side, its migration through the crystal, and its exit on the right-hand side; this process causes the lower half of the crystal to slip by a distance b under the upper half.

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Rev.0

Contd...



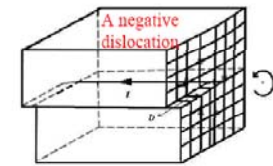
IES-2009

Which one of the following is correct for 'Climb'?

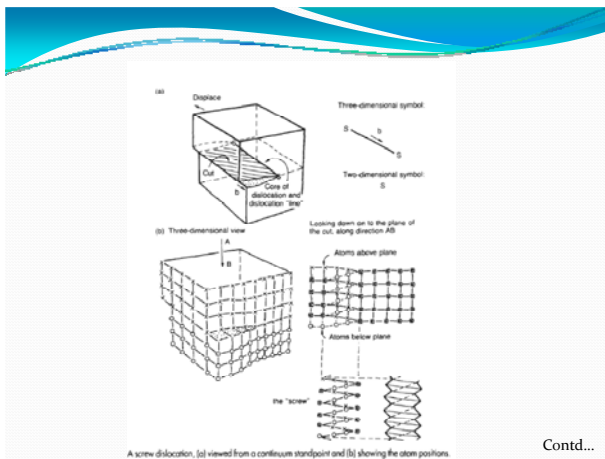
- Dislocation moves parallel to the slip plane
- Dislocation moves perpendicular to the slip plane
- Sliding of one plane of atoms over the other plane
- Dislocation moves from a slip plane to another slip plane

Line defects- Screw dislocation

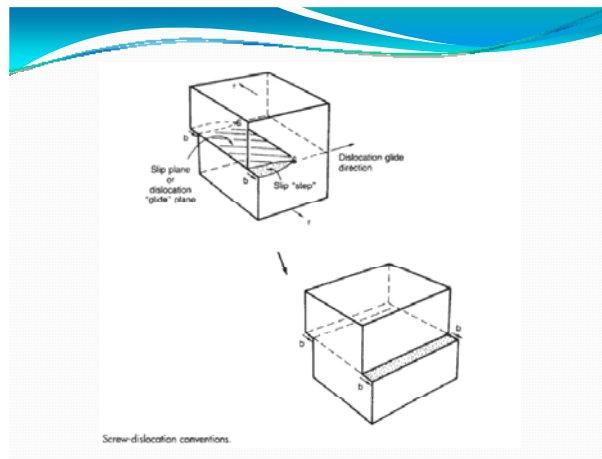
- It is also called as Burger's dislocation.
- It will have regions of shear stress around the dislocation line
- For positive screw dislocation, dislocation line direction is parallel to Burger's vector, and vice versa.



Contd...



Contd...



Line defects- Dislocation motion

- Dislocations move under applied stresses, and thus causes plastic deformation in solids.
- Dislocations can move in three ways – glide/slip, cross-slip and climb – depending on their character. Slip is conservative in nature, while the climb is non-conservative, and is diffusion-controlled.
- Any dislocation can slip, but in the direction of its burger's vector.
- Edge dislocation moves by slip or climb.
- Screw dislocation moves by slip / cross-slip. Possibility for cross-slip arises as screw dislocation does not have a preferred slip plane as edge dislocation have.

Line defects – Dislocation characteristics

- Dislocations have distortional energy associated with them.
- Stored elastic energy per unit length of the dislocation

$$E = \frac{Gb^2}{2}$$

[Where G – shear modulus and b – Burger's vector]

IES-2003

A screw dislocation

- Lies parallel to its Burger's vector
- Lies perpendicular to its Burger's vector
- Moves in a perpendicular direction to the Burger's vector
- Moves in an inclined direction to the Burger's vector

Select the correct answer using the codes given below:

Codes:

- 1 and 4
- 1 and 3
- 2 and 3
- 2 and 4

IES-2009

Which one of the following is correct for "Burger's vector" in screw dislocation?

- Perpendicular to the dislocation line
- Inclined to the dislocation line
- Parallel to the dislocation line
- Opposite to the dislocation line

IES-2008

Which one of the following statements is correct in the case of screw dislocations?

(\vec{b} = Burgers Vector; \vec{t} = Imaginary Vector

- (a) \vec{b} is perpendicular to \vec{t}
- (b) \vec{b} is parallel to \vec{t}
- (c) \vec{b} is inclined to \vec{t}
- (d) \vec{b} and \vec{t} are non-coplanar and non-intersecting

IES 2007

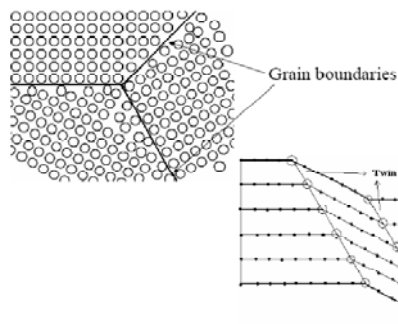
What is the approximate strain energy expression for a dislocation of unit length, irrespective of its edge or screw character?

- (a) $\frac{G^2b}{2}$
- (b) $\frac{Gb^2}{2}$
- (c) $\frac{G^2b}{4}$
- (d) $\frac{Gb^2}{4}$

Interfacial defect

- An interfacial defect is a 2-D imperfection in crystalline solids and have different crystallographic orientations on either side of it.
- They usually arise from clustering of line defects into a plane..
- E.g.: External surface, Grain boundaries, Stacking faults, Twin boundaries, Dislocations and Phase boundaries.

Contd...



IES 2010

Surface imperfections which separate two orientations that are mirror image of one another is called

- (a) Stacking fault
- (b) Grain boundary
- (c) Tilt boundary
- (d) Twinned boundary

IES-2008

What is a surface imperfection, which separates crystals of different orientations in a polycrystalline aggregate, called?

- (a) Edge dislocation
- (b) Stacking fault
- (c) Grain boundary
- (d) Screw dislocation

Stacking faults

- The planner imperfection produced by the passage of a partial dislocation is called stacking fault.
- They are faults in stacking sequence of atom planes.
- Stacking sequence in an FCC crystal is ABC ABC ABC ..., and the sequence for HCP crystals is AB AB AB....
- Two kinds of stacking faults in FCC crystals are:
 - (a) ABC AC ABC...where CA CA represent thin HCP region which is nothing but stacking fault in FCC,
 - (b) ABC ACB CABC is called extrinsic or twin stacking fault. Three layers ACB constitute the twin. Thus stacking faults in FCC crystal can also be considered as submicroscopic twins.

For-2015 (IES, GATE & PSUs)

Contd...

- This is why no microscopic twins appear in FCC crystals as formation of stacking faults is energetically favorable.
- The total energy of a perfect lattice is lower than one with a stacking fault. This difference is stacking fault energy, and varies in range 0.01-0.1 J/m².
- Lower the stacking fault energy, wider the stacking fault, metal strain hardens rapidly and twin easily. Otherwise, metals of high stacking fault energy i.e. narrower stacking faults show a deformation structure of banded, linear arrays of dislocations.

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Bulk or a Volume defects

- Volume defects are three-dimensional in nature.
- These defects are introduced, usually, during processing and fabrication operations like casting, forming etc.
E.g.: Pores, Cracks, Foreign particles
- These defects act like stress raisers, thus deleterious to mechanical properties of parent solids.
- In some instances, foreign particles are added to strengthen the solid – dispersion hardening. Particles added are hindrances to movement of dislocations which have to cut through or bypass the particles thus increasing the strength.

Rev.0

IES 2011

Assertion (A): Excess defects are created by hammering the crystalline materials.

Reason (R) : The thermal fluctuations create the point defects in crystalline materials.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES 2010

Assertion (A): Natural crystals always contain defects.

Reason (R): The defects may affect colour and can make a crystal a valuable gem.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2003

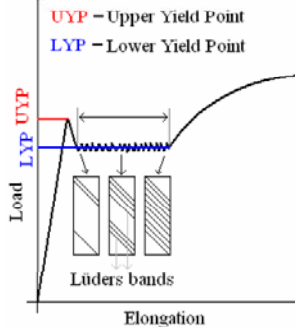
Which one of the following pairs is *not* correctly matched?

- (a) Point defect in crystal lattice : Self interstitials
- (b) Linear defect in crystal lattice : Grain boundary
- (c) Planar defect in crystal lattice : External surface
- (d) Volume defect in crystal lattice: other phases

Yield point phenomenon

- Localized, heterogeneous type of transition from elastic to plastic deformation marked by abrupt elastic-plastic transition – Yield point phenomenon.

- It characterizes that material needs higher stress to initiate plastic flow than to continue it.



Yield point phenomenon (contd...)

- The bands are called Lüders bands / Hartmann lines / stretcher stains, and generally are approximately 45° to the tensile axis.
- Occurrence of yield point is associated with presence of small amounts of interstitial or substitutional impurities. It's been found that either unlocking of dislocations by a high stress for the case of strong pinning or generation of new dislocations are the reasons for yield-point phenomenon.
- Magnitude of yield-point effect will depend on energy of interaction between solute atoms and dislocations and on the concentration of solute atoms at the dislocations.

Strain hardening

- Phenomenon where ductile metals become stronger and harder when they are deformed plastically is called strain hardening or work hardening.
- Increasing temperature lowers the rate of strain hardening. Hence materials are strain hardened at low temperatures, thus also called cold working.
- During plastic deformation, dislocation density increases. And thus their interaction with each other resulting in increase in yield stress.
- Dislocation density (ρ) and shear stress (τ) are related as follows:

$$\tau = \tau_0 + A\sqrt{\rho}$$

Strain hardening (contd...)

- During strain hardening, in addition to mechanical properties physical properties also changes:
 - a small decrease in density
 - an appreciable decrease in electrical conductivity
 - small increase in thermal coefficient of expansion
 - increased chemical reactivity (decrease in corrosion resistance).
- Deleterious effects of cold work can be removed by heating the material to suitable temperatures – Annealing. It restores the original properties into material. It consists of three stages – recovery, recrystallization and grain growth.
- In industry, alternate cycles of strain hardening and annealing are used to deform most metals to a very great extent.

Semiconductivity

- Electrical properties of semiconductors are unique, in the sense that their electrical properties are extremely sensitive to even minute concentrations of impurities.
- Two kinds of semiconductors – *intrinsic* and *extrinsic*.
- For intrinsic semiconductors, their electrical behavior is based on inherent electronic structure of the pure material.
- On the other hand, if the electrical properties are dominated by impurities, they are called extrinsic semiconductors.
- In semiconductors, the valence and conduction bands do not overlap as in metals, but they possess enough electrons in the valence band those can be promoted to the conduction band at a certain temperature.

IES-1997

Which of the following properties of a solid are dependent on crystal imperfections?

- 1. Yield stress
- 2. Melting point
- 3. Semi-conductivity
- 4. Ductility

Select the correct answer using the codes given below:

- (a) 1 and 3
- (b) 1, 3 and 4
- (c) 2, 3 and 4
- (d) 2 and 4

Heat Treatment of Metals

Heat Treatment

- Heating a metal or alloy to various definite temperatures, holding these for various time durations and cooling at various rates.
- Combination of controlled heating and cooling determine not only the nature and distribution of micro-constituents (which determine the properties of a metal or alloy), but also the grain size.

Contd...

Purpose of heat treatment:

1. To remove or relieve strains or stresses induced by cold working or non-uniform cooling (for example welding): Annealing
2. To increase strength or hardness of the material for improved wear resistance: Hardening
3. To improve machinability: Annealing
4. To soften the material: Annealing
5. To decrease hardness and increase ductility and toughness. (Tempering)

Contd...

6. To improve the cutting properties of tools.
7. To change or modify the physical properties of the material such as electrical properties, magnetic properties, corrosion resistance and heat resistance etc.
8. Elimination of H₂ gas dissolved during pickling or electro-plating which causes brittleness.

Main Processes Include

- Annealing
- Stress Relieving
- Quench Hardening
- Tempering
- Carburizing
- Carbon Nitriding
- Age Hardening
- Ion Nitriding

Contd...

IES-1992

Which of the following generally decreases in the steel after quench-hardening?

1. Brittleness
 2. Percentage elongation
 3. Impact strength
- (a) 1 and 2 only (b) 2 and 3 only
(c) 1 and 3 only (d) 1, 2 and 3

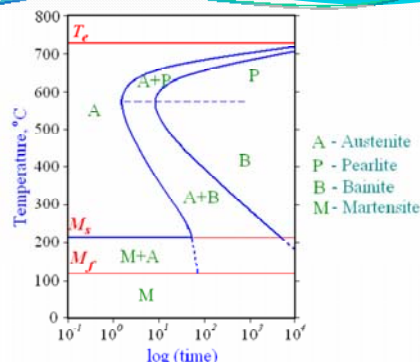


Fig. TTT diagram for eutectoid transformation in Fe-C
For-2015 (IES, GATE & PSUs)

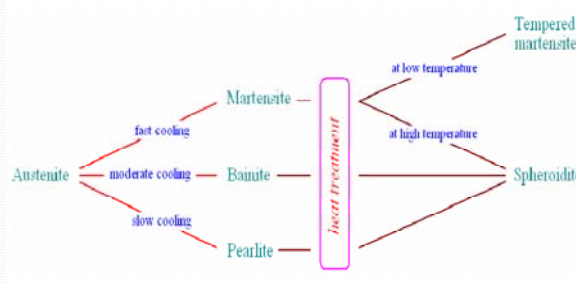
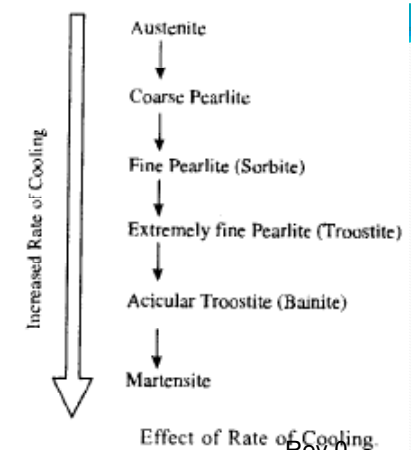


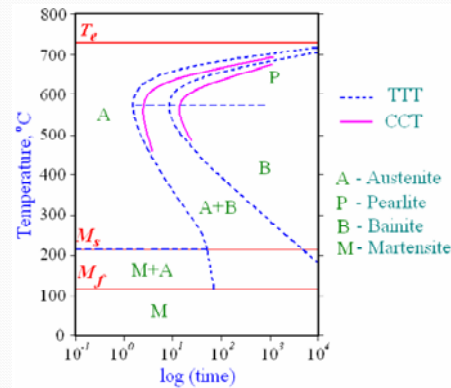
Fig. Transformations involving austenite for Fe-C system



Effect of Rate of Cooling.

CCT diagram for Fe-C system

- TTT diagram is less practical since an alloy has to be cooled rapidly and then kept at a temperature to allow for respective transformation to take place.
- Usually materials are cooled continuously, thus Continuous Cooling Transformation diagrams are appropriate.
- For continuous cooling, the time required for a reaction to begin and end is delayed, thus the isothermal curves are shifted to longer times and lower temperatures.
- Main difference between TTT and CCT diagrams: no space for bainite in CCT diagram as continuous cooling always results in formation of pearlite.



- **Critical Rate of Cooling:** The minimum rate of cooling at which the austenite is transformed into martensite alone.
- **Spheroidite:** If pearlite is heated just below the eutectoid temperature (say 700°C) and held at this temperature for a day or so, the cementite lamelle in pearlite get transformed to spherical shape. The structure is called "spheroidite".
- This structure is less conducive to stress concentration because of spherical grains, as compared to cementite (lamelle structure).
- This, spheroidite is more tough but less hard as compared to pearlite.

GATE-2003

During heat treatment of steel, the hardness of various structures in increasing order is

- Martensite, fine pearlite, coarse pearlite, spheroidite
- Fine pearlite, coarse pearlite, spheroidite, martensite
- Martensite, coarse pearlite, fine pearlite, spheroidite
- Spheroidite, coarse pearlite, fine pearlite, martensite

GATE-1996

The iron-carbon diagram and the TTT curves are determined under

- Equilibrium and non-equilibrium conditions respectively
- Non-equilibrium and equilibrium conditions respectively
- Equilibrium conditions for both
- Non-equilibrium conditions for both

IES-2002

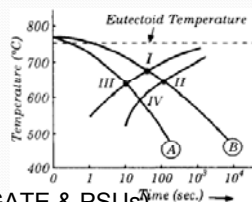
TTT diagram indicates time and temperature transformation of

- Cementite
- Pearlite
- Ferrite
- Austenite

IES-1998

Two cooling curves A and B for a eutectoid iron-carbon alloy are superimposed on a continuous cooling transformation diagram as shown in the given figure. Fine pearlite microstructure is represented by the points labelled

- I and III
- II
- IV
- I



For-2015 (IES, GATE & PSUs)

IAS-2002

Two plain carbon steel specimens having 0.8% carbon content are welded. If we observe the weldment under Metallurgical Microscope from centre towards either side, the following structures are observed at different zones:

- Fine Pearlite
- Coarse Pearlite
- Martensite

Select the correct sequence using the codes given below:

Codes:

- 1, 2, 3
- 1, 3, 2
- 2, 1, 3
- 3, 1, 2

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GATE-1997

On completion of heat treatment, the resulting structure will have retained Austenite if

- Rate of cooling is greater than the critical cooling rate
- Rate of cooling is less than the critical cooling rate
- Martensite formation starting temperature is above the room temperature
- Martensite formation finish temperature is below the room temperature

Rev.0

Annealing processes

- *Annealing* is a heat treatment process in which the material is taken to a high temp. kept there for some time and then **cooled in furnace**.
- Cooling is done slowly to avoid the distortion.

Contd...

- Benefits of annealing are:
 - relieve stresses
 - increase softness, ductility and toughness
 - produce a specific microstructure
- Depending on the specific purpose, annealing is classified into various types: process annealing, stress relief, full annealing and normalizing.

Full annealing

- Metal is heated above the upper critical temperature & held there until the temperature of the work piece is uniform throughout, and finally cooling the work piece at a slowly controlled rate in furnace so that the temperature of the surface and that of the centre of the workpiece is approximately the same.

IES 2010

Consider the following statements regarding annealing process:

1. All structural imperfections are removed
2. The hypoeutectoid steel is heated to about 50 – 70° C below upper critical temperature.
3. Cooling can be done in heat treating furnace, by heating it, keeping the metal in it and turning off furnace till it cools to room temperature.
4. Uniform grain structure is resulted.

Which of these statements are correct?

- (a) 1, 2 and 3 only (b) 2, 3 and 4 only
(c) 1, 3 and 4 only (d) 1, 2, 3 and 4

IES-1999

Heating the hypoeutectoid steels to 30°C above the upper critical temperature line, soaking at that temperature and then cooling slowly to room temperature to form a pearlite and ferrite structure, is known as

- (a) Hardening (b) Normalizing
(c) Tempering (d) Annealing

IES-1993

Which of the following statements are true of annealing of steels?

1. Steels are heated to 500 to 700°C.
2. Cooling is done slowly and steadily.
3. Internal stresses are relieved.
4. Ductility of steel is increased.

Select the correct answer using the codes given below:

Codes:

- (a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 1, 2 and 3

IES-1992

Temperature required for full annealing in hyper-eutectoid steel is

- (a) 50°C above upper critical temperature (AC_3)
(b) 50°C below upper critical temperate (AC_3)
(c) 50°C above lower critical temperature (AC_1)
(d) 50°C below lower critical temperature (AC_1)

IES – 2003

Primary object of full annealing is to

- (a) Increase toughness and yield point
(b) Reduce ductility and resilience
(c) Remove foreign impurities and improve surface finish
(d) Increase ductility and machinability

Process annealing

- After cold working the metal can be softened by process annealing or "recrystallization" to reduce the distortions of the crystal lattice produced by cold working.

IES-2005

The complete phase recrystallization and fine grain structure is obtained in casting, forging and rolled parts by:

- (a) Recrystallization annealing
- (b) Normalizing
- (c) Spheroidizing
- (d) Austenising

Isothermal annealing

- Increases the machinability.
- Heat above the upper critical point and held for some time, then rapidly cool to a temp. 600 - 700°C, and is held at this new temperature until the austenite is completely decomposed to form pearlite.
- Finally cooled in still air.

Contd...

IES 2010

Isothermal annealing is mainly used in alloy steels to improve

- (a) Machinability
- (b) Toughness
- (c) Ductility
- (d) Weld ability

Stress relief annealing

- Stress relief annealing process consists of three steps.
- *The first step* is heating the cold worked steel to a temperature between 500° C and 550°C C i.e. below its recrystallization temperature.
- *The second step* involves holding the steel component at this temperature for 1-2 hours.
- *The final step* is to cool the steel component to room temperature in air.
- It partly relieves the internal stress in cold worked steels without loss of strength and hardness i.e. without change in the microstructure. Since only low carbon steels can be cold worked, the process is applicable to hypoeutectoid steels containing less than 0.4% carbon.

GATE 2014 (PI)

For a metal alloy, which one of the following descriptions relates to the **stress-relief annealing** process?

- (a) Heating the workpiece material above its recrystallization temperature, soaking and then cooling in still air
- (b) Heating the workpiece material below its recrystallization temperature, holding for some time and then furnace cooling
- (c) Heating the workpiece material up to its recrystallization temperature and then rapid cooling
- (d) Heating the workpiece up to its recrystallization temperature and cooling to room temperature alternately for a few cycles

Normalizing

Main objective

1. Refine grain, improve machinability, tensile strength and structure of weld.
2. Remove cold worked stress.
3. Remove dislocations due to hot working.

Process

- Heat the steel from 30°C to 50°C above its upper critical temp, held about fifteen minutes and then allowed to cool down in still air.
- Homogeneous structure provides a higher yield point, ultimate tensile strength and impact strength with lower ductility to steels.

Contd...

GATE-2014

The process of reheating the reduce its brittleness without any significant loss in its hardness is

- (a) normalizing
- (b) annealing
- (c) quenching
- (d) tempering

IES 2011

Which one of the following statements is NOT correct for normalizing?

- (a) It is often applied to casting to relieve stresses
- (b) It increases strength of medium carbon steel to some extent
- (c) Better surface finish can be obtained in machining
- (d) It increases grain size

IES-2000

Assertion (A): Normalized steel will have lower hardness than annealed steel.

Reason (R): The pearlite of normalized steel is finer and has lower intermolecular space.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Spheroidizing

- Heat them to slightly above the critical temperature, hold them at this temp for a period of time, and then letting them cool in the furnace.
- Spheroidizing produces a rounded or globular form of carbide.
- It improve abrasion resistance.

GATE-2006

The main purpose of spheroidising treatment is to improve

- Harden ability of low carbon steel
- Mach inability of low carbon steels
- Harden ability of high carbon steels
- Mach inability of high carbon steels

IES-2003

Globular form of cementite in the structure of steel is obtained through

- Normalizing
- Malleabilising
- Spheroidizing
- Carbonizing

The difference between the different annealing processes is made clear in Fig., a diagram between temperature and time.

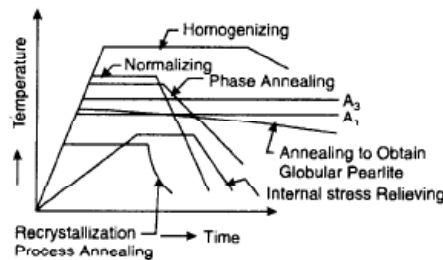


Fig. 2.9. Various Types of Annealing Process.

Quenching

- Quenching** is heat treatment process where material is cooled at a rapid rate from elevated temperature to produce Martensite phase.

Comparative cooling rates of Quench Media

Brine	1.20 to 1.30
Water	1
Water + NaOH or KOH	<1
Oil	0.40 to 0.50
Forced air	0.03
Still air	0.02

- Brine has fastest cooling rate of steel quenching and is also used as secondary refrigerant.

Tempering

- Tempering** is the process of heating martensitic steel at a temperature below the eutectoid transformation temperature to make it softer and more ductile.
- During the tempering process, Martensite transforms to a structure containing iron carbide particles in a matrix of ferrite.

IES 2010

Match List I with List II and select the correct answer using the code given below the lists:

List I (Quenching media)				List II (Structure produced)			
A. Water				1. Coarse pearlite			
B. Oil				2. Martensite			
C. Air				3. Very fine pearlite			
D. Furnace cools				4. Fine pearlite			
	A	B	C		A	B	C
(a)	1	3	4	2	(b)	2	3
(c)	1	4	2	3	(d)	3	1

IES-2001

Consider the following quenching media:

- Oil
- Water
- Water + NaOH
- Brine

The correct sequence of these media in order of increasing hardness of steel undergoing heat treatment is

- 1, 3, 2, 4
- 2, 1, 3, 4
- 1, 2, 3, 4
- 4, 3, 2, 1

IES-2009

Which one of the following mediums is used for the fastest cooling rate of steel quenching?

- Air
- Oil
- Water
- Brine

IES-2006

Match List-I (Effect of Cooling) with List-II (Cooling Medium) and select the correct answer using the code given below:

List - I

- A. Martensite
- B. Very fine pearlite
- C. Fine pearlite
- D. Coarse pearlite

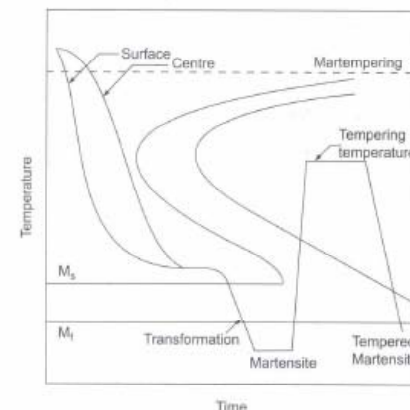
List - II

- 1. Water quenched
- 2. Air cooled
- 3. Furnace cooled
- 4. Oil quenched

	A	B	C	D
(a)	1	4	2	3
(b)	2	3	1	4
(c)	2	3	4	1
(d)	1	2	3	4

Martempering

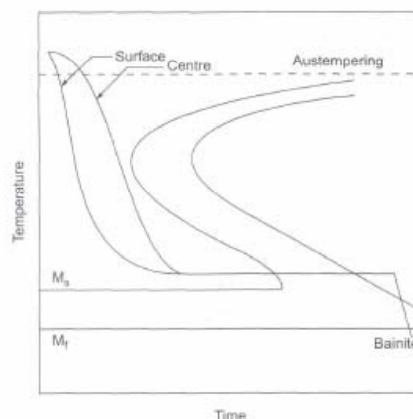
- Quench steel from the austenizing temperature to a bath just above M_s .
- Since, austenite transforms to martensite simultaneously throughout the steel, the distortion in quenching is minimized.
- This induces greater toughness in the steel.



Transformation diagram with cooling curve for martempering

Austempering

- This hardening process is basically the same as the martempering, but has a longer holding time above the martensitic transformation temperature.



Transformation diagram with cooling curve for austempering

GATE-2004

From the lists given below, choose the most appropriate set of heat treatment process and the corresponding process characteristics

Process

- P. Tempering
- Q. Austempering
- R. Martempering

Characteristics

- 1. Austenite is converted into bainite
- 2. Austenite is converted into martensite
- 3. Cementite is converted into globular structure
- 4. Both hardness and brittleness are reduced
- 5. Carbon is absorbed into the metal

- (a) P-3 Q-1 R-5
- (c) P-4 Q-1 R-2

- (b) P-4 Q-3 R-2
- (d) P-1 Q-5 R-4

IES-1994

Consider the following treatments:

- 1. Normalizing
- 2. Hardening
- 3. Martempering
- 4. Cold working

Hardness and tensile strength in austenitic stainless steel can be increased by

- (a) 1, 2 and 3
- (b) 1 and 3
- (c) 2 and 4
- (d) 4 alone

IES-2006

Tempering is a process of annealing

- (a) Martensite at low temperatures
- (b) Martensite at higher temperatures
- (c) Bainite at low temperatures
- (d) Bainite at higher temperatures

IES-2005

Austempering is employed to obtain:

- (a) 100% martensitic structure
- (b) 100% bainitic structure
- (c) 50% martensitic and 50% bainitic structure
- (d) 100% pearlitic structure

IES-2004

Consider the following pairs:

Heat treatment	Effect on medium carbon steel
1. Normalizing	: Grain refinement
2. Full annealing	: Uniform grain structure
3. Martempering	: Decreased ductility
4. Spheroidizing	: Maximum softness

Which of the pairs given above are correctly matched?

- (a) 1 and 2 (b) 2 and 3
(c) 3 and 4 (d) 1, 2, 3 and 4

IES-2001

'Tempering' of quenched martensitic steel is necessary to improve the

- (a) Hardness of the metal
(b) Surface texture of the metal
(c) Corrosion resistance of the metal
(d) Ductility of the metal

IES-2006

The pattern known as Widmanstatten structure is encountered in:

- (a) Tempering (b) Normalizing
(c) Spheroidizing (d) Annealing

GATE-2014

Match the heat treatment processes (Group A) and their associated effects on properties (Group B) of medium carbon steel

Group A	Group B
P: Tempering	I. Strengthening and grain refinement
Q: Quenching	II. Inducing toughness
R: Annealing	III. Hardening
S: Normalizing	IV. Softening

- (a) P Q R S P Q R S
(a) III IV II I (b) II III IV I
(c) III II IV I (d) II III I IV

Solutionizing

- **Solutionizing** (solution heat treatment), where the alloy is heated to a temperature between solvus and solidus temperatures and kept there till a uniform solid-solution structure is produced.

Aging

- **Aging** finely dispersed precipitate particle will form. Aging the alloy at room temperature is called natural aging, whereas at elevated temperatures is called artificial aging. Most alloys require artificial aging, and aging temperature is usually between 15-25% of temperature difference between room temperature and solution heat treatment temperature.

Case Hardening

- In case hardening, the surface of the steel is made hard and wear resistant, but the core remains soft and tough.

Induction hardening

- Alternating current of high frequency passes for few second through an induction coil enclosing the steel part to be heat treated.
- Immediately after heating, water jets are activated to quench the surface.
- Martensite is produced at the surface, making it hard and wear resistant.

GATE-2000

Cast steel crankshaft surface is hardened by

- (a) Nitriding (b) Normalising
(c) Carburising (d) Induction heating

IES-1992

Induction hardening is basically a

- (a) Carburising process
- (b) Surface hardening process
- (c) Core-hardening process
- (d) None of the above

Flame hardening

- For large work pieces flame hardening is done by means of an oxyacetylene torch.
- Heating should be done rapidly by the torch and the surface quenched.

IES-1996; 1997

Guideways of lathe beds are hardened by

- (a) Carburising
- (b) Cyaniding
- (c) Nitriding
- (d) Flame hardening

Laser hardening

- Laser beams are of high intensity, a lens is used to reduce the intensity by producing a defocused spot of size ranging from 0.5 to 25 mm.

Carburizing

- Carburizing is the most widely used method of surface hardening.
- Here, the surface layers of low carbon steel are enriched with carbon up to 0.8-1.0%. The source of carbon may be a solid medium, a liquid or a gas.
- In all cases, the carbon enters the steel at the surface and diffuses into the steel as a function of time at an elevated temperature.
- Carburizing is done at 920-950°C.

Contd...

- There is fully austenitic state is essential. If carburizing is done in the ferritic region, the carbon, with very limited solubility in ferrite, tends to form massive cementite particles near the surface, making the subsequent heat treatment difficult.
- For this reason, carburizing is always done in the austenitic state, even though longer times are required due to the diffusion rate of carbon in austenite being less than in ferrite at such temperatures.

IES 2011

Assertion (A): Carburizing is used for machine elements which have to have a wear resistant working surface.

Reason (R) : The composition of surface layers are changed in carburizing.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

GATE-1992

Carburized machine components have high endurance limit because carburization

- (a) Raises the yield point of the material
- (b) Produces a better surface finish
- (c) Introduces a compressive layer on the surface
- (d) Suppresses any stress's, concentration produced in the component.

IES-1992

In case carburising Carbon is introduced to form a high carbon layer at the surface. The carbon is introduced in the form of

- (a) Graphite flakes
- (b) Pearlite
- (c) Cementite
- (d) Free carbon

IES-2005

If the surface of a component is heavily stressed while the stresses in the core are of comparative small magnitude, which one of the following heat treatment methods is employed?

- (a) Annealing (b) Tempering
(c) Quenching (d) Case hardening

Cyaniding

- Cyaniding is done in a liquid bath of NaCN, with the concentration varying between 30 and 97%.
- The temperature used for cyaniding is lower than that for carburizing and is in the range of 800-870°C.
- The time of cyaniding is 1-3 hr to produce a case depth of 0.25 mm or less.

GATE-2003

Hardness of steel greatly improves with

- (a) Annealing (b) Cyaniding
(c) Normalising (d) Tempering

Nitriding

- During nitriding, pure ammonia decomposes to yield nitrogen which enters the steel.
- The temperature of nitriding is 500-590°C. The time for a case depth of 0.02 mm is about 2 hr.
- Most of the nitrogen, that enters the steel, forms hard nitrides (e.g., Fe₃N).
- No phase change occurs after nitriding.

IES-1992

Quenching is not necessary when hardening is done by

- (a) Case carburizing
(b) Flame hardening
(c) Nitriding
(d) Any of the above processes

IES-1995

Match List I with List II and select the correct answer using the codes given below the lists:

List I (Heat treatment)

List II (Effect on the properties)

A. Annealing	1. Refined grain structure
B. Nitriding	2. Improves the hardness of the whole mass
C. Martempering	3. Increases surface hardness
D. Normalising	4. Improves ductility
Codes: A B C D	A B C D
(a) 4 3 2 1	(b) 1 3 4 2
(c) 4 2 1 3	(d) 2 1 3 4

IES-2004

Match List I (Name of treatment) with List II (Media used) and select the correct answer using the codes given below the Lists

List I	List II
A. Pack carburizing	1. Ammonia gas
B. Gas carburizing	2. Sodium cyanide
C. Cyaniding	3. Carburizing compound
D. Nitriding	4. Ethane
Codes: A B C D	A B C D
(a) 3 4 2 1	(b) 2 1 3 4
(c) 3 1 2 4	(d) 2 4 3 1

For-2015 (IES, GATE & PSUs)

IAS 2009 Main

Give chemical reactions and temperature ranges in the cases of cyaniding, carbonitriding and nitriding processes. What is the serious problem encountered in nitriding process? In which process is case hardened thickness maximum?

20

Precipitation & Dispersion hardening

- Foreign particles can also obstructs movement of dislocations i.e. increases the strength of the material.
- Foreign particles can be introduced in two ways – precipitation and mixing-and-consolidation technique.
- Precipitation hardening is also called age hardening because strength increases with time.
- Requisite for precipitation hardening is that second phase must be soluble at an elevated temperature but precipitates upon quenching and aging at a lower temperature.
- E.g.: Al-alloys, Cu-Be alloys, Mg-Al alloys, Cu-Sn alloys
- If aging occurs at room temperature – Natural aging
- If material need to be heated during aging – Artificial aging.

Rev.0

Contd...

- In dispersion hardening, fine second particles are mixed with matrix powder, consolidated, and pressed in powder metallurgy techniques.
- For dispersion hardening, second phase need to have very low solubility at all temperatures.
- E.g.: oxides, carbides, nitrides, borides, etc.
- Dislocation moving through matrix embedded with foreign particles can either cut through the particles or bend around and bypass them.
- Cutting of particles is easier for small particles which can be considered as segregated solute atoms. Effective strengthening is achieved in the bending process, when the particles are submicroscopic in size.

Contd...

Stress (τ) required to bend a dislocation is inversely proportional to the average interspacing (λ) of particles: $\tau = Gb/\lambda$

Interspacing (λ) of spherical particles:

$$\lambda = \frac{4(1-f)r}{3f}$$

where r – particle radius, f – volume fraction

- Optimum strengthening occurs during aging once the right interspacing of particles is achieved.
 - Smaller the particles, dislocations can cut through them at
- lower stresses
 - larger the particles they will be distributed at wider distances.

IES-2009

Which one of the following materials can be subjected to an age hardening process?

- HSS
- Aluminium
- Pure iron
- Stellite

IES-1994; 2005

Assertion (A): Carburizing is done on non-ferrous alloys to increase the surface hardness.

Reason (R): Precipitation hardening of non-ferrous alloys involves solution heat treatment followed by precipitation heat treatment.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

IES 2007

Which one among the following is the most effective strengthening mechanism of non-ferrous metal?

- Solid solution hardening
- Strain hardening
- Grain size refinement
- Precipitation hardening

IES-2001

Which one of the following pairs is correctly matched?

- Solid solution strengthening... Increasing density of dislocations
- Dispersion hardeningCreating strained region in the crystal
- Strain-hardeningCreating particles to resist the movement of dislocations
- Precipitation-hardening..... Creating particles by decreasing solubility of one phase in another

Grain growth

- Grain growth follows complete crystallization if the material is left at elevated temperatures.
- Grain growth does not need to be preceded by recovery and recrystallization; it may occur in all polycrystalline materials.
- In contrary to recovery and recrystallization, driving force for this process is reduction in grain boundary energy.
- Tendency for larger grains to grow at the expense of smaller grains is based on physics.
- In practical applications, grain growth is not desirable.
- Incorporation of impurity atoms and insoluble second phase particles are effective in retarding grain growth.
- Grain growth is very strongly dependent on temperature.

For-2015 (IES, GATE & PSUs)

Season cracking or stress-corrosion cracking.

- Brasses with more than 15% zinc often experience season cracking or stress-corrosion cracking.
- Both stress and exposure to corrosive media are required for this failure to occur (but residual stresses and atmospheric moisture may be sufficient!).
- As a result, cold-worked brass is usually stress relieved (to remove the residual stresses) before being placed in service.

IES 2007

Which one of the following elements/ alloy exhibits season cracking?

- Iron
- Brass
- Aluminium
- Steel

IAS 1994

Major operations in the manufacture of steel balls used for Ball bearings are given below

1. Oil lapping
2. Cold heading
3. Annealing
4. Hardening
5. Rough grinding

The correct sequence of these operations is

- (a) 3,2,4,1,5 (b) 3,2,1,4,5
(c) 2,3,4,5,1 (d) 2,3,5,4,1

IES 2011

Assertion (A) : The steel when heated above a certain temperature and cooled to room temperature, structure adjustment stabilizes.

Reason (R) : The modification is mainly based on cooling rate.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Strengthening mechanisms in Metals

- Ability of a metal to deform plastically depends on ease of dislocation motion under applied external stresses.
- As strengthening of a metal consist hindering dislocation motion. Dislocation motion can be hindered in many ways, thus are strengthening mechanisms in metals.
- Strengthening by methods of grain-size reduction, solid-solution alloying and strain hardening applies for single-phase metals.
- Precipitation hardening, dispersion hardening, fiber strengthening and Martensite strengthening are applicable to multi-phase metallic materials.

Strengthening by Grain Size Reduction

- This strengthening mechanism is based on the fact that crystallographic orientation changes abruptly in passing from one grain to the next across the grain boundary.
- Thus it is difficult for a dislocation moving on a common slip plane in one crystal to pass over to a similar slip plane in another grain, especially if the orientation is very misaligned.
- In addition, the crystals are separated by a thin non-crystalline region, which is the characteristic structure of a large angle grain boundary.

Contd...

- With decrease in grain size, the mean distance of a dislocation can travel decreases, and soon starts pile up of dislocations at grain boundaries. This leads to increase in yield strength of the material.
- Grain size reduction improves not only strength, but also the toughness of many alloys.
- Grain size can be controlled by rate of cooling, and also by plastic deformation followed by appropriate heat treatment.

IES-1998

Assertion (A): Refining the grain size of a polycrystalline material renders it harder and stronger.

Reason (R): Grain boundaries provide easy paths to dislocation motion.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

GATE-1998

Decreasing grain size in a polycrystalline material

- (a) Increases yield strength and corrosion resistance.
(b) Decreases yield strength and corrosion resistance
(c) Decreases yield strength but increases corrosion resistance
(d) Increases yield strength but decreases corrosion resistance.

IES 2010

Assertion (A): Polycrystalline material is stronger than ordinary one.

Reason (R): Crystals in polycrystalline material have different orientations with respect to each other.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Solid Solution

- A solid solution is formed when two metals are completely soluble in liquid state and also completely soluble in solid state. In other words, when homogeneous mixtures of two or more kinds of atoms (of metals) occur in the solid state, they are known as solid solutions.
- The more abundant atomic form is referred as solvent and the less abundant atomic form is referred as solute.
- Example is brass. Brass is a solid solution of copper (64 percent) and zinc (36 percent). In this case copper atoms are solvent atoms whereas zinc atoms are solute atoms.

Rev.0

TYPES OF SOLID SOLUTIONS

- Solid solutions are of two types.
- They are:
 - (a) Substitutional solid solutions.
 - (b) Interstitial solid solutions.

1. Substitutional Solid Solutions

- If the atoms of the solvent or parent metal are replaced in the crystal lattice by atoms of the solute metal then the solid solution is known as substitutional solid solution.
- For example, copper atoms may substitute for nickel atoms without disturbing the F.C.C. structure of nickel.
- In the substitutional solid solutions, the substitution can be either disordered or ordered.
- Hume Rothery formulated certain rules which govern the formation of substitutional solid solutions.

Solid solubility

- Extent of solid solubility in a two element system can be predicted based on Hume-Rothery conditions.
- If the system obeys these conditions, then complete solid solubility can be expected.

Hume-Rothery conditions:

- Crystal structure of each element of solid solution must be the same.
- Size of atoms of each two elements must not differ by more than 15%.
- Elements should not form compounds with each other i.e. there should be no appreciable difference in the electro negativities of the two elements.
- Elements should have the same valence.

2. Interstitial Solid Solutions

- In interstitial solid solutions, the solute atom does not displace a solvent atom, but rather it enters one of the holes or interstices between the solvent atoms.
- An excellent example is iron-carbon system which is shown in Fig.

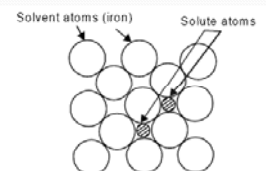


Fig. 5.2 Interstitial solid solutions

Contd...

- In this system the carbon (solute atom) atom occupies an interstitial position between iron (solvent atom) atoms.
- Normally, atoms which have atomic radii less than one angstrom are likely to form interstitial solid solutions.
- Examples are atoms of carbon (0.77 \AA), nitrogen (0.71 \AA), hydrogen (0.46 \AA), Oxygen (0.60 \AA) etc.

IES 2011

Assertion (A) : Solid solutions of metal are crystal whose properties are close to those of the solvent.

Reason (R) : They retain the same crystal lattice and type of bond.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is NOT the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

INTERMETALLIC COMPOUNDS

- Intermetallic compounds are generally formed when one metal (for example magnesium) has chemical properties which are strongly metallic and the other metal (for example antimony, tin or bismuth) has chemical properties which are only weakly metallic.
- Examples of intermetallic compounds are Mg_2Sn , Mg_2Pb , Mg_3Sb_2 and Mg_3Bi_2 .
- These intermetallic compounds have higher melting point than either of the parent metal.
- This higher melting point indicates the high strength of the chemical bond in intermetallic compounds.

For-2015 (IES, GATE & PSUs)

IES-2001

Which of the following factors govern solubility of two non-ferrous metals both in liquid state, as well as in solid state?

- | | |
|-----------------------------|----------------------------|
| 1. Crystal structure | 2. Relative size factor |
| 3. Chemical-affinity factor | 4. Relative valence factor |

Select the correct answer using the codes given below:

Codes:

- | | |
|----------------|-------------------|
| (a) 1, 2 and 3 | (b) 2, 3 and 4 |
| (c) 1 and 4 | (d) 1, 2, 3 and 4 |

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IES 2010

Consider the following:

- | | |
|----------------------|------------------|
| 1. Crystal structure | 2. Relative size |
| 3. Chemical affinity | 4. Valency |

Which of these factors govern relative solubility of two metals in each other in the solid state?

- (a) 1, 2 and 3 only
 (b) 2, 3 and 4 only
 (c) 1, 2 and 4 only
 (d) 1, 2, 3 and 4

Rev.0

IES-2006

Which one of the following factors is more relevant to represent complete solubility of two metals in each other?

- (a) Chemical affinity (b) Valency factor
(c) Crystal structure factor (d) Relative size factor

Allotropic transformation

- When metals solidify, they assume a crystalline structure; that is, the atoms arrange themselves in a geometric lattice.
- Many metals exist in only one lattice form. Some, however, can exist in the solid state in two or more lattice forms, the particular form depending on the conditions of temperature and pressure. Such metals are said to be **allotropic or polymorphic**, and the change from one lattice form to another is called an **allotropic transformation**.
- The most notable example of such a metal is iron, where the allotropic change makes it possible for heat-treating procedures to produce a wide range of final properties.
- It is largely because of its allotropy that iron has become the basis of our most important alloys.

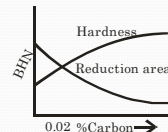
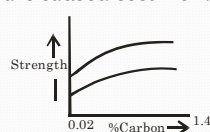
IES 2010

An allotropic material has

- (a) Fixed structure at all temperatures
(b) Atoms distributed in random pattern
(c) Different crystal structures at different temperatures
(d) Fixed structure but random atom distribution

Plain Carbon Steel

- Due to lack of tensile strength and hardness pure iron is not used.
- Most important alloy's element is carbon.
- Maximum amount of carbon that can be alloyed with iron is 6.67%.
- Alloy containing upto 2% carbon is steel and above 2% are called cast iron.



IES-2005

Consider the following statements:

- Strength of steel increases with carbon content.
- Young's Modulus of steel increases with carbon content.
- Young's Modulus of steel remains unchanged with variation of carbon content.

Which of the statements given above is/are correct?

- (a) 1 only (b) 2 only
(c) 1 and 2 (d) 1 and 3

Low-carbon steel: (less than 0.3%C)

- Good formability and weld ability but lack hardenability
- Used in hot-forming, cold-forming etc.

Medium carbon steel or Mild steel (0.3% to 0.8 % carbon)

- high toughness & ductility
- Most widely used steel
- Heat treatable (austenitizing, quenching and tempering).
- Hardenability is increased by adding Ni, Cr, Mo.
- Used in various tempered conditions.
- Typical applications: gears, railway tracks, machine parts.

High carbon steel (more than 0.8 %C)

- Hardness & wear resistance are high but Toughness & formability is very low
- Note** → purest form of Iron i.e. wrought iron has least carbon content.

IES-2005

Consider the following statements about medium carbon steel:

- It can be quench-hardened but not case-hardened.
- It cannot be quench-hardened but case-hardening can be done.
- It exhibits distinct yield point under tension test.

Which of the following statements given above are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

IES-1995

Match List I with List II and select the correct answer using the codes given below the lists:

List I (Alloy)

- A. Low carbon steel
B. Hadfield manganese steel
C. Constantan
D. Babbitt alloy

List II (Use)

1. Bearing
2. Thermocouple
3. Wire nails.
4. Bulldozer blades.

Code:	A	B	C	D	A	B	C	D	
(a)	1	2	3	4	(b)	3	4	1	2
(c)	3	2	1	4	(d)	3	4	2	1

IES-2005

Match List I (Steel) with List II (Application) and select the correct answer using the code given below the Lists:

List I	List II
A. Mild Steel	1. Ball bearing
B. Tool Steel	2. Cold chisels
C. High Carbon Steel	3. Shaft and axles
D. Medium Carbon Steel	4. Rolled steel sections

Codes: A	B	C	D
(a) 2	1	4	3
(b) 4	3	2	1
(c) 2	3	4	1
(d) 4	1	2	3

IES 2007

Which of the following factors influence in a plain carbon steel?

1. Percentage carbon
2. Quenching media
3. Work size

Select the correct answer using the code given below

- | | |
|------------------|------------------|
| (a) 1 and 2 only | (b) 2 and 3 only |
| (c) 1 and 3 only | (d) 1, 2 and 3 |

IAS-2002

Match List I (Percentage of carbon content in plain carbon steel) with List II (Application) and select the correct answer using the codes given below the lists:

List I (Percentage of carbon content in plain carbon steel)	List II (Application)
A. 0.10 - 0.20	1. Drop hammers
B. 0.30 - 0.40	2. Razors
C. 0.60 - 0.70	3. Structures
D. 1.10 - 1.40	4. Crane hooks

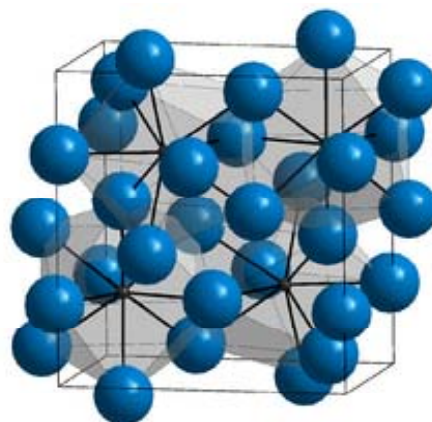
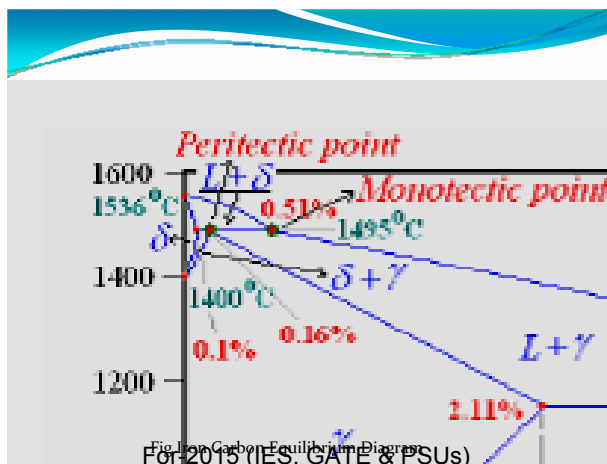
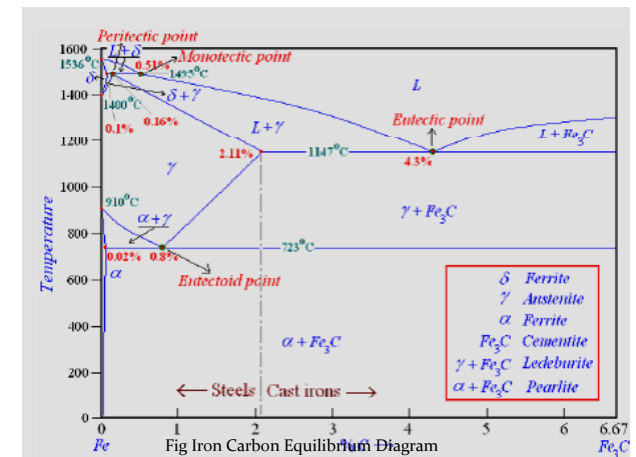
Codes: A	B	C	D
(a) 3	4	2	1
(b) 4	3	1	2
(c) 3	4	1	2
(d) 4	3	2	1

GATE-1992

The true strain for a low carbon steel bar which is doubled in length by forging is

- 0.307
- 0.5
- 0.693
- 1.0

Iron carbon equilibrium diagram



Orthorhombic Fe₃C. Iron atoms are blue.

Fe-C equilibrium diagram

- The structural form of pure iron at room temperature is called ferrite or α -iron.
- Ferrite is soft and ductile.
- Since ferrite has a body-centred cubic structure, the inter-atomic spaces are small and pronouncedly oblate, and cannot readily accommodate even a small carbon atom. Therefore, solubility of carbon in ferrite is very low, of the order of 0.006% at room temperature.
- The maximum carbon content in ferrite is 0.05% at 723 °C.

- In addition to carbon, a certain amount of silicon, manganese and phosphorous may be found in ferrite.
- The face-centred modification of iron is called austenite or γ -iron. It is the stable form of pure iron at temperatures between 910°C and 1400°C. At its stable temperature austenite is soft and ductile and consequently, is well suited for manufacturing processes.
- The face-centred cubic structure of iron has larger inter-atomic spacing than in ferrite. Even so, in FCC structure the interstices are barely large enough to accommodate carbon atoms, and lattice strains are produced. As a result, not all the interstitial sites can be filled at any one time.

Contd...

- The maximum solubility is only 2% of carbon at 1130°C.
- Above 1400°C, austenite is no longer the most stable form of iron, and the crystal structure changes back to a body-centred cubic phase called delta iron. This is the same phase as the α -iron except for its temperature range.
- The solubility of carbon in δ -ferrite is small, but it is appreciably larger than in α -ferrite, because of higher temperature. The maximum solubility of carbon in δ -iron is 0.1% at 1490°C.

Contd...

- In iron-carbon alloys, carbon in excess of the solubility limit must form a second phase, which is called iron carbide or cementite.
- Iron carbide has the chemical composition of Fe_3C . This does not mean that iron carbide forms molecules of Fe_3C but simply that the crystal lattice contains iron and carbon atoms in a three-to-one ratio.
- The compound Fe_3C has an orthorhombic unit cell with twelve iron atoms and four carbon atoms per cell, and thus has a carbon content of 6.67%.
- As compared to austenite and ferrite, cementite being an inter-metallic compound, is very hard and brittle.
- The presence of iron carbide with ferrite in steel greatly increases the strength of steel.

Contd...

- In the reaction, the simultaneous formation of ferrite and cementite from austenite results at the temperature of 723°C and composition of 0.80% carbon.
- There are nearly 12% of iron carbide and slightly more than 88% of ferrite in the resulting mixture.
- Since the ferrite and cementite are formed simultaneously, they are intimately mixed. Characteristically, the mixture is lamellar, i.e., it is composed of alternate layers of ferrite and cementite.
- This micro-structure is called pearlite which is very important in iron and steel technology, because it can be formed in almost all steels by means of suitable heat treatments.

Contd...

- The alloy containing 0.80% of carbon is called the eutectoid steel.
- Upon cooling the eutectoid steel below 723°C, all of the austenite is transformed into pearlite.
- Alloys with less than 0.80% C are called hypo-eutectoid steels and those with higher composition are called hyper-eutectoid steels.

Contd...

- Fe-Fe₃C phase diagram is characterized by five individual phases: α -ferrite (BCC) Fe-C solid solution, γ -austenite (FCC) Fe-C solid solution, δ -ferrite (BCC) Fe-C solid solution, Fe_3C (iron carbide) or cementite - an inter-metallic compound and liquid Fe-C solution and four invariant reactions:
- **peritectic reaction** at 1495 °C and 0.16%C, δ -ferrite + L \leftrightarrow γ -iron (austenite)
- **monotectic reaction** 1495 °C and 0.51%C, L \leftrightarrow L + γ -iron (austenite)
- **eutectic reaction** at 1147 °C and 4.3 %C, L \leftrightarrow γ -iron + Fe_3C (cementite) [ledeburite]
- **eutectoid reaction** at 723 °C and 0.8%C, γ -iron \leftrightarrow α -ferrite + Fe_3C (cementite) [pearlite]

Contd...

Three- phase reactions

- Suffix – ic denotes at least one liquid phase is there
- Suffix – oid all phases involve are solid

IES-2004

Consider the following temperature ranges:

- | | |
|---------------------|----------------------------------|
| 1. Room temperature | 2. 0 to 910°C |
| 3. 910°C to 1400°C | 4. 1400°C to below melting point |

In which of the above temperature ranges ferrite with body centered cubic structure is indicated in, the Fe-Fe₃C phase diagram?

- (a) 1, 2 and 4 (b) 2, 3 and 4 (c) 1 and 3 (d) 2 and 3

IES-1992

The microstructure composition of pearlite for a Fe₃C diagram consists of

- Carbon dissolved in alpha iron having a body centered cubic structure.
- Carbon dissolved in gamma iron having a face centered cubic structure.
- A mixture of body-centered alpha iron and face-centered gamma iron
- Carbon dissolved in body-centered alpha iron and an Fe, Fe₃C.

IES 2011

Liquid + solid (1) on cooling converting solid (2) reaction is known as:

- (a) Eutectoid reaction
- (b) Eutectic reaction
- (c) Peritectic reaction
- (d) Peritectoid reaction

IES 2010

Iron-carbon equilibrium diagram

- (a) Correlates the microstructure and properties of steel and cast iron
- (b) Indicates the phase changes occurring during heating and cooling
- (c) Is made by plotting carbon percentage along X-axis and temperature along Yaxis.
- (d) All of the above

IES 2010

Pearlite phase in an iron-carbide phase diagram is

- (a) Eutectic phase
- (b) Hypoeutectic mixture
- (c) Eutectoidal mixture
- (d) Hypereutectic phase

IES-1995

Match List I with List II and select the correct answer using the codes given below the lists:

List I (Name of Material) List II (% Carbon Range)

- | | | |
|-----------------------------|----|-------------|
| A. Hypo-eutectoid steel | 1. | 4.3 - 6.67 |
| B. Hyper-eutectoid steel | 2. | 2.0 - 4.3 |
| C. Hypo-eutectic cast iron | 3. | 0.8 - 2.0 |
| D. Hyper-eutectic cast iron | 4. | 0.008 - 0.8 |

Codes:	A	B	C	D	A	B	C	D	
(a)	4	3	2	1	(b)	1	3	2	4
(c)	4	1	2	3	(d)	1	2	3	4

IES-2004

An iron-carbon binary alloy has 0.5% C by weight. What is this alloy called?

- (a) Eutectoid alloy
- (b) Eutectic alloy
- (c) Hypo-eutectoid alloy
- (d) Hypereutectoid alloy

IES-1995

Eutectoid reaction occurs at

- (a) 600°C
- (b) 723°C
- (c) 1147°C
- (d) 1493°C

IES-2005

The eutectoid of carbon in iron, above lower critical temperature, when cooled, results in:

- (a) Ferrite and austenite
- (b) Ferrite and cementite
- (c) Cementite and austenite
- (d) Ferrite, cementite and austenite

GATE-1992

Match the terms used in connection with heat-treatment of steel with the micro structural/physical characteristics:

Terms	Characteristics
(A) Pearlite	(P)Extremely hard and brittle phase
(B) Martensite	(Q)Cementite is finely dispersed in ferrite
(C) Austenite	(R)Alternate layers of cementite and ferrite
(D) Eutectoid	(S)Can exist only above 723°C
	(T)Pertaining to state of equilibrium between three solid phases
	(U)Pertaining to state of equilibrium between one liquid and two solid phase

Codes:	A	B	C	D	A	B	C	D
(a)	R	P	S	T	(b)	R	S	T
(c)	T	R	P	S	(d)	T	R	S

IES-2006

Match List-I (Fe-Fe₃C Phase Diagram Characteristic) with List-II (Phase) and select the correct answer using the code given below the Lists:

List-I	List-II
A. Alpha (α) iron	1. δ iron
B. Iron carbide having crystal lattice with 3 iron and 1 carbon atom	2. Eutectic
C. BCC pure allotrope of iron is stable between 1388 °C and is melting point at 1535°C	3. Ferrite
	4. Cementite

Codes:	A	B	C	A	B	C	
(a)	4	2	3	(b)	3	4	1
(c)	4	2	1	(d)	3	1	2

IES-2002

Match List I with List II and select the correct answer:

List I (Phase diagram)

List II (Characteristic)

A. Isomorphous system

1. One liquid decomposes into another liquid and solid

B. Eutectic system

2. One liquid and another solid combine to form a new solid

C. Peritectic system

3. Two metals are completely soluble in liquid state and completely insoluble in solid state

D. Monotectic system

4. Two metals, soluble in solid and liquid state

Codes:	A	B	C	D		A	B	C	D
(a)	2	3	4	1	(b)	4	1	2	3
(c)	2	1	4	3	(d)	4	3	2	1

IES-1999

In a eutectic system, two elements are completely

- (a) Insoluble in solid and liquid states
- (b) Soluble in liquid state
- (c) Soluble in solid state
- (d) Insoluble in liquid state

IES-1993

Eutectic reaction for iron-carbon system occurs at

- (a) 600°C
- (b) 723°C
- (c) 1147°C
- (d) 1493°C

IES-2000

During peritectic solidification, one liquid

- (a) Combines with one solid to form a second new solid
- (b) Solidifies into two different solids
- (c) Forms one solid
- (d) Forms one solid and another liquid

IES 2007

Which one of the following is the correct statement?

Pearlite in iron-carbon system is a

- (a) Phase consisting of ferrite and cementite at room temperature
- (b) Mechanical mixture of ferrite and cementite at room temperature
- (c) Eutectic mixture ferrite and cementite at room temperature
- (d) All the above three are correct

IES-2005

Increase of ferrite phase in steel increases:

- (a) Strength
- (b) Hardness
- (c) Ductility
- (d) Brittleness

IES-2005

A 60 C plain carbon steel has, approximately:

- (a) 75% of pearlite and 25% of ferrite
- (b) 25% of pearlite and 75% of ferrite
- (c) 75% of cementite and 25% of ferrite
- (d) 75% of pearlite and 25% of cementite

IES-2000

Pearlite consists of

- (a) 6.67% C and 93.33% ferrite
- (b) 13% Fe and 87% cementite
- (c) 13% C and 87% ferrite
- (d) 13% cementite and 87% ferrite

IES-1997

A given steel test specimen is studied under metallurgical microscope. Magnification used is 100 X. In that different phases are observed. One of them is Fe_3C . The observed phase Fe_3C is also known as

- (a) Ferrite
- (b) Cementite
- (c) Austenite
- (d) Martensite

IES-1995

Which one of the following sets of constituents is expected in equilibrium cooling of a hypereutectoid steel from austenitic state?

- (a) Ferrite and pearlite
- (b) Cementite and pearlite
- (c) Ferrite and bainite
- (d) Cementite and martensite

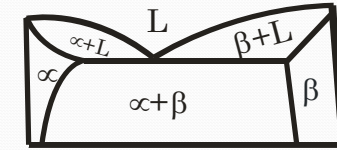
IES-2001

Martensite is a super-saturated solution of carbon in

- (a) Alpha iron
- (b) Beta iron
- (c) Gamma iron
- (d) Delta iron

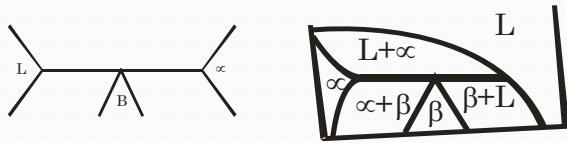
1. Eutectic (Fe-C)

- ($L_1 \rightarrow S_1 + S_2$)
- Two materials are completely soluble in liquid state and completely insoluble in solid state.



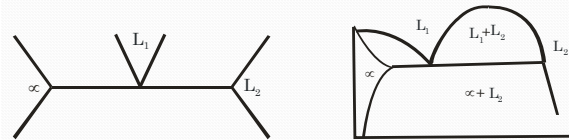
2. Peritectic (Fe-C)

- ($L + S_1 \rightarrow S_2$)
- One Liquid and another solid combine to form a new solid.



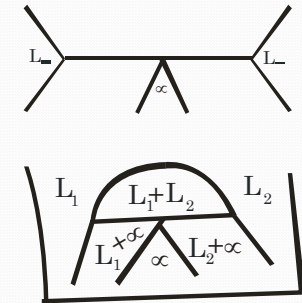
3. Monotectic FeO₂-SiO₂

- ($L_1 \rightarrow S_1 + L_2$)
- One Liquid decomposes into another liquid and solid.



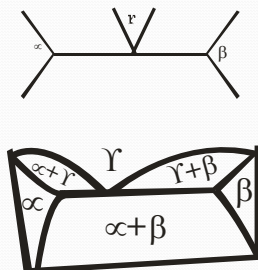
4. Syntectic Na-Zn

- ($L_1 + L_2 \rightarrow S_1$)



5. Eutectoid Fe-C

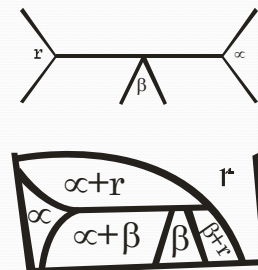
- ($S_1 \rightarrow S_2 + S_3$)



For-2015 (IES, GATE & PSUs)

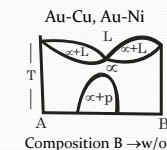
6. Peritectoid Cu-Al

- $S_1 + S_2 \rightarrow S_3$



Page 201 of 240

- **Isomorphous system:** In a binary system when there is complete inter-solubility between components in all phases, the system is isomorphous.
Ex: Cu-Ni, Al₂O₃-Cr₂O₃, NiO-MgO
- **Azeotropic system:** Some of isomorphous binary system, the liquidus touches the solid tangentially at a minimum temperature which is lower than melting temperature of either of the two components.



Composition B \rightarrow w/o

Rev.0

IES 2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I (Name of the Invariant Reaction)	List II (Invariant Reaction during cooling)
A. Monotectic	1. LIQUID.....SOLID ₁ + SOLID ₂
B. Eutectic	2. LIQUID ₁LIQUID ₂ + SOLID
C. Eutectoid	3. SOLID ₁SOLID ₁ + SOLID ₂
D. Peritectic	4. LIQUID + SOLID ₁SOLID ₂

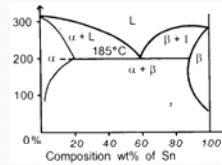
Code: A	B	C	D	A	B	C	D
(a) 3	1	2	4	(b) 2	4	3	1
(c) 3	4	2	1	(d) 2	1	3	4

IES-2004

Consider the following lead-tin phase diagram given below:

For which one of the following alloy compositions, the alloy will have the lowest melting point at 185°C

- (a) 20% Sn and 80% Pb by weight
- (b) 60% Sn and 40% Pb by weight
- (c) 97% Sn and 3% Pb by weight
- (d) 40% Sn and 60% Pb by weight

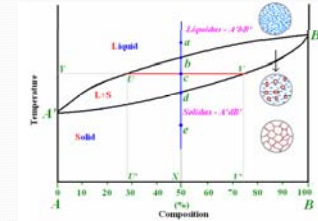


Lever Rule

- At a point in a phase diagram, phases present and their composition (tie-line method) along with relative fraction of phases (lever rule) can be computed.
- Relative amount of liquid and solid phases is given respectively by:

$$C_L = \frac{cV}{UV} \quad C_S = \frac{Uc}{UV} \quad C_L + C_S = 1$$

- Therefore it is not restricted to solid phases only.



IES-2008

Assertion (A): Lever Rule can be applied to determine relative amounts of phases present at any temperature.

Reason (R): Lever Rule is restricted to estimate relative phases, only if they are solid phases.

- (a) Both A and R are true and R is the correct explanation of A
- (b) Both A and R are true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Example

- In a binary system of A and B, if a liquid of 35% A (65% B) is co-exists with a solid of 75% A (25% B), for an overall composition of 40% A, the fraction of the liquid is given by

$$C_L = \frac{75 - 40}{75 - 35} = 0.875$$

Example: If the alloy content 60 gm of Cr_2O_3 and 40 gm of Al_2O_3 at top 2150°C. Find liquid and solid phase present in the stable.

Solution: Tie line corresponded to 2150°C intersects the liquidus of 40% w/o Cr_2O_3 and solid at 67% w/o Cr_2O_3 . Hence

$$\text{w/o Liquid} = \frac{67 - 60}{67 - 40} \times 100 = 25.93\%$$

$$\text{and w/o solid} = \frac{60 - 40}{67 - 40} \times 100 = 74.07\%$$

Fe-C alloy classification

- Fe-C alloys are classified according to wt.% C present in the alloy for technological convenience as follows:
 - Commercial pure irons % C < 0.008
 - Low-carbon/mild steels 0.008 - %C - 0.3
 - Medium carbon steels 0.3 - %C - 0.8
 - High-carbon steels 0.8 - %C - 2.11
 - Cast irons 2.11 < %C

Gibbs phase rule

- In a system under a set of conditions, number of phases (P) exist can be related to the number of components (C) and degrees of freedom (F) by Gibbs phase rule.
- Degrees of freedom refers to the number of independent variables (e.g.: pressure, temperature) that can be varied individually to effect changes in a system.
- Thermodynamically derived *Gibbs phase rule*:

$$P + F = C + 2$$

- In practical conditions for metallurgical and materials systems, pressure can be treated as a constant (1 atm.). Thus *Condensed Gibbs phase rule* is written as:

$$P + F = C + 1$$

IES-2003

According to Gibbs' phase rule, the number of degrees of freedom of an eutectic point in a binary system is

- (a) 1
- (b) 2
- (c) 0
- (d) 3

Cast Iron

Cast Iron

- The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola.
- It is primarily an alloy of iron and carbon.
- The carbon content in cast iron varies from more than 2 per cent to 4.5 per cent.
- The carbon in a cast iron is present in either of the following two forms:
 1. Free carbon or graphite, and
 2. Combined carbon or cementite.

Contd...

- The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability.
- The compressive strength of cast iron is much greater than the tensile strength.

IES 2010

Assertion (A): A cast iron specimen shall fail due to shear when subjected to a compressive load.

Reason (R): Shear strength of cast iron in compression is more than half its compressive strength.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-2005

Consider the following statements:

1. Cast Iron has poor ability to damp vibrations.
2. Cast Iron has higher compressive strength compared to that of steel.
3. Cast Iron parts are suitable where permanent deformation is preferred over fracture.

Which of the statements given above is/are correct?

- (a) 1, 2 and 3 (b) 1 and 3
(c) 3 only (d) 2 only

IES-1999

Cast iron is used for machine beds because of its high

- (a) Tensile strength
(b) Endurance strength
(c) Damping capacity
(d) Compressive strength

IES-1998

Assertion (A): Cast iron is generally hard, brittle and wear resistant.

Reason (R): Cast iron contains more than 2% carbon and as such the percentage cementite in it is higher.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IES-1997

Assertion (A): The notch sensitivity of cast iron component is zero.

Reason (R): Cast iron does not have a yield point.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is **not** the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

IAS-2003

Consider the following statements:

1. From design considerations, it is always advantageous to place cast iron ribs on the tension side rather than on the compression side.
2. Cast iron is an excellent choice for machine tool guides and frames.
3. Cast iron parts have low notch sensitivity.

Which of these statements are correct?

- (a) 1, 2 and 3 (b) 2 and 3
(c) 1 and 3 (d) 1 and 2

IES-1992

Which of the following metal shrinks most from molten state to solid state?

- (a) Cast iron
- (b) Cast steel
- (c) Brass
- (d) Admiralty metal

Types of Cast Iron

- Cast irons that were slowly cooled to room temperature consist of cementite, look whitish – white cast iron.
- If it contains graphite, look grayish – gray cast iron.
- It is heat treated to have graphite in form of nodules – malleable cast iron.
- If inoculants are used in liquid state to have graphite nodules – spheroidal graphite (SG) cast iron.

Contd...

1. Grey cast iron

- Carbon = 3 to 3.5%;
- The grey colour is due to the fact that the carbon is present in the form of free graphite.
- It has a low tensile strength, high compressive strength and no ductility.
- It can be easily machined.
- A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding action is desired.

Contd...

- The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.
- The grey cast iron is designated by the alphabets 'FG' followed by a figure indicating the minimum tensile strength in MPa or N/mm². For example, 'FG 150' means grey cast iron with 150 MPa or N/mm² as minimum tensile strength.

IES-1994

Assertion (A): Machine tool beds are generally made of grey cast iron.

Reason (R): Cast iron possesses good self-lubricating properties.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2005

Which of the following pairs are correctly matched?

(Designation of Steel/Cast Iron)	(Description)
1. Fe E 250	:Minimum tensile strength of 250 N/mm ²
2. 40 C 8	:Percentage of Manganese is 0.7% - 0.9%
3. FG 200	:Grey cast iron with ultimate tensile strength of 200 N/mm ²

Select the correct answer using the code given below:

- (a) 1 and 2
- (b) 2 and 3
- (c) 1 and 3
- (d) 1, 2 and 3

GATE-2004

The percentage of carbon in gray cast iron is in the range of

- (a) 0.25 to 0.75 percent
- (b) 1.25 to 1.75 percent
- (c) 3 to 4 percent
- (d) 8 to 10 percent

IES 2007

Vibration damping in machinery is best achieved by means of base structures made of which one of the following materials?

- (a) Low carbon steel
- (b) Nodular iron
- (c) Grey cast iron
- (d) White cast iron

IES-2003

Machine tool manufacturers prefer grey cast-iron grade 40 for producing machine columns and tables because grey cast-iron is

- 1. Heavy
- 2. Easily castable
- 3. Easily weldable
- 4. Having good damping capacity

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2
- (b) 2 and 4
- (c) 1 and 3
- (d) 3 and 4

IES-1993

Assertion (A): Fracture surface of grey cast iron is dark.

Reason (R): Failure takes place along the weak cementite plates.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

2. White cast iron

- Carbon = 1.75 to 2.3%.
- The white colour is due to fact that it has no graphite and whole of the carbon is in the form of carbide (known as cementite) which is the hardest constituent of iron.
- The white cast iron has a high tensile strength and a low compressive strength.

IES-2005

Which of the following materials is used in the manufacture of extrusion nozzles?

- (a) Grey cast iron
- (b) Malleable cast iron
- (c) White cast iron
- (d) Nodular cast iron

3. Chilled cast iron

- It is a white cast iron produced by quick cooling of molten iron.
- The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron.
- Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

4. Mottled cast iron

- It is a product in between grey and white cast iron in composition, colour and general properties.
- It is obtained in castings where certain wearing surfaces have been chilled.

5. Malleable cast iron

- The malleable iron is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, i.e. total carbon content is present in its combined form as cementite (Fe_3C).
- It is ductile and may be bent without breaking or fracturing the section.
- The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities.

Contd...

- It is used for machine parts for which the steel forgings would be too expensive and in which the metal should have a fair degree of accuracy, e.g. hubs of wagon wheels, small fittings for railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks etc.
- In order to obtain malleable iron castings, it is first cast into moulds of white cast iron. Then by a suitable heat treatment (i.e. annealing), the combined carbon of the white cast iron is separated into nodules of graphite.
- There are two process:
 1. Black-heart process,
 2. White-heart process

For-2015 (IES, GATE & PSUs)

Contd...

1. Black-heart process

- In this process the white iron castings are heated in airtight boxes out of contact with air at 850-950 deg C for 50-170 hours, depending upon the mass and thickness of the castings.
- The effect of this prolonged heating is to break down the iron carbide (cementite) of the white cast iron into small rosettes of graphite.
- The name 'black-heart' comes from the darkened appearance of the iron, when fractured, resulting from the formation of free graphite.
- It is used in the wheel hubs, break drums, conduit fitting control levers and pedals.

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2. White-heart process

- In this process the castings are packed into airtight boxes with iron oxide in the form of high-grade ore.
- They are then heated to about 1000 deg C for between 70 and 100 hours, depending upon the mass and thickness of the castings.
- The ore oxidises the carbon in the castings and draws it out, leaving a ferritic structure near the surface and a pearlitic structure near the centre of the casting.
- There will also be some fine rosettes of graphite.
- White-heart castings behave much as expected of a mild steel casting, but with the advantage of a very much lower melting point and higher fluidity at the time of casting.
- It is used in the wheel hubs, bicycle and motor cycle frame fittings, gas, water and steam pipe fittings.

Rev.0

IES-1992

Which of the following display properties similar to that of steel

1. Black-heart cast iron
 2. White-heart cast iron
 3. Gray cast iron
 4. Pig iron
- (a) 1 and 2 only (b) 3 and 4 only
(c) 2 and 4 only (d) 1 and 3 only

IES-1992

For the pipe fitting like elbow, tee, union etc. which of the following is preferred?

- (a) Pig iron
- (b) Malleable iron
- (c) Spheroidal graphite cast iron
- (d) High carbon steel

6. Nodular or spheroidal graphite cast iron

- The nodular or spheroidal graphite cast iron is also called **ductile cast iron** or **high strength cast iron**.
- This type of cast iron is obtained by adding small amounts of magnesium (0.1 to 0.8%) to the molten grey iron.
- The addition of magnesium causes the graphite to take form of small nodules or spheroids instead of the normal angular flakes.

Contd...

- It has high fluidity, castability, tensile strength, toughness, wear resistance, pressure tightness, weldability and machinability.
- It is generally used for castings requiring shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads, rolls for rolling mill and centrifugally cast products.
- SG 400/15 means spheroidal graphite cast iron with 400 MPa as minimum tensile strength and 15 percent elongation.

IES-2001

Nodular grey cast iron is obtained from the grey cast iron by adding a small amount of

- (a) Manganese
- (b) Phosphorus
- (c) Magnesium
- (d) Chromium

IES-2009

Which one of the following cast irons consists of carbon in rosette form?

- (a) White cast iron
- (b) Gray cast iron
- (c) Malleable cast iron
- (d) Nodular cast iron

IES-1995

Addition of magnesium to cast iron increases its

- (a) Hardness
- (b) Ductility and strength in tension
- (c) Corrosion resistance
- (d) Creep strength.

Wrought Iron

- It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron.
- The wrought iron is produced from pig iron by remelting it in the puddling furnace of reverberatory type.
- The wrought iron is a tough, malleable and ductile material.
- It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, water and steam pipes.

Effect of Impurities on Cast Iron

1. **Silicon.** It may be present in cast iron upto 4%. It provides the formation of free graphite which makes the iron soft and easily machinable. It also produces sound castings free from blow-holes, because of its high affinity for oxygen.
2. **Sulphur.** It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept well below 0.1% for most foundry purposes.

3. **Manganese.** It makes the cast iron white and hard. It is often kept below 0.75%. It helps to exert a controlling influence over the harmful effect of sulphur.

4. **Phosphorus.** It aids fusibility and fluidity in cast iron, but induces brittleness. It is rarely allowed to exceed 1%. Phosphoric irons are useful for casting of intricate design and for many light engineering castings when cheapness is essential.

IES-1995

Consider the following statements:

Addition of silicon to cast iron

- Promotes graphite module formation.
- Promotes graphite flake formation.
- Increases the fluidity of the molten metal.
- Improves the ductility of cast iron.

Select the correct answer using the codes given below:

- (a) 1 and 4 (b) 2 and 3
(c) 1 and 3 (d) 3 and 4

IES 2007

Piston compression rings are made of which one of the following

- (a) Cast iron (b) Bronze
(c) Aluminium (d) White metal

IES-1995

Consider the following work materials:

- Titanium
- Mild steel
- Stainless steel
- Grey cast iron.

The correct sequence of these materials in terms of increasing order of difficulty in machining is

- (a) 4,2,3,1 (b) 4,2, 1,3
(c) 2,4,3,1 (d) 2, 4, 1, 3.

IES-1994

Which of the following pairs are correctly matched?

- Lead screw nut..... Phosphor bronze
- Piston..... Cast iron.
- CamEN-31 steel
- Lead screwWrought iron.

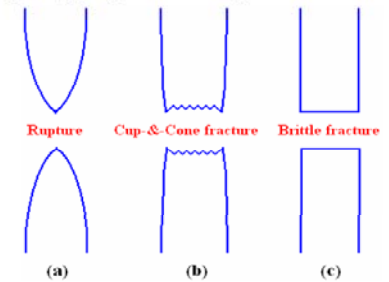
Select the correct answer using the codes given below:

Codes:

- (a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 1, 2 and 3

Fracture modes

- Ductile and Brittle are relative terms.
- Most of the fractures belong to one of the following modes: (a) rupture, (b) cup-&-cone and (c) brittle.



Ductile fracture Vs Brittle fracture

Parameter	Ductile fracture	Brittle fracture
Strain energy required	Higher	Lower
Stress, during cracking	Increasing	Constant
Crack propagation	Slow	Fast
Warning sign	Plastic deformation	None
Deformation	Extensive	Little
Necking	Yes	No
Fractured surface	Rough and dull	Smooth and bright
Type of materials	Most metals (not too cold)	Ceramics, Glasses, Ice

For-2015 (IES, GATE & PSUs)

IAS-2002

A cast iron specimen in a torsion test gives a

- (a) Cup-and-cone fracture
(b) Fracture along a plane normal to the axis of the specimen
(c) Fracture along a helix of approximately 45°
(d) Fracture along a plane inclined at 60° to the axis

Alloying Element of Steel and alloy Steel

Rev.0

Alloy Steel

- **Definition:** A steel to which one or more alloying elements other than carbon have been deliberately added (e.g. chromium, nickel, molybdenum) to achieve a particular physical property.

1. Nickel

- It increases the strength and toughness of the steel.
- These steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon.
- In this range, nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion.
- An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature.

Contd...

- It has proved to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines.
- A nickel steel alloy containing 36% of nickel is known as **invar**. It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.

IES-1992

Invar is used or measuring tapes primarily the to its

- (a) Non-magnetic properties
- (b) High nickel content
- (c) Low coefficient of thermal expansion
- (d) Hardenability

IES-2008

Coefficient of Expansion is practically nil in a particular alloy. What is this alloy?

- (a) Hadfield Manganese Steel
- (b) Invar
- (c) Vitallium
- (d) Stellite

IES 2011

Which one of the following is the major alloying element in Invar?

- (a) Aluminium
- (b) Nickel
- (c) Vanadium
- (d) Copper

2. Chromium

- It is used in steels as an alloying element to combine hardness with high strength and high elastic limit.
- It also imparts corrosion-resisting properties to steel.
- The most common chrome steels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon.
- The chrome steel is used for balls, rollers and races for bearings.
- A **nickel chrome steel** containing 3.25% nickel, 1.5% chromium and 0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.

For-2015 (IES, GATE & PSUs)

3. Tungsten

- It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour.
- It is usually used in conjunction with other elements.
- Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools.
- The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.

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IES-2004

For improving the strength of steel at elevated temperatures, which one of the following alloying element is used?

- (a) Copper
- (b) Tungsten
- (c) Aluminium
- (d) Zinc

Rev.0

4. Vanadium

- It aids in obtaining a fine grain structure in tool steel.
- The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility.
- The **chrome-vanadium steel** containing about 0.5 to 1.5% chromium, 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility.
- These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.

GATE-1997

The alloying element mainly used to improve the endurance strength of steel materials is

- (a) Nickel
- (b) Vanadium
- (c) Molybdenum
- (d) Tungsten

IES-2000

Addition of vanadium to steel results in improvement of

- (a) Heat-treatability by quenching
- (b) Hardenability
- (c) Fatigue strength
- (d) Resistance to oxidation at elevated temperature

5. Manganese

- It improves the strength of the steel in both the hot rolled and heat treated condition.
- The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required.
- The principal uses of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

IES

Alloy steel which is work hardenable and which is used to make the blades of bulldozers, bucket wheel excavators and other earth moving equipment contain iron, carbon and

- (a) Chromium
- (b) Silicon
- (c) Manganese
- (d) Magnesium.

6. Silicon

- The silicon steels behave like nickel steels.
- These steels have a high elastic limit as compared to ordinary carbon steel.
- Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.

7. Cobalt

- It gives red hardness by retention of hard carbides at high temperatures.
- It tends to decarburise steel during heat-treatment.
- It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

IES 2010

Some high speed steels have cobalt (Co) added to them in amounts ranging from 2% to 15%, since this element improves the

- (a) Cutting efficiency, especially at high temperature
- (b) Depth hardening ability of the HSS tool
- (c) Red hardness of the HSS tool
- (d) Grain structure of the HSS tool

8. Molybdenum

- A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel.
- These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels.

9. Boron

- Boron (not exceeding 0.003%) is a very powerful hardenability agent, being from 250 to 750 times as effective as nickel, 75 to 125 times as effective as molybdenum, and about 100 times as powerful as chromium.
- Only a few thousandths of a percent are sufficient to produce the desired effect in low-carbon steels, but the results diminish rapidly with increasing carbon content.
- Since no carbide formation or ferrite strengthening is produced, improved machinability and cold-forming capability often result from the use of boron in place of other hardenability additions.
- It has no effect on tensile strength of steel.

IES-1992

Small percentage of boron is added to steel to

- Increases hardenability
- Reduce machinability
- Increases wear resistance
- Increase endurance strength

10. sulphur

- It is an undesirable impurity in steel because its forms iron sulphide, which can result in cracking.
- However, in the presence of proper amount of Mn, it forms Mn S which improves the machinability of steels.
- Its content may vary from 0.06 - 0.30%.

11. Copper

- Copper has been known to resist atmospheric corrosion for centuries, but only recently has it been used as an addition to steel (in amounts from 0.10 to 0.50%) to provide this property.
- Low-carbon steel sheet and structural steels often contain a copper addition to enhance corrosion resistance, but surface quality and hot-working behavior tend to deteriorate somewhat.

Alloy Steel at a glance

Do-not form carbide: nickel, Silicon, Aluminium

Carbide forming ↑ order: Manganese, chromium, Tungsten, Molybdenum, vanadium, titanium, niobium.

- Manganese: ↑ Toughness & ductility
↑ Machinability with sulphur
- Chromium: ↑ Corrosion resistance
↑ Wear resistance
- Nickel: ↑ toughness

Contd...

- Tungsten, Molybdenum, Vanadium: → ↑ hot hardness
Tungsten → ↑ wear resistance,
Vanadium: → ↑ endurance limit
Molybdenum → ↑ creep property
- Si & Al → deoxidizer, restrict grain growth
Si → ↑ Magnetic permissibility
- Cobalt: ↓ hardenability
↑ Impact strength
- Phosphorus: reduce strength to impact ↓
conductivity of copper
- Copper: Raises yield point
- Magnesium: because light weight it is used
where weight is important.

Super alloy: Is for high temperature use [jet engine, gas turbine blade etc]

Ex: Hastelloy X

- C - 0.1%
Mn - 1%
Cr - 21.8%
Si - 1%
Ni - balance
Co - 2.5%
Mo - 9%
W - 0.6%
Fe - 18.5%

For-2015 (IES, GATE & PSUs)

IES 2011

Match List -I with List -II and select the correct answer using the code given below the lists :

List -I	List -II
A. Copper	1. Corrosion
B. Nickel	2. Demagnetization
C. Manganese	3. Non Sparking
D. Vanadium	4. Deformation restriction

Codes

	A	B	C	D		A	B	C	D
(a)	1	2	3	4	(b)	4	3	2	1
(c)	1	3	2	4	(d)	4	2	3	1

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IES - 1996

Which of the following pairs regarding the effect of alloying elements in steel are correctly matched?

- Molybdenum: Forms abrasion resisting particles.
- Phosphorus: Improves machinability in free cutting steels.
- Cobalt: Contributes to red hardness by hardening ferrite.
- Silicon Reduces oxidation resistance

Select the correct answer using the codes given below:

- (a) 2, 3 and 4 (b) 1, 3 and 4
(c) 1, 2 and 4 (d) 1, 2 and 3

Rev.0

IES-1992

Match the following:

List I (Alloying element in steel) List II (Effect)

- | | |
|---------------|-------------------------------|
| A. Lead | 1. Restricts grain growth |
| B. Aluminium | 2. Raises yield point |
| C. Copper | 3. Reduces strength to impact |
| D. Phosphorus | 4. Free machining |

Codes:	A	B	C	D	A	B	C	D
(a)	1	2	3	4	(b)	2	3	4
(c)	3	4	1	2	(d)	4	1	2

IAS-1995

Assertion(A): In high speed steels, alloying elements tungsten, chromium and vanadium are added to make them suitable to work at higher speeds than tool steel or low alloy steels.

Reason(R): Vanadium adds to the property of red hardness and tungsten and chromium add to high wear resistance.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is not the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

IAS-2002

Watch List I (Alloying elements for tool steel) with List II (Improved mechanical property) and select the correct answer using the codes given below the Lists

- | List I
(Alloying elements for tool steel) | List II
(Improved mechanical property) |
|--|---|
| A. Carbon | 1. Hardness |
| B. Manganese | 2. Hot Hardness |
| C. Chromium | 3. Lower Critical Temp |
| D. Vanadium | 4. Toughness |

Codes:	A	B	C	D	A	B	C	D
(a)	1	3	4	2	(b)	2	4	3
(c)	1	4	3	2	(d)	2	3	4

Stainless Steel

- They typical consists min.12% Cr along with other alloying elements, thus highly corrosion resistant owing to presence of chromium oxide.
- Three kinds - ferritic & hardenable Cr steels, austenitic and precipitation hardenable (martensitic, semi-austenitic) - based on presence of prominent micro-structural constituent.
- Typical applications - cutlery, surgical knives, storage tanks, domestic items.
- *Ferritic steels* are principally Fe-Cr-C alloys with 12-14% Cr. And small additions of Mo, V, Nb, Ni.

Contd...

- Austenitic steels contain 18% Cr and 8% Ni plus minor alloying elements. Ni stabilizes the austenitic phase assisted by C and N.
- For, martensitic steels Ms is made to be above the room temperature. These alloys are heat treatable. Major alloying elements are: Cr, Mn and Mo.
- Ferritic and austenitic steels are hardened and strengthened by cold work because they are not heat treatable.
- Austenitic steels are non-magnetic as against ferritic and martensitic steels, which are magnetic.

Contd...

- Austenitic stainless steels are non-magnetic and are highly resistant to corrosion 304 alloy is 18-8 when 18% chromium & 8% nickel used costly material.
- Austenitic stainless steels usually contain 18% Cr and 8% Ni in addition to other minor alloying elements. Ni stabilizes the austenitic phase assisted by C and N. Other alloying additions include Ti, Nb, Mo (prevent weld decay), Mn and Cu (helps in stabilizing austenite).
- These steels are very tough and can be forged and rolled but offer great difficulty in machining.
- These steels cannot be hardened by quenching, in fact they are softened by rapid cooling from about 1000°C.

IES-2002

The correct composition of austenitic stainless steel used for domestic utensils is

- (a) 0.08% C, 18% Cr, .8% Ni, 2% Mn, 1% Si
 (b) 0.08% C, 24% Cr, 12% Ni, 2% Mn, 1% Si
 (c) 0.15% C, 12% Cr, 0.5% Ni, 1% Mn, 1% Si
 (d) 0.30% C, 12% Cr, 0.4% Ni, 1% Mn, 1% Si

IES-2008

Consider the following statements in respect of austenitic stainless steels:

1. Austenitic stainless steels are hardened and strengthened by cold working.
2. Austenitic stainless steels cannot be quenched and tempered.

Which of the statements given above is/are correct?

- (a) 1 only (b) 2 only
 (c) Both 1 and 2 (d) Neither 1 nor 2

IES-1997

Assertion (A): Austenitic stainless steel contains 18% chromium and 8% nickel. Since it retains its austenitic structure at room temperature, it is called austenitic stainless steel.

Reason (R): Chromium present in the steel improves its corrosion resistance by forming a thin film of chromium oxide on the surface.

- (a) Both A and R are individually true and R is the correct explanation of A
 (b) Both A and R are individually true but R is not the correct explanation of A
 (c) A is true but R is false
 (d) A is false but R is true

IES-2009

Which one of the following elements is an austenitic stabilizer?

- Chromium
- Tungsten
- Nickel
- Molybdenum

IES-2009

Which one of the following elements is a ferritic stabilizer?

- Nickel
- Manganese
- Copper
- Chromium

IES-2004

Match List I (Name of alloy) with List II (Major alloying elements) and select the correct answer using the codes given below the Lists:

List I				List II			
A.	Invar			1.	Manganese		
B.	Hadfield steel			2.	Chromium		
C.	Stellite			3.	Nickel		
D.	Stainless steel			4.	Tungsten		
				5.	Molybdenum		
Codes: A B C D				A B C D			
(a)	5	1	4	2	(b)	3	2
(c)	5	2	4	1	(d)	3	1
						5	2

IES-2005

Match List I (Alloying Element) with List II (Effect on Steel) and select the correct answer using the code given below the Lists:

List I				List II			
A.	Vanadium			1.	Increases endurance strength		
B.	Molybdenum			2.	Improves creep properties		
C.	Silicon			3.	Increases hardness		
D.	Chromium			4.	Increases resistance to high temperature oxidation		
Codes: A B C D				A B C D			
(a)	2	1	3	4	(b)	1	3
(c)	2	1	4	3	(d)	1	2
						3	4

IES

Match List-I (Alloying element in steel) with List-II (Property conferred on steel by the element) and select the correct answer using the codes given below the lists:

List-I				List-II			
A.	Nickel			1.	Corrosion resistance		
B.	Chromium			2.	Magnetic permeability		
C.	Tungsten			3.	Heat resistance		
D.	Silicon			4.	Hardenability		
Codes: A B C D				A B C D			
(a)	4	1	3	2	(b)	4	1
(c)	1	4	3	2	(d)	1	4
						2	3

IES-2008

Which of the following elements given below determine(s) the maximum attainable hardness in steel?

- Chromium
 - Manganese
 - Carbon
 - Molybdenum
- elect the correct answer using the code given below:
- 1 only
 - 1 and 2
 - 3 only
 - 2 and 4

IES 2010

Consider the following statements:

Alloying elements are added to

- Improve hardness and toughness.
- Corrosion and oxidation resistance improvement.
- Improve machinability and hardenability.
- Increase weight and volume.

Which of the above statements are correct?

- 1, 2 and 3 only
- 2, 3 and 4 only
- 1, 2 and 4 only
- 1, 2, 3 and 4

DESIGNATION OF STEEL, (INDIAN STANDARD)

- Two systems of notation are recommended by IS :
 - Based on ultimate tensile strength.
 - Based on chemical composition.
- (a) Based on Ultimate Tensile Strength:** This is applicable to carbon and low alloy steels.
- The symbol consists of the letter St followed by the number representing the ultimate tensile strength in kgf/mm², for example, St 32. The new coding consists of the letter Fe followed by the number representing the ultimate tensile strength in N/mm², for example, Fe 410.

(b) Based on Chemical Composition: This type of designation is preferred if subsequent heat treatment is carried out.

1. Plain Carbon Steels: These are designated by letter C followed by a number representing the average percentage carbon content, for example, C 14 - carbon steel with 0.14% C.

- Its new designation is 14 C4. Here, the first figure indicates 100 times the average of Carbon content, then letter C, and the last figure indicates 10 times the average percentage of Mn content rounded off to the next integer.

2. Alloy Steels: Here the letter C is omitted and the numbers representing the carbon content are followed by chemical symbols for one or more of the predominant alloying elements followed by numbers indicating their average contents, for example, 15 Cr 65 - chromium steel with 0.15% C and 0.65% Cr.

- 20 Cr 18 Ni 2 - Nickel - chromium steel with 0.2% C, 18% Cr and 2% Ni.
- The coding of the alloy steels is given below :- The average alloy content upto 1 per cent, Alloy index number will be :- Average alloy content upto two decimal places, underlined by a bar. For average alloy content one per cent and above, alloy index number will be : rounded to the nearest whole number upto 0.5 rounded down and above rounded up.

IES-2001

The alloy steel designated as 40 Cr18 Ni 2 by Bureau of Indian Standards contains

- 0.4% C, 18% Cr and 2% Ni
- 4.0% C, 1.8% Cr and 0.2% Ni
- 0.4% C, 1.8% Cr and 2% Ni
- 0.4% C, 1.8% Cr and 0.2% Ni

IES-1996

18/8 stainless steel contains

- 18% stainless, 8% chromium.
- 18% chromium, 8% nickel.
- 18% tungsten, 8% nickel.
- 18% tungsten, 8% chromium.

Plastics

Plastics or polymer

- **Definition:** A group of engineered materials characterized by large molecules that are built up by the joining of smaller molecules.
- They are natural or synthetic resins.

Properties of plastics

- Light weight
- Good resistance to corrosion
- Easy of fabrication into complex shapes
- Low electrical and thermal conductivity
- Good surface finish
- Good optical properties
- Good resistance to shock and vibration.

IES 2010

Consider the following properties for plastics:

- Become hard on heating.
- Increasing plasticity.
- Ability to deform with rise in temperature.
- Long chain structure.

Which of these properties for plastics are correct?

- 1, 2, 3 and 4
- 3 and 4 only
- 1 and 4 only
- 2 and 3 only

IES 2010

Plastic material is used for the component which requires characteristics of

- Low density, machinability and high strength
- Machinability, high strength and large plastic deformation
- High strength, large plastic deformation and low density
- Low density, machinability and large plastic deformation

IAS-2007

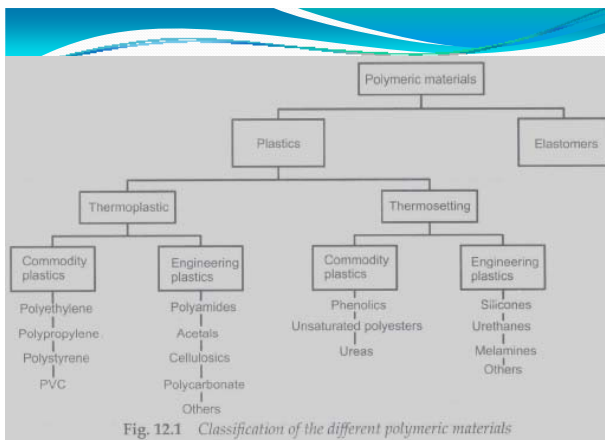
Consider the following:

Which of the following properties are possessed by plastics?

- Good resistance to corrosive atmosphere
- Ease of fabrication into complex shapes.
- Good resistance to shocks and vibrations.

Select the correct answer using the code given below:

- 1, 2 and 3
- 2 and 3 only
- 1 and 3 only
- 1 and 2 only



IES-2008

Structure of a polymer is:

- (a) Long chain
- (b) Rhombic
- (c) Cubic
- (d) Closed pack hexagonal

Classification – Polymers

- Classification based on their industrial usage:
 - (a) plastics and
 - (b) elastomers.
- Classification based on their temperature dependence:
 - (a) thermoplasts and
 - (b) thermosets

Thermoplasts

- Plastics which softens up on heating and hardens up on cooling where the softening and hardening are totally reversible processes.
- Hence thermoplasts can be recycled.
- They consist of linear molecular chains bonded together by weak secondary bonds or by inter-winding.
- Cross-linking between molecular chains is absent in thermoplasts.
- E.g.: Acrylics, PVC, Nylons, Perspex glass, etc.

Thermoplastics

- **Acrylonitrile-butadiene-styrene (ABS):**
Characteristics: Outstanding strength and toughness, resistance to heat distortion; good electrical properties; flammable and soluble in some organic solvents.
Application: Refrigerator lining, lawn and garden equipment, toys, highway safety devices.
- **Acrylics (poly-methyl-methacrylate) PMMA**
Characteristics: Outstanding light transmission and resistance to weathering; only fair mechanical properties.
Application: Lenses, transparent aircraft enclosures, drafting equipment, outdoor signs.

Contd...

- **Fluorocarbons (PTFE or TFE, Teflon)**

Characteristics: Chemically inert in almost all environments, excellent electrical properties; low coefficient of friction; may be used to 2600°C; relatively weak and poor cold-flow properties.

Application: Anticorrosive seals, chemical pipes and valves, bearings, anti adhesive coatings, high temperature electronic parts.

- **Polyamides (nylons)**

Characteristics: Good mechanical strength, abrasion resistance, and toughness; low coefficient of friction; absorbs water and some other liquids.

Application: Bearings, gears, cams, bushings, handles, and jacketing for wires and cables.

Contd...

- **Polycarbonates**

Characteristics: Dimensionally stable; low water absorption; transparent; very good impact resistance and ductility.

Application: Safety helmets, lenses light globes, base for photographic film

- **Polyethylene**

Characteristics: Chemically resistant and electrically insulating; tough and relatively low coefficient of friction; low strength and poor resistance to weathering.

Application: Flexible bottles, toys, tumblers, battery parts, ice trays, film wrapping materials.

For-2015 (IES, GATE & PSUs)

Contd...

- **Polypropylene**

Characteristics: Resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light.

Application: Sterilizable bottles, packaging film, TV cabinets, luggage

- **Polystyrene**

Characteristics: Excellent electrical properties and optical clarity; good thermal and dimensional stability; relatively inexpensive

Application: Wall tile, battery cases, toys, indoor lighting panels, appliance housings.

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Contd...

Chemical Classification	Trade name	Characteristics	Typical Applications
1. Cellulose acetate	Tenite 1 plastacel Fibestos Lumarith	Nonflammable, good dielectric, good toughness, high impact strength, moulding and fabricating versatility, available in wide range of colours, dimensional stability may not be good.	Machine guards and covers, tool and cutlery handles, toys and knobs. Brush backs, Jewellery. Electrical insulation.
2. Cellulose	Celluloid pyralin Nitron Pyrosylm	Flammable, but otherwise same as cellulose acetate. Oldest commercial plastic.	Toilet articles, moviefilm. Drawing instruments. Piano and typewriter keys.
3. Methyl	Lucite plexiglass Crystalite	Light weight, weather resistant. Best of plastics for light piping, transmission and edge illumination effects.	Aircraft cockpits and windows outdoor signs
4. Polyamide	Nylon zytel	Low co-efficient of friction. Dimensional stability. Good electrical properties. Not affected by gasoline or hydraulic fluids. Bearings can operate without lubricant. Abrasion resistance.	Small moulded gear and bushings brush bristles fuel container coatings.

Rev.0

5. Polyethylene	Alathon Polythene	Flexible and tough. Excellent dielectric properties. Flammable but slow burning. Dimensional variations difficult to predict.	Automotive parts, House wares, containers, electrical cable jacketing, tubing, Squeeze bottles.
6. Polystyrene	Lystrex Styron Cetex	Resistant to acids and alkalis. Good dimensional stability. Good electrical properties.	Electrical insulation, containers and closures. Instrument panels, knobs, wall tile, radio cabinets.
7. Polytetrafluoroethylene (PTFE)	Teflon	Low co-efficient of friction. Resistance to chemical attack. Tough at low temperature. Bushings can operate without lubricant in presence of abrasives.	Gaskets, packings, seals, bushings, lining for pipe and vessels. Non stick surfacing. Electrical insulation.
8. Polyvinyl Chloride	Vinylite Q Koroseal Tygon Geen	Flame resistant. Resistant to chemicals, oils, and solvents. Abrasion resistant. Sound and vibration deadening.	Automotive panels, parts for vacuum cleaners and refrigerators, floor coverings, pipe fittings, tanks, balls and floats.

IES 2011

Windows of aeroplane are made of :

- (a) PVC
- (b) PTFE
- (c) PMMA
- (d) PEEK

IES-2003

Teflon is a

- (a) Thermosetting fluorocarbon polymer
- (b) Thermo-plastic fluorocarbon polymer
- (c) Inorganic compound of fluorine and carbon
- (d) Laminated phenolic material

IES-1992

Polyamides are characterized by

- (a) Flexible chain
- (b) Rigid chain
- (c) Amorphous structure
- (d) Crystalline structure

IES-2002

Consider the following statements:

Polytetrafluoroethene is

1. A thermoplastic material
2. Having high friction coefficient
3. A thermosetting material
4. Having low friction coefficient
5. An electric insulator
6. Non sticking to surfaces

Which of the above statements are correct?

- (a) 1, 2 and 5
- (b) 2, 3 and 6
- (c) 3, 4 and 5
- (d) 3, 2 and 5

IAS-2000

Weldable type plastic(s) include (s)

- (a) Thermosets alone
- (b) Thermoplastics alone
- (c) Both thermosets and thermoplastics
- (d) Neither thermosets and thermoplast

IES-1995

The structure of a polymer is shown in the given



Finds special application in

- (a) Packaging
- (b) Adhesives
- (c) Bearings
- (d) Fertilizer

Thermosets

- Plastics which are 'set' under the application of heat and/or pressure.
- This process is not reversible, hence thermosets can not be recycled.
- They consist of 3-D network structures based on strong covalent bonds to form rigid solids. linear molecular chains bonded together by weak secondary bonds or by interwinding.
- Characterized by high modulus / rigidity / dimensional stability when compared with thermoplasts.
- E.g.: Epoxies, Amino resins, some polyester resins, etc.

- Thermosets are strengthened by reinforcements .
- Different reinforcements are in use according to the necessity. Glass fibers are most commonly used to form structural and molding plastic compounds.
- Two most important types of glass fibers are E (electrical)- and S (high strength)- glasses.
- E-glass (lime-aluminium-borosilicate glass with zero or low sodium and potassium levels) is often used for continuous fibers.
- S-glass (65%SiO₂, 25%Al₂O₃ and 10% MgO) has higher strength-to-weight ratio and is more expensive thus primary applications include military and aerospace applications.
- Carbon fiber reinforced plastics are also often used in aerospace applications. However they are very expensive.

- The other classes of reinforcements include **aramid** (aromatic polyamide) fibers.
- They are popularly known as **Kevlar**.

IES 2011

Kevlar Epoxy composite is widely used in :

- Automobiles
- Aerospace
- Navy
- Interior Decoration

Examples – Thermo setting polymers

• Epoxies

Characteristics: Excellent combination of mechanical properties and corrosion resistance; dimensionally stable; good adhesion; relatively inexpensive; good electrical properties.

Application: Electrical moldings, sinks, adhesives, protective coatings, used with fiberglass laminates.

• Phenolics

Characteristics: Excellent thermal stability to over 1500 C; may be compounded with a large number of resins, fillers, etc.; inexpensive.

Application: Motor housing, telephones, auto distributors, electrical fixtures.

Contd...

• Polyester (PET or PETE)

Characteristics: One of the toughest of plastic films; excellent fatigue and tear strength, and resistance to humidity acids, greases, oils and solvents

Application: Magnetic recording tapes, clothing, automotive tire cords, beverage containers.

Chemical classification	Trade name	characteristics	Typical application
Epoxy	Araldite oxiron	Good toughness. Resistant to acids, alkalis and solvents. excellent adhesion to metal, glass and wood.	Adhesive and coatings, tools and dies, filament wound vessels, laminates for aircraft, patching compound for metal and plastics.
Melamine-formaldehyde		Good for application requiring cycling between wet and dry conditions. Hard and abrasion resistant. Good dielectric.	Table-ware, electric insulation, automotive Ignition parts, cutlery handles, jars and bowls.

Phenol-formaldehyde	Bakelite Marblette Durez Cataljn	Good dimensional stability Excellent insulating qualities. Inert to most solvents and weak acids. Good strength around inserts.	Industrial electrical parts. automotive electrical components, paper impregnated battery separators. Electrical insulation.
Phenol-furfural	Durite	Similar to Phenolfonnaldehyde.	Electrical insulation. Mechanical parts. Housings and containers.
Alkyd (Modified polyester)	Glyptal Duraplex Beckosol Teglac Rezly	Can be made flexible, resilient or rigid. Can resist acids but not alkalis, with glass fibre reinforcement resists salt water and fungus growth.	Boats, Tanks, Trailer and Tractor components. Ducts, shrouds. Vaulting poles.

IES-1997

Match List-I with List-II and select the correct answer using the codes given below the Lists:

List-I

- Neoprene
- Bakelite
- Foamed polyurethane
- Araldite

List-II

- Electric switches
- Adhesive
- Thermal insulator
- Oil seal

Code:	A	B	C	D		A	B	C	D
a)	4	1	2	3	(b)	1	4	2	3
c)	4	1	3	2	(d)	1	4	3	2

IES-1992

Assertion (A): Linear polymers are rigid at low temperatures but soft and mouldable at elevated temperatures.

Reason (R): Linear polymers are thermo-setting.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is **not** the correct explanation of A
- A is true but R is false
- A is false but R is true

IES

Consider the following statements:

Fibre Reinforced Plastics are

- Made of thermosetting resins and glass fibre
- Made of thermoplastic resins and glass fibre
- Anisotropic
- isotropic

Select the correct answer using the codes given below:

- 1 and 4
- 1 and 3
- 2 and 3
- 2 and 4

IES-1994

Match List I (materials) with List II (applications) and select the correct answer using the codes given below the Lists:

List I				List II			
A. Engineering ceramics				1.	Bearings		
B. Fibre reinforced plastics				2.	Control rods in nuclear reactors		
C. Synthetic carbon				3.	Aerospace industry		
D. Boron				4.	Electrical insulator		
Codes:A	B	C	D	(a)	1	4	3
(a)	1	2	3	(b)	1	4	3
(c)	2	3	1	(d)	4	3	1

IES 2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I (Material)				List II (Application)			
A. Fibre reinforced plastics				1.	Automobile tyres		
B. Acrylics				2.	Aircraft		
C. Phenolics				3.	Lenses		
D. Butadiene rubber				4.	Electric switch cover		
Code:A	B	C	D	(a)	1	4	3
(a)	1	4	3	(b)	2	3	4
(c)	1	3	4	(d)	2	4	3

IES-2006

Phenol formaldehyde is a/an

- (a) Thermoplastic polymer (b) Thermoset polymer
(c) Elastomer (d) Rubber

IES

Consider the following statements:

Thermosetting plastics are

- Formed by addition polymerisation.
- Formed by condensation polymerisation.
- Softened on heating and hardened on cooling for any number of times
- Moulded by heating and cooling.

Select the correct answer using the codes given below:

- (a) 1 and 3 (b) 2 and 4
(c) 1 and 4 (d) 2 and 3

IES-1999

Consider the following pairs of plastics and their distinct characteristics:

- Acrylics Very good transparency to light
- Polycarbonate..... Poor impact resistance
- PTFELow coefficient of friction.
- Polypropylene.... Excellent fatigue strength

Which of these pairs are correctly matched?

- (a) 2 and 3 (b) 1 and 3
(c) 1 and 4 (d) 2 and 4

IES

Match List I with List II and select the correct answer

List I (Material)				List II (Nature of product)			
A. Polyethylene				1.	Adhesive		
B. Polyurethane				2.	Film		
C. Cyano-acrylate				3.	Wire		
D. Nylon				4.	Foam		
Codes:A	B	C	D	(a)	2	4	3
(a)	2	4	3	(b)	4	2	3
(c)	2	4	1	(d)	4	2	1

IAS-2003

Consider the following statements:

- Thermoplastics possess a strong intermolecular bonding compared to that of thermosetting plastics.
- Plastics have a high creep under continuous loading.
- Embrittlement occurs in plastics at low temperature.

Which of these statements are correct?

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

Elastomers

- These polymers are known for their high elongations, which are reversible upon release of applied loads.
- They consist of coil-like molecular chains, which straightens up on application of load.
- Characterized by low modulus / rigidity / strength, but high toughness.
- E.g.: natural and synthetic rubber.

Polymer synthesis

- Processing of polymers primarily limits to synthesis followed by forming.
- Polymers are synthesized by process known as polymerization.
- Polymerization is process in which multi-functional monomers are attached to form linear/3-D macro molecular chains.

Addition Polymerization

- This polymerization process involves single kind of monomers. Resultant macro-molecule's composition is an exact multiplication of composition of individual monomer.
- Process involves three stages namely initiation, propagation and termination.
- Initiation process will be started by an initiator (e.g. benzoyl peroxide) which forms an reactive site where carbon atom of another monomer is attracted, upon which reaction site transfers to different place leading to molecular chain growth.
- As molecular chain grows longer, reaction rate decreases. However the growth process is terminated either by the combination or *disproportionation* process.

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- Initiation process will be started by an initiator (e.g. benzoyl peroxide) which forms an reactive site where carbon atom of another monomer is attracted, upon which reaction site transfers to different place leading to molecular chain growth.
- As molecular chain grows longer, reaction rate decreases. However the growth process is terminated either by the combination or *disproportionation* process.

Addition Polymerization

E.g., polyethylene

$$\begin{array}{c} \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \\ | \quad | \qquad \qquad | \quad | \\ \text{R} - \text{C} = \text{C} \longrightarrow \text{R} - \text{C} - \text{C} \\ | \quad | \qquad \qquad | \quad | \\ \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \end{array}$$

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \quad | \quad | \\ \text{R} - \text{C} - \text{C} - \text{C} = \text{C} \longrightarrow \text{R} - \text{C} - \text{C} - \text{C} - \text{C} \\ | \quad | \quad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{R} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} + \text{C} - \text{C} - \text{C} - \text{C} - \text{R} \longrightarrow \\ | \quad | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$

Combination:

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{H} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} + \text{C} - \text{C} - \text{C} - \text{C} - \text{R} \longrightarrow \\ | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{R} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{R} \\ | \quad | \quad | \quad | \quad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$

Disproportionation:

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \quad | \quad | \\ - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} + \text{R} \longrightarrow \text{C} - \text{C} - \text{C} - \text{C} - \text{R} \\ | \quad | \quad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$
$$\begin{array}{c} \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \\ | \quad | \qquad \qquad | \quad | \\ \text{R} - \text{C} = \text{C} \longrightarrow \text{R} - \text{C} - \text{C} \\ | \quad | \qquad \qquad | \quad | \\ \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \end{array}$$

$$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ | \quad | \quad | \quad | \qquad \qquad | \quad | \quad | \quad | \\ \text{R} - \text{C} - \text{C} - \text{C} = \text{C} \longrightarrow \text{R} - \text{C} - \text{C} - \text{C} - \text{C} \\ | \quad | \quad | \quad | \qquad \qquad | \quad | \quad | \quad | \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \qquad \qquad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$$
$$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | & | & | & | \\ \text{R}-\text{C}-\text{C}-\text{C}-\text{C}+\text{C}-\text{C}-\text{C}-\text{R} \longrightarrow \\ | & | & | & | & | & | & | \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$$

$$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | & | & | & | \\ \text{R}-\text{C}-\text{C}-\text{C}-\text{C}+\text{C}-\text{C}-\text{C}-\text{R} \longrightarrow \\ | & | & | & | & | & | & | \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$$

$$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | & | & | & | \\ \text{R}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{I} \\ | & | & | & | & | & | & | \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$$
$$\begin{array}{ccccccc} \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | & & | & | & | & | \\ -\text{C} & -\text{C} & -\text{C} & -\text{C} & + \text{R} \longrightarrow & -\text{C} & -\text{C} & -\text{C} & -\text{C}-\text{R} \\ | & | & | & | & & | & | & | & | \\ \text{H} & \text{H} & \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$$

Condensation Polymerization

- It involves more than one monomer species. This process is also known as step growth polymerization.
- In condensation polymerization, smaller macromolecule by-product such as water is eliminated.
- No resultant product has the chemical formula of mere one monomer.
- Repeat unit in condensation process itself is product of polymerization involving basic constituents.
- Reaction times for condensation polymerization is usually longer than those for addition polymerization.

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- Reaction times for condensation polymerization is usually longer than those for addition polymerization.

Condensation Polymerization

- Formation of a polyester from Ethylene glycol and Adipic acid

Ethylene glycol Adipic acid

$$\begin{array}{c} \text{H} & \text{H} \\ | & | \\ \text{HO}-\text{C}-\text{C}-\text{OH} \\ | & | \\ \text{H} & \text{H} \end{array} + \begin{array}{c} \text{O} \\ || \\ \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & | & | \\ \text{C}-\text{C}-\text{C}-\text{C}-\text{C} \\ || & & & & || \\ \text{O} & & & & \text{OH} \end{array} \longrightarrow$$

$$\begin{array}{c} \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} \\ | & | & & | & | & | & | \\ \text{HO}-\text{C}-\text{C}-\text{O}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{O} \\ | & | & & & & & & | \\ \text{H} & \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} & \text{OH} \end{array} + \text{H}_2\text{O}$$

- [illegible]

- Polyesters, phenol-formaldehyde, nylons, polycarbonates etc are produced by condensation polymerization.
- Condensation polymerization reactions also occur in sol-gel processing of ceramic materials.
- Polymers, unlike organic/inorganic compounds, do not have a fixed molecular weight. It is specified in terms of **degree of polymerization** – number of repeat units in the chain or ratio of average molecular weight of polymer to molecular weight of repeat unit.

Contd...

- **Average molecular weight** is however defined in two ways. Weight average molecular weight is obtained by dividing the chains into size ranges and determining the fraction of chains having molecular weights within that range.
- **Number average molecular weight** is based on the number fraction, rather than the weight fraction, of the chains within each size range. It is always smaller than the weight average molecular weight.

IES-2001

The molecular weight of vinyl chloride is 62.5. Thus the molecular weight of a polyvinyl chloride with a degree of polymerization of 20000 is

(a) $\frac{20000}{62.5}$ (b) $\frac{62.5}{20000}$

(c) 62.5×20000 (d) 20000

For-2015 (IES, GATE & PSUs)

(a) $\frac{20000}{62.5}$ (b) $\frac{62.5}{20000}$

(c) 62.5×20000 (d) 20000

IES-2003

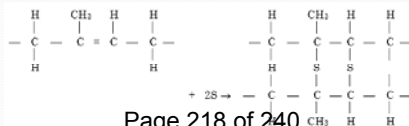
In the case of rubber, vulcanization refers to the process of producing a

- (a) Linear polymer
- (b) Branched polymer
- (c) Cross-linked polymer
- (d) Net-work polymer

Rev 0

- Linear polymer
- Branched polymer
- Cross-linked polymer
- Net-work polymer

- **Cross linking:** The cross-linking can occur due to the presence of some elements called vulcanizing agents, e.g. S, Se, Te, and O_2 .
 - In case of poly isoprene (natural rubber), the sulphur bridges are formed between two macromolecules during vulcanization.
 - In this vulcanization process sulphur bridge are formed at the point of opening of double bonds. If the number of cross-links is small; the final product is soft and flexible. The stiffness of the polymeric material increases with the density of cross-lines. When the sulphur content in rubber is as high as 32 weight percent, the hard product is called **ebonite**.
- + 28 \rightarrow
- Page 218 of 240



IES-2006

Assertion (A) In Addition Polymerization method, polymer is produced by adding a second monomer to the first, then a third monomer to this dimer and so on.

Reason (R): There must exist at least one double bond in the monomer for Addition Polymerization reaction.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-2000

Assertion (A): Addition polymerization is a primary summation of individual molecules into long chains,

Reason (R): In addition polymerization, the reaction produces a small molecule as by-product.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES-1994

Which of the following pairs of plastics and their modes of formation are correctly matched?

- 1. Polythene..... Condensation polymerization.
- 2. PolycarbonateAddition polymerisation.
- 3. Polystyrene..... Addition polymerisation.
- 4. PolyamideEither by addition or by condensation polymerisation.

Select the correct answer using the codes given below:

- (a) 1 and 2
- (b) 2 and 4
- (c) 1 and 4
- (d) 3 and 4

IES-2008

What is the process by which two or more chemically different monomers are polymerised to form a cross link polymer together with a by-product such as water or ammonia, known as?

- (a) Addition polymerization
- (b) Co-polymerisation
- (c) Linear polymerisation
- (d) Condensation polymerization

IES-2003

Polyesters can be defined as the condensation products of

- (a) Dicarboxylic acids with dihydroxy alcohols
- (b) Bisphenol-A and epichloro-hydrin
- (c) Phenol and formaldehyde
- (d) Benzene and toluene

Additives to Polymers

- The properties of polymers can be further modified by the addition of agents which are basically of two types.
- Those that enter the molecular structure are usually called "additives", whereas those that form a clearly defined second phase are called "fillers".

Contd...

1. Plasticizers

- Plasticizers are liquids of high boiling point and low molecular weight, which are added to improve the plastic behaviour of the polymer.
- They are essentially oily in nature. Organic solvents, resins and even water are used as plasticizers.

2. Fillers

- A filler is used to economize on the quantity of polymer required and/or to vary the properties to some extent, for example, mechanical strength, electrical resistance etc.
- A filler, whose function is to increase mechanical strength, is termed a "reinforcing filler".
- A filler is commonly fibrous in nature and is chemically inert with respect to the polymer with which it is to be used.
- Common fillers are wood flour, cellulose, cotton flock, and paper (for improving mechanical strength); mica and asbestos (for heat resistance); talc (for acid resistance). Other filler materials are : fabric, chipped-wood moulding compound, wood veneer, textile or glass fibres.
- The commonly used "reinforcing filler agents" with plastics are : fibres/filaments of glass, graphite or boron.

3. Catalysts:

- These are usually added to promote faster and more complete polymerization and as such they are also called 'accelerators' and 'hardeners' e.g., ester is used as a catalyst for Urea Formaldehyde.

4. Initiators:

- As the name indicates, the initiators are used to initiate the reaction, that is, to allow polymerization to begin. They stabilize the ends of the reaction sites of the molecular chains. H_2O_2 is a common initiator.

5. Dyes and Pigments:

- These are added, in many cases, to impart a desired colour to the material.

Rev.0

6. Lubricants:

- Lubricants are added to the polymers for the following purposes : to reduce friction during processing, to prevent parts from sticking to mould walls, to prevent polymer films from sticking to each other and to impart an elegant finish to the final product. Commonly used lubricants include : oils, soaps and waxes.

7. Flame retardants:

- Most plastics will ignite at sufficiently high temperatures. The non-inflammability of the plastics can be enhanced either by producing them from less inflammable raw materials or by adding "flame retardants". The common flame retardants are : compounds of chlorine, bromine and phosphorous.

8. Solvents:

- Solvents are useful for dissolving certain fillers or plasticizers and help in manufacturing by allowing processing in the fluid state. For example, alcohol is added in cellulose nitrate plastics to dissolve Camphor. However, subsequently, the solvents must be removed by evaporation.

9. Stabilisers and anti-oxidants are added to retard the degradation of polymers due to heat, light and oxidation.

10. Elastomers are added to plastics to enhance their elastic properties.

Note: Above, excepting fillers, all other materials used, fall under the category of "Additives".

IES-1992

Fillers are added to plastics to

- (a) Improve flow
- (b) Reduce brittleness
- (c) Facilitate process ability
- (d) Reduce cost

IAS-2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I
(Additive for Polymers)

- A. Plasticizer
- B. Filler
- C. Initiator

List II
(Purpose)

- 1. Allows polymerization to begin
- 2. Colours the material
- 3. Acts as internal lubricants
- 4. Improves strength

Code:	A	B	C		A	B	C
(a)	1	4	3	(b)	3	2	1
(c)	1	2	3	(d)	3	4	1

IAS-1998

Match List - I (Name of moulding composition to prepare plastics) with List-II (Property of moulding composition) and select the correct answer using the codes given below the lists:

List - I

- A. Binder
- B. Filler
- C. Plasticizer
- D. Lubricant

List - II

- 1. Reduce cost, shrinkage
- 2. Make the moulding of plastic easier
- 3. Cellulose derivatives
- 4. Accelerate condensation and polymerization
- 5. Toughness and resistance to temperature.

Codes:	A	B	C	D		A	B	C	D
(a)	3	1	2	5	(b)	3	1	5	2
(c)	5	3	1	4	(d)	3	5	1	4

IAS 1994

To reduce the consumption of synthetic resins, the ingredient added is

- (a) Accelerator
- (b) Elastomer
- (c) Modifier
- (d) Filler

Plastic Process

- The common forms of raw materials for processing plastics into products are :- pellets, granules, powders, sheet, plate, rod and tubing.
- Liquid plastics are used especially in the fabrication of reinforced - plastic parts.
- Thermoplastics can be processed to their final shape by moulding and extrusion processes.
- However, extruding is often used as an intermediate process to be followed by other processes, for example, vacuum forming or machining.

Injection Moulding

- The polymer is melted and then forced into a mould.
- Thermoplastic pellets melted and melt injected under high pressure (70 MPa) into a mold. Molten plastic takes the shape of the mold, cools, solidifies, shrinks and is ejected.
- Molds usually made in two parts (internal and external part).
- Use of injection molding machine mainly used for thermoplastics (gears, cams, pistons, rollers, valves, fan blades, rotors, washing machine agitators, knobs, handles, camera cases, battery cases, sports helmets etc...)

– thermoplastic & some thermosets

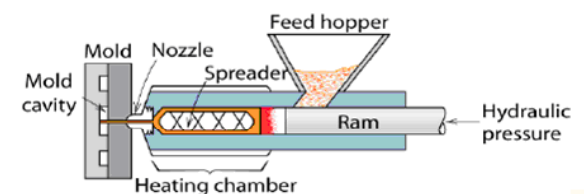


Fig. Injection moulding

Extrusion

- Long plastic products with uniform cross sections are readily produced by the extrusion process.
- Thermoplastic pellets & powders are fed through a hopper into the barrel chamber of a screw extruder. A rotating screw propels the material through a preheating section, where it is heated, homogenized, and compressed, and then forces it through a heated die and onto a conveyor belt.
- As the plastic passes onto the belt, it is cooled by jets of air or sprays of water which harden it sufficiently to preserve its newly imparted shape.
- It continues to cool as it passes along the belt and is then either cut into lengths or coiled.

Contd...

- The process is continuous and provides a cheap and rapid method of moulding.
- Common production shapes include a wide variety of solid forms, as well as tubes, pipes, and even coated wires and cables.

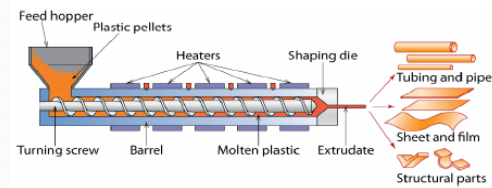


Fig. Extrusion

Compression moulding

- A compression mould is made of two halves with one each being connected to the platens of the press.
- The mould is electrically heated to maintain the required temperature.
- Material is placed in the mould, and it is closed with a hydraulic cylinder, or toggle clamp.
- The pressure maintained on the material is of the order of 14 to 40 MPa of moulding area.
- As the material comes in contact with the heated mould surface, it softens and fills the entire cavity and at the same time initiates the chemical reaction which cures the part.

Contd...

- Cure time is determined by the thickest cross section, mould temperature, material type and grade.
- After curing, the mould opens and the part is ejected.
- The most widely used plastic is phenol-formaldehyde, commonly known as 'Bakelite'.

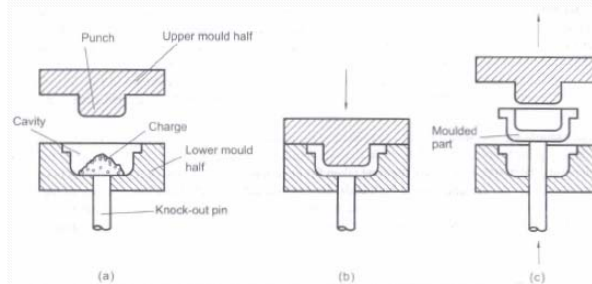
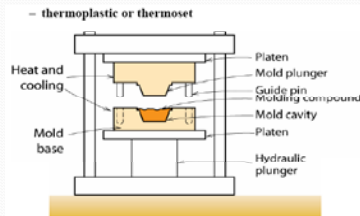


Fig. 12.20 Steps in compression moulding for thermosetting materials

Transfer Moulding

- Transfer moulding is very similar to compression moulding and is developed to avoid the disadvantages found in that process.
- In this method, thermosetting charge is heated and compressed in a separate chamber and then injected into the closed mould where it is allowed to cool and solidify.
- Transfer moulding is capable of moulding part shapes that are more intricate than compression moulding but not as intricate as injection moulding.

Contd...

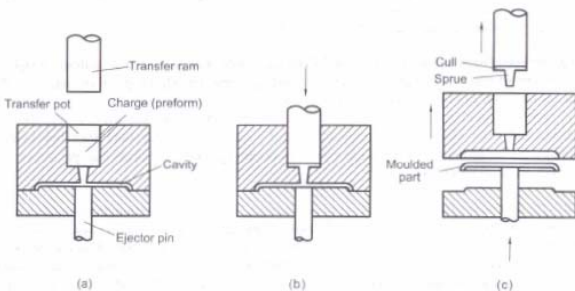


Fig. 12.21 Steps in transfer moulding for thermosetting materials

For-2015 (IES, GATE & PSUs)

Blow moulding

- Blow moulding is the process of inflating a hot, hollow, thermoplastic preform or parison inside a closed mould so that its shape conforms to that of the mould cavity.
- Typical parts made are bottles, toys, air ducts of automobiles, chemical and gasoline tanks, and a number of household goods.

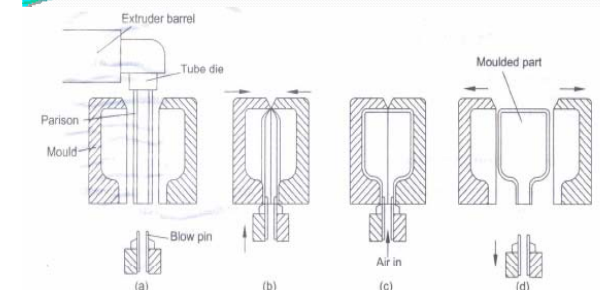


Fig. 12.13 Operating steps in a blow-moulding operation: (a) Hollow parison is formed with the extruder (b) Mould closes around the parison and blow pin inserted (c) Air is blown into the parison thus expanding it to conform to the contours of the mould (d) Mould opens and the finished part is removed

Rev.0

IES-2005

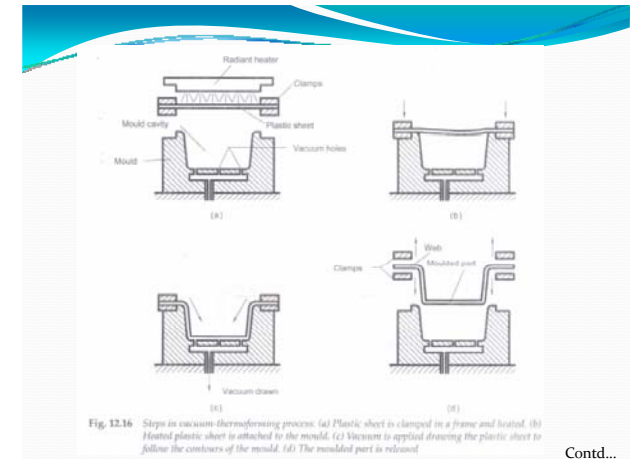
Thermoplastic materials cannot be produced by:

- Injection moulding process
- Extrusion process
- Blow moulding process
- Both (a) and (b) above

Thermoforming

- In this process, a thermoplastic sheet can be formed into a three-dimensional shape by the application of heat and differential pressures.
- First, the plastic sheet is clamped to a frame and uniformly heated to make it soft and flowable.
- Then a differential pressure (either vacuum or pressure or both) is applied to make the sheet conform to the shape of a mould or die positioned below the frame.
- It is possible to use most of the thermoplastic materials. The starting material is a plastic sheet of uniform thickness.
- It is a relatively simple process and is used for making such parts as covers, displays, blister packaging, trays, drinking cups and food packaging.

Contd...



Contd...

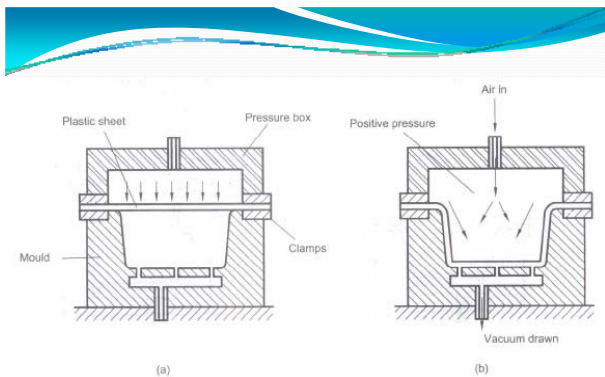


Fig. 12.17 Steps in pressure thermoforming process: (a) Plastic sheet is clamped in a frame, attached to the mould and heated. (b) Pressure applied on the top forces the plate to follow the contour of the mould. Vacuum is applied from the bottom to assist the forming process.

IES-2004

Match List I (Type of moulding) List II (Mechanism involved) and select the correct answer using the codes given below the Lists:

List I	List II
A. Compression moulding	1. Mould cavity must be heated to cure the plastic forced into it.
B. Injected moulding	2. Similar to Hydraulic extrusion
C. Jet moulding	3. Analogous to the hot pressing of powdered metals
D. Extrusion moulding	4. Analogous to die casting of metals
A B C D	A B C D
(a) 2 4 1 3	(b) 3 1 4 2
(c) 2 1 4 3	(d) 3 4 1 2

IES-2009

Match List-I with List-II and select the correct answer using the code given below the Lists:

List-I (Article)	List-II (Processing Method)
A. Disposable coffee cups	1. Rotomoulding
B. Large water tanks	2. Expandable bead moulding
C. Plastic sheets	3. Thermoforming
D. Cushion pads	4. Blow moulding
	5. Calendering
Code: A B C D	A B C D
(a) 3 5 1 2	(b) 4 5 1 2
(c) 4 3 2 1	(d) 3 1 5 2

IAS-1999

Which one of the following are the processes for thermosetting materials?

- Compression
- Transfer moulding
- Injection moulding
- Extrusion

Select the correct answer using the codes given below:

- 1 and 4
- 1 and 2
- 2 and 3
- 2, 3 and 4

IAS-2007

Which one of the following statements is not correct?

- In injection die moulding, exact amount of material to fill the cylinder is delivered
- Injection die moulding is generally limited to forming thermoplastic material
- Thermosetting plastics are more suitable for extrusion moulding
- Extrusion moulding process is used for giving shapes, such as rods, tubes, pipes, ropes etc.

IAS-2004

Which of the following are the characteristics of the injection moulding of plastics?

- It is the most economical method of mass producing a single item
- In most cases finished products are obtained
- There is lot of waste of thermoplastic since the runners and sprues can not be reused.

Select the correct answer by using the following codes:

- 1 and 2
- 2 and 3
- 1 and 3
- 1, 2 and 3

IAS-2003

Consider the following statements in respect of fabrication of plastic products:

1. Compression moulding is analogous to hot pressing of powdered metals.
2. Jet moulding is a modification of compression moulding.
3. Injection moulding is analogous to die casting of metals
4. Transfer moulding is similar to hydraulic extrusion.

Which of these statements are correct?

- (a) 1 and 2 (b) 1 and 3
(c) 1, 2 and 4 (d) 2, 3 and 4

IAS-1997

Which of the following processes can be used for mass production of plastic containers (with lid) of 5 liter capacity?

1. Injection moulding
2. Jolt moulding
3. Blow moulding

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

IES-2002

Which of the following are fabricated using engineering plastics?

1. Surface plate
2. Gears
3. Guide ways for machine tools
4. Foundry patterns

Select the correct answer using the codes given below:

- (a) 1, 2 and 3 (b) 1
(c) 2, 3 and 4 (d) 1, 2, 3 and 4

IES-2004

Match List I (Material) with List II (Typical use) and the correct answer using the codes given below the Lists:

List I				List II			
A.	Branched polyethylene			1.	Bottles		
B.	Polyester			2.	Textile fibres		
C.	Polyvinylidene chloride			3.	Films for packaging		
D.	Linear Polyethylene			4.	Transparent film		
A	B	C	D	A	B	C	D
(a) 2	3	4	1	(b) 3	2	1	4
(c) 2	3	1	4	(d) 3	2	4	1

IES 2011

Assertion (A) : The plastic organic materials can be easily shaped or moulded by mechanical action.

Reason (R): It is widely in use as it can be permanently moulded.

- (a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Elastomer

Elastomers

- Elastomers are a special class, of linear polymers that display an exceptionally large amount of elastic deformation when a force is applied.
- Many can be stretched to several times their original length. Upon release of the force, the deformation can be completely recovered, as the material quickly returns to its original shape. In addition, the cycle can be repeated numerous times with identical results, as with the stretching of a rubber band.
- In the elastomeric polymers, the linear chain-type molecules are **twisted or curled**, much like a coil spring.

- When a force is applied, the polymer stretches by uncoiling. When the load is removed, the molecules recoil and the material returns to its original size and shape.
- The relationship between force and stretch does not, however, follow Hooke's Law.
- In reality, the behaviour of elastomers is a bit more complex. While the chains indeed uncoil when placed under load, they also tend to slide over one another to produce a small degree of viscous deformation. When the load is removed, the molecules recoil, but the viscous deformation is not recovered and the elastomer retains some permanent change in shape.
- By cross-linking the coiled molecules, however, it is possible to restrict the viscous deformation while retaining the large elastic response.

- The elasticity or rigidity of the product can be determined by controlling the number of cross-links within the material.
- Small amounts of cross-linking leave the elastomer soft and flexible, as in a rubber band.
- Additional cross-linking restricts some of the uncoiling, and the material becomes harder, stiffer, and more brittle, like the rubber used in bowling balls.
- If placed under constant strain, however, even highly cross-linked material will exhibit some viscous flow over time. This phenomenon is known as stress relaxation.
- The rate of this relaxation depends on the material, the force, and the temperature.

IES 2011

During tensile testing it has been observed that for some material the deformation is fully recoverable and time-independent, but does not obey Hook's law. The material is :

- (a) Elastomer
- (b) Rubber
- (c) Polymer
- (d) Aluminium alloy

Rubber

- Natural rubber, the oldest commercial elastomer, is made from the processed sap of a tropical tree.
- It could be vulcanized (cross-linked) by the addition of about 30% sulphur followed by heating to a suitable temperature. The cross-linking restricts the movement of the molecular chains and imparts strength.
- Properties could be further improved by various additives (e.g., carbon black) which act as stiffeners, tougheners, and antioxidants.
- Accelerators have been found that speed up the vulcanization process. These have enabled a reduction in the amount of sulfur such that most rubber compounds now contain less than 3% sulphur.

Contd...

- Natural rubber compounds **are outstanding for their flexibility, good electrical insulation**, low internal friction, and resistance to most inorganic acids, salts, and alkalis.
- However, they have poor resistance to petroleum products, such as oil, gasoline, and naphtha.
- In addition, they lose their strength at elevated temperatures, so it is advisable that they not be used at temperatures above 175°F (80°C).
- They also deteriorate fairly rapidly in direct sunlight unless specially compounded.

Contd...

- Rubber and similar synthetic materials such as Neoprene have a variety of application in machinery.
- Rubber should be protected from high temperature, oil and sunlight.
- It is an excellent material for seats and diaphragms, for water lubricated bearings, for parts subjected to vibrations (such as vibration mountings, flexible couplings and flexible bearing) and for tubes and hose.
- In industry, hard rubber is used for electric insulation, switch handles, bearings, etc.

Contd...

Different types of rubber	Applications
Natural rubber	Tires, gaskets, hose
Polyacrylate	Oil hose, O-rings
EDPM(ethylene propylene)	Electric insulation, footwear, hose, belts
Chlorosulfonated polyethylene	Tank lining, chemical hose, polyethylene shoe, soles and heels
Polychloroprene (neoprene)	Wire insulation, belts, hose, (neoprene) gaskets, seals, linings
Polybutadiene	Tires, soles and heels, gaskets, seals
Polyisoprene	Same as natural rubber
Polysulfide	Seals, gaskets, diaphragms, valve disks
SBR (styrene butadiene)	Moulded mechanical goods, disposable pharmaceutical items, tyres
Silicone	Electric insulation, seals, gaskets, O-rings
Epichlorohydrin	Diaphragms, seals, moulded goods, low-temperature parts
Urethane	Caster wheels, heels, foam padding
Fluoroelastomers	O-rings, seals, gaskets, roll coverings

IES-2008

Which material is used for bushes in the bushed-pin type of flexible coupling?

- (a) Gun metal
- (b) Plastic
- (c) Rubber
- (d) Aluminium

IES-1997

Which one of the following materials is used for car tyres as a standard material?

- (a) Styrene-butadiene rubber (SBR)
- (b) Butyl rubber
- (c) Nitrile rubber
- (d) Any of the above depending upon the need

Ceramic

- Ceramic materials are compounds of metallic and nonmetallic elements (often in the form of oxides, carbides, and nitrides) and exist in a wide variety of compositions and forms.
- The American Ceramic Society has defined ceramic products as those manufactured "by the action of heat on raw materials, most of which are of an earthy nature (as distinct from metallic, organic etc.) while of the constituents of these raw materials, the chemical element silicon, together with its oxide and the compounds thereof (the silicates), occupies a predominant position."

- Most have crystalline structures, but unlike metals, the bonding electrons are generally captive in strong ionic or covalent bonds. The absence of free electrons makes the ceramic materials poor electrical conductors and results in many being transparent in thin sections.
- Because of the strength of the primary bonds, most ceramics have high melting temperatures.
- Ceramic articles of industry are : Dinner ware, electrical and chemical porcelain, refractory bricks and tiles, glass, porcelain enamels, abrasives, cutting tools, bricks and tiles, cements and concretes, whitewares, mineral Ores, slags and fluxes and insulators etc.

Rev.0

Contd...

Contd...

- Ceramics can be natural or manufactured:
- **Natural Ceramics** : The most frequently used, naturally occurring Ceramics we : Silica (SiO), Silicates and Clay minerals.
- **Manufactured Ceramics** : Such ceramics include : SiC, Al₂O₃, Silicon Nitride (Si₃N₄) and many varieties of Oxides, Carbides, Nitrides, Borides and more complex ceramics.

Properties of Ceramics

- The co-valent bonding of ceramic materials, alongwith their high melting point and relative resistance to oxidation, make ceramics good candidates for high temperature applications.
- In addition, they are relatively cheap and abundant and are not dependent on import for supply.
- Many ceramics retain strength to much higher temperatures than metals.
- There being virtual absence of ductility in ceramics, so, in general, they can not be machined or built up from stock.

Contd...

- In general, ceramics are hard, brittle and high melting point materials with :-
 - desirable electrical, magnetic and optical properties, i.e., low electrical and thermal conductivity.
 - good chemical and thermal stability, that is, high hot-strength and high corrosion resistance, and freedom from oxidation.
 - good creep resistance, and
 - High compressive strength and excellent resistance to wear.
 - Their low density is also an attractive feature to minimise centrifugal stresses in parts rotating at high speed.

IES-2008

Consider the following statements relating to mechanical properties of ceramics:

1. Tensile strength is theoretically high but in practice quite low.
2. Compressive strength is many times lower than tensile strength.
3. Shear strength is high.
4. Transverse strength is easy to ascertain.

Which of the statements given above are correct?

- | | |
|-------------|-------------|
| (a) 1 and 3 | (b) 1 and 4 |
| (c) 2 and 3 | (d) 2 and 4 |

IES-2002

Which one of the following is true?

- (a) Structure of metallic materials consists of atoms having valence of 5, 6 or 7
- (b) Ceramic materials have long range electron matrix bond
- (c) Polymers are composed of long chain of repeating molecules
- (d) Ceramics are weaker than metals because of weak electrostatic bond

Processing of Ceramics

The processing of ceramics, except glass, follows the Powder Metallurgy route, that is, consists of the following steps :-

1. Preparation of powders
2. Mixing and Blending of powders
3. Compacting of powders
4. Firing or Sintering.

Machining of Ceramics

- Most ceramics are sintered to their finish dimensions.
- However, sometimes, they are machined to get better dimensional accuracy and surface finish.
- Machining of ceramics can be done with Diamond abrasives, LBM, EBM and CHM.

PRODUCT APPLICATIONS

1. **Clay products** : Clay body ceramics include whitewares and stoneware.
- Whitewares includes such families of products as earthenwares, China and porcelain.
- Whitewares are largely used as tile, sanitary ware, low and high voltage insulators, and high frequency applications.
- Stoneware applications are : Glazed pipes, roofing tiles and tableware.

2. Refractories

- Refractory ceramics are the materials which are capable of withstanding high temperature in various situations. The refractory materials are of three types.
- **Acidic refractories** are based on alumina-silica composition, varying from pure silica to nearly pure alumina, through a wide range of alumina silicates.
- The basic constituent of **basic refractories** is magnesia, MgO. Basic refractories include chrome-magnesite, dolomite, limestone and magnesite.
- **Neutral refractories** include substances which do not combine with either acidic or basic oxides. With increasing alumina content, silica-alumina refractories may gradually change from an acidic to neutral type. A typical neutral character is exhibited by such refractories as Carbon, graphite, carbide, chromite, bauxite and forsterite.

- Refractories are used in the construction or lining of furnaces, boilers, flues, regenerators, convertors, crucibles, dryers, pyrometer tubes and in many others, primarily to withstand the high temperature.
- The most widely used **oxide refractory ceramic** is alumina Al_2O_3 . It is sintered into cutting tool bits, spark plug insulators, high temperature tubes, melting crucibles, wear components and substrates for electronic circuits and resistors.

Carbide refractory

- Carbides have the highest melting point of all the substances.
- Silicon carbide, SiC, is difficult to sinter, but pressure sintered or reactive sintered solid bodies of SiC are used as high-temperature resistance-heating elements, rocket nozzles and sand blast nozzles.
- Ceramics such as UO_2 , UC and UC, are used in nuclear applications as fuel elements, fuel containers, moderators, control rods and structural parts.
- Boron carbide, B_4C , is extremely hard and is used as a grinding grit.
- Other carbides (Tungsten Carbide, Tantalum Carbide and Titanium carbide) are used in the sintered form as cutting tool materials.

Contd...

- Nitrides** have only slightly lower melting points than carbides.
- Cubic boron nitride, CBN, is the hardest material after diamond and is used as cutting tool material. Silicon nitride, Si_3N_4 , is used for ceramic engine components, turbine disks and rocket nozzles.
- Sialon** (Si - Al - O - N), that is oxynitrides, have better oxidation resistance and is used for cutting tools and welding pins.
- Borides** (of Chromium, Zirconium and Titanium) are used as turbine- blades, Rocket nozzles and Combustion chamber liners.
- Cermet** is a composition of ceramic and metal. This material shows better thermal shock resistance than ceramics, but at the same time retains their high refractoriness.
- It is used as cutting tool material, as crucibles and as jet engine nozzles.

3. Electrical and Magnetic Applications

- Ceramics find wide applications in electrical and electronic industries.
- As insulators, semi-conductors, dielectrics, ferroelectrics, piezoelectric crystals.
- Ceramics such as glass, porcelain, alumina, quartz and mica, are getting heavy demands.
- Ceramics, such as SiC, are used as resistors and heating elements for furnaces.
- Ceramics, having semiconducting properties, are used for thermistors and rectifiers. Barium titanate, for example, is used in capacitors and transducers.

4. Optical Applications

- Ceramics are notably useful as a pigment, because it is exceptionally durable. It is completely oxidised and not subject to chemical attack and variation.
- Yttralox (a new ceramic material) is useful in optical applications, because it is as transparent as window glass and can resist very high temperature. Yttralox is completely free from pores.
- Generally, Ceramics are opaque, because of the presence of tiny pores within them that scatter light.

5. Phosphorescence

- Ceramic phosphors emit light of a characteristic wavelength when excited or pumped by some appropriate energy source (an electric discharge or electron beam).
- Light tubes, VDT's and colour T.V. rely on this phenomenon.
- Of increasing interest are Laser materials, The most widely used Laser is ruby (an Al_2O_3 , crystal doped with Cr ions).
- They are being used for machining, welding and cutting etc.

IES-2002

Match List I with List II and select the correct answer:

List I (Material)

- A. Ceramics
B. Refractory
C. Stones
D. High silica glass

List II (Application)

1. Construction of chemical plants
2. Columns and pillars
3. Lining of furnaces
4. Tiles

Codes:	A	B	C	D	A	B	C	D	
(a)	4	3	2	1	(b)	2	1	4	3
(c)	4	1	2	3	(d)	2	3	4	1

For-2015 (IES, GATE & PSUs)

Glass

- Glasses are, by definition, "Ceramics" because the starting materials needed to produce glass are typical of ceramic materials. However, they are produced by the melt processing route, instead of the powder metallurgy route used for other ceramics.
- In ceramic science, the word "glass" signifies any amorphous component of ceramic mixture.
- However, in general terms, glass is a transparent silica product which may be amorphous or crystalline, depending on heat treatment.
- Glasses may be either inorganic or organic.

Contd...

- Vitreous materials or inorganic glasses are the fusion products which during solidification from a **liquid** state failed to crystallise.
- During the cooling process, the glasses exhibit no discontinuous change at any temperature and only a progressive increase in viscosity is noticed. In fact, glass is a hard liquid.
- Glass Forming Constituents** : Silica, which is obtained from high-purity silica sand is the most widely used glass-forming constituent.
- Other glass forming constituents are the oxides of boron, vanadium, germanium and phosphorous. Some other elements and compounds such as tellurium, selenium and BeF_2 can also form glasses.

Rev.0

Contd...

- Along with oxides, fluxes are also added to the charge for a glass. Fluxes lower the fusion temperature of the glass and render the molten glass workable at reasonable temperature.
- However, fluxes may reduce the resistance of glass to chemical attack, render it water soluble or make it subject to partial or complete **devitrification** (that is, crystallisation) upon-cooling; Such a glass is undesirable since the crystalline are extremely weak and brittle.
- Stabilizers are therefore, added to the glass batch to overcome these problems.

IES 2011

Structure of common glass is

- Amorphous
- Partially crystalline
- Fully crystalline
- None of the above

IES-2008

Which one of the following is correct?

When "devitrification" of inorganic glasses is done,

- Glass transforms from crystalline to non-crystalline state
- Glass transforms into a fully transparent material
- Glass transforms from non-crystalline state to poly-crystalline state
- Glass is relieved of internal stresses

Composites

What are composites?

- Composites are the multiphase materials, which can be defined as any multiphase material that is artificially made and exhibits a significant proportion of the properties of the constituent phases.
- The constituent phases of a composite are usually of macro sized portions, differ in form and chemical composition and essentially insoluble in each other.

Why do we need composites?

- Composites are the class of materials with special properties.
- Properties of the composite can be tailored to meet the required purpose such as superior properties like higher strength to weight ratio, high modulus and high temperature stability along with good damping ability.

IES 2011

Assertion (A) : A composite is a multiphase material which is artificially made as one that occurs naturally.

Reason (R): Technology of modern age requires a material with unusual combination of properties that cannot be met by metal or alloys.

- Both A and R are individually true and R is the correct explanation of A
- Both A and R are individually true but R is NOT the correct explanation of A
- A is true but R is false
- A is false but R is true

IES-2009

Nano composite materials are highly preferable in design consideration for their

- High resistance to crack propagation
- Vibration resistance
- Impact resistance
- High resilience

TYPES OF COMPOSITE MATERIALS

- Composite materials may roughly be classified as :
 - Agglomerated materials or Particulate Composites
 - Reinforced materials
 - Laminates
 - Surface-Coated materials.
- The particulate composites and reinforced composites are constituted by just two phases, the matrix phase and the dispersed phase.
- The matrix phase is continuous and surrounds the dispersed phase. The aim is to improve the strength properties of the matrix material.

- The matrix material should be : ductile with its modulus of elasticity much lower than that of the dispersed phase. Also, the bonding forces between the two phases must be very strong.
- Depending upon the nature of the reinforcing materials (shape and size), the reinforced composites can be classified as:
 - Particle reinforced composites or particulate reinforced composites.
 - Fibre reinforced composites.
- In particle reinforced composites, the dispersed phase is in the form of exi-axed particles, whereas in fibre-reinforced composites, it is in the form of fibres.

Agglomerated Materials

- Agglomerated materials or particulate composites consist of discrete particles of one material, surrounded by a matrix of another material. The materials are bonded together into an integrated mass.
- Two classic examples of such a composite material are : Concrete formed by mixing gravel, sand, cement and water and agglomeration of asphalt and stone particles, that is used for paving the highway surfaces. Other examples of particulate composite materials include :-
 - Grinding and cutting wheels, in which abrasive particles (Al_2O_3 , SiC, CBN or diamond) are held together by a vitreous or a resin bond

2. **Cemented carbides**, in which particles of ceramic materials, such as WC, TaC, TiC and of Cobalt and nickel, are bonded together via Powder Metallurgy process, to produce cutting tool materials. Cobalt acts as the binder for ceramic particles. During sintering, the binder melts and forms a continuous matrix between the ceramic particles. This method is called as "**Vitreous sintering**", that is, sintering with the formation of liquid phase.

3. **Cermets** (Ceramics + metals). Metals (W, Mo, Ni, Co act as binders and the product is made by Powder Metallurgy method.

- The sintering temperature is the melting point of the metal.
- In the resulting composite material, the metal contributes high toughness and thermal shock resistance, while the ceramic contributes higher refractoriness and creep resistance, superior chemical stability and abrasion resistance.

IES-2009

Which of the following composites are dispersion-strengthened composites?

- Particulate composites
- Laminar composites
- Fiber reinforced composites
- Short-fiber discontinuous composites

Reinforced Materials

- Reinforced materials form the biggest and most important group of composite materials.
- The purpose of reinforcing is always to improve the strength properties.
- Reinforcement may involve the use of a dispersed phase or strong fibre, thread or rod.
- The matrix material provides ductility and toughness and supports and binds the fibres together and transmits the loads to the fibres.
- The fibres carry most of the load.

Contd...

- The toughness of the composite material increases, because extra energy will be needed to break or pull out a fibre.
- Also, when any crack appears on the surface of a fibre, only that fibre will fail and the crack will not propagate catastrophically as in bulk material.
- Wood and bamboo are two naturally occurring fiber composites, consisting of cellulose fibers in a lignin matrix.
- The commonly used matrix materials are : Metals and polymers, such as, Al, Cu, Ni etc. and commercial polymers.

Contd...

- **Reinforcing Fibres** :A good reinforcing fibre should have : high elastic modulus, high strength, low density, reasonable ductility and should be easily wetted by the matrix.
- Metallic fibres such as patented steel, stainless steel, tungsten and molybdenum wires are used in a metal matrix such as aluminium and titanium.
- Carbon fibres and whiskers are also used to produce ultra-high strength composites.
- Fibres need not be limited to metals. Glass, ceramic and polymer fibres are used to produce variety of composites having wide range of properties.
- The ductile matrix material can be aluminium, magnesium, nickel or titanium and the reinforcing fibres may be of boron, graphite, alumina or SiC.

IES 2010

Consider the following statements regarding composite materials:

1. Material is termed as advanced composite, if fibers are directionally oriented and continuous.
2. Reinforced fiber glass products are strong and light weight.
3. Concrete is reinforced with steel rebar, the rebar becomes matrix.
4. Pearlite steels are composite materials.

Which of the above statements are correct?

- (a) 1, 2 and 3 only
- (b) 2, 3 and 4 only
- (c) 1, 2 and 4 only
- (d) 1, 2, 3 and 4

IES 2007

Wood is a natural composite consisting of which of the following?

- Lignin fibres in collagen matrix
- Lignin fibres in apatite matrix
- Cellulose fibres in apatite matrix
- Cellulose fibres in lignin matrix

IES-2002

Which of the following fibre materials are used for reinforcement in composite materials?

1. Glass
2. Boron carbide
3. Graphite

Select the correct answer using the codes given below:

- (a) 1 and 2
- (b) 1 and 3
- (c) 2 and 3
- (d) 1, 2 and 3

IES-1999

Consider the following statements:

The strength of the fibre reinforced plastic product

1. Depends upon the strength of the fibre alone
2. Depends upon the fibre and plastic
3. Is isotropic
4. Is anisotropic

Which of these statements are correct?

- (a) 1 and 3
- (b) 1 and 4
- (c) 2 and 3
- (d) 2 and 4

Whiskers

- Whiskers are single crystals in the form of fine filaments, a few microns in diameter (20-50 nm dia.) and short in length (a few mm).
- These single crystal whiskers are the strongest known fibres.
- Their high strength is due to the high degree of perfection and the absence of dislocation in their structure.
- Their strength is many times greater than that of the normal metals.
- They are introduced into resin or metallic matrix for the purpose of high strength and high stiffness at high temperatures.

IES 2011

'Whiskers' are

- Very thin metallic particles
- Very thin single crystals
- Very thin polycrystals
- Fiber particles of aspect ratio less than 10

Applications of reinforced materials

- Glass-fibre reinforced plastics** : Here, we have glass fibres in a matrix of unsaturated polyester.
 - Glass fibre-reinforced plastics are used to make : boat hulls, Car bodies, truck, cabins and aircraft fittings.
- C-C Composites** : These composites have graphite fibres in a carbon matrix.
 - This material is being used to make : Nose cone and leading edge of the missiles and space shuttles, racing car disk brakes, aerospace turbine and jet engine components, rocket nozzles and surgical implants.

Contd...

- Graphite fibre-reinforced epoxy** : (Organic or Resin matrix composites) : This material is being used to make many parts of a fighter plane.
- Automotive uses** : Body panels, drive shafts, springs and bumpers, Cab shells and bodies, oil pans, fan shrouds, instrument panels and engine covers.
- Sports equipment** : Golf club shafts, baseball parts, fishing rods, tennis rackets, bicycle frames, skis and pole vaults.

IES-2009

Which one of the following materials is not a composite?

- Wood
- Concrete
- Plywood
- Sialon

Hardness Test

Hardness Test

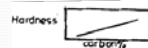
Definition: Hardness is a very important but hard to define property of materials.

"Hardness is the resistance offered by a material to indentation."

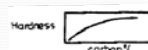
IES-1992

Hardness as a function of carbon content is shown in

(a) Fig-A



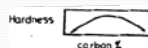
(b) Fig-B



(c) Fig-C



(d) Fig-D



IAS-2001

With the increase of percentage of carbon in the steel, which one of the following properties does increase?

- Modulus of elasticity
- Ductility
- Toughness
- Hardness

Moh's Scale of Hardness

Material	Moh's hardness
Talc	1
Gypsum	2
Calcite	3
Fluorite	4
Apatite	5
Orthoclase	6
Quartz	7
Topaz	8
Corundum	9
Diamond	10

Brinell Hardness test

- Most commonly used tests.
- A 10 mm tungsten carbide or hardened steel ball intended.
- Gradually applied load.
- Load applied at right angle to the specimen surface
- Indentation diameter made on the specimen is measured.

$$BHN = \frac{\text{Load}}{\text{Surface Area of Indentation}} = \frac{P}{\pi D \times \frac{D - \sqrt{D^2 - d^2}}{2}} \text{ kgf/mm}^2$$

$P \rightarrow \text{Kgf}$; D and d in mm

Contd...

- It cannot be used on very hard or very soft material.
- It is best if the thickness of the material is at least 10 times the depth.

Tensile strength = $k \times BHN$ MPa

$k = 3.296$ for alloy steel

$= 3.342$ for Plain Carbon steel.

- For steel, flexural endurance limit σ_e

$\sigma_e = 1.75 \times BHN$ MPa

$VHN \approx BHN$

$Rc \approx \frac{BHN}{10}$

IES 2010

The hardness of lathe bed material should be measured by

- Rockwell tester
- Brinell hardness tester
- Shore Scleroscope
- Vickers hardness tester

IES-1992

A carbon steel having Brinell Hardness number 100 should ultimate tensile strength closer it

- 100 N/mm²
- 200 N/mm²
- 350 N/mm²
- 1000 N/mm²

Rockwell Hardness test

- A sphere – conical diamond cone of 120° angle and a spherical apex of radius 0.2 mm is used
- Depth of indentation t is measured.
- Gradually applied load,
- Load is applied at right angle to the specimen surface.
- $R = 100 - 500 \times t$
- Depending on the load used a scale A, B, C, etc. used.
- Rockwell test should not be used on thin materials (generally less than 0.16 mm, on rough surface or on materials that are not homogeneous).

IAS-1999

A measure of Rockwell hardness is the

- Depth of penetration of indenter
- Surface area of indentation
- Projected area of indentation
- Height of rebound

Vickers hardness test

- A square based diamond pyramid having 136° between the opposite faces is used.
- Average Diagonal of the indentation (D) is measured.

$$VHN = \frac{1.854 p}{D^2}, \quad \begin{matrix} p \text{ in kgf} \\ D \text{ in mm.} \end{matrix}$$

- Even a light load will produce plastic deformation that so why we may use VHT on very hard material likes Tungsten Carbide.

The Scleroscope

- Based on the rebound height of a ball from the specimen.
- Harder the material, higher is the height to which the ball rebounds.
- Scleroscope hardness numbers are comparable only among similar materials. A comparison between steel and rubber would not be valid.

Knoop Test (Micro Hardness Test)

- Various micro hardness tests have been developed for application where it is necessary to determine the hardness of a very precise area of material, or where the material or surface layer is exceptionally thin.
- Special machine have been developed for this purpose. The location for this test is select in the high magnification.
- A small diamond penetrator is then loaded with a predetermined load ranging fm 25g to 300og.

IES-1992

Which of the following would you prefer for checking the hardness of very thin sections?

- (a) Hebert cloud burst test
- (b) Shore's Scleroscope
- (c) Knoop hardness test
- (d) Vickers hardness test

Durometer

- When testing soft, elastic materials, such as rubbers and non rigid plastics, a durometer is use

Herbert Cloudburst hardness test:

- It is used to know the uniformity of hardness over a surface.

IES-1992

Herbert cloudburst Hardness test is conducted to know

- (a) Uniformity of hardness over a surface
- (b) Softness of non-metallic components
- (c) Hardness of non-metallic components
- (d) Hardness at specified depth inside the surface.

Charpy and Izod test

- Toughness of a material is measured by means of impact tests.
- Notched bar prepared as per standard from the test material, is held in a vice and a weight is allowed to swing from a known height in such a way that it hits the notched bar in its path and breaks it.
- Since the material has absorbed some amount of energy during its fracture, the swinging mass loses part of its energy and therefore will not be able to reach the same height from where it started.
- The loss in height (h) multiplied by the weight represents the energy absorbed by the specimen during fracture, which can be directly measured from the indicator on the tester.

Contd...

- In the **Charpy** impact test, the specimen is held between two grips whereas in the **Izod** impact test the specimen is held at one end like a cantilever .
- The standard test specimens used in the izod and Charpy impact tests are made of bars with a square cross section of 10 mm.
- The impact resistance is dependent upon the material composition as well as the heat treatment process given to it.
- The annealed materials normally would have better toughness than the corresponding normalized or quenched specimens. Coarse-grained structure would tend to have higher ductility compared to fine grain structure and consequently better toughness.

Sheet Formability Tests

- During the various sheet metal forming processes, the stresses and strains developed in the material are quite complex. So, any measure of the formability of the sheet metal on the basis of material properties derived from a simple tension test(for example, % elongation as an index of ductility of the material) is not very accurate.
- So cupping tests have been developed to evaluate the formability of the sheet metals.

GATE-2006

Match the items in Column I and Column II.

Column I

- P. Charpy test
- Q. Knoop test
- R. Spiral test
- S. Cupping test

Column II

- 1. Fluidity
- 2. Micro hardness
- 3. Formability
- 4. Toughness
- 5. Permeability

- (a) P - 4, Q - 5, R - 3, S - 2
- (b) P - 3, Q - 5, R - 1, S - 4
- (c) P - 2, Q - 4, R - 3, S - 5
- (d) P- 4, Q - 2, R - 1, S - 3

IES-2002

Assertion (A): The hardness test is a slow, expensive method of assessing the mechanical properties of materials.

Reason (R): The hardness is a function of yield stress and the work hardening rate of material.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is **not** the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

Use of Materials

Duralumin

- It is an important and interesting wrought alloy.
- Its composition is as follows:
 - Copper = 3.5 - 4.5%; Manganese = 0.4 - 0.7%; Magnesium = 0.4 - 0.7%, and the remainder is aluminium.
- This alloy possesses maximum tensile strength (upto 400 MPa) after heat treatment and age hardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. This phenomenon is known as **age hardening**.
- It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets.

IES-1993

Duralumin Alloy contains aluminium and copper in the ratio of

	%Al	%Cu
(a)	94	4
(b)	90	8
(c)	88	10
(d)	86	12

IES-1992

Which of the following statement is incorrect about duralumin?

- (a) It is prone to age hardening
- (b) It can be forged
- (c) It has good machining properties
- (d) It is lighter than pure aluminium

Magnalium

- It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres.
- It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

Hindalium

- It is an alloy of aluminium and magnesium with a small quantity of chromium.

Copper-zinc alloys (Brass)

- The most widely used copper-zinc alloy is brass.
- There are various types of brasses, depending upon the proportions of copper and zinc.
- This is fundamentally a binary alloy of copper with zinc each 50%.
- By adding small quantities of other elements, the properties of brass may be greatly changed.
- Applications of Cu alloys include: costume jewellery, coins, musical instruments, electronics, springs, bushes, surgical and dental instruments, radiators, etc.

- The addition of zinc strengthens the material and incidentally changes the colour to a yellow or gold effect.
- The ratio of copper and zinc can be varied for advantages and the addition of other elements gives still more variety of combinations of properties such as machinability, strength, hardness, ductility (hot or cold), conductivity and corrosion resistance as well as many others.
- Lead additions are used to improve machinability. The lead is insoluble in the solid brass and segregates as small globules that help the swarf to break up in to small pieces and may also help to lubricate the cutting tool action.

IES-1992

Addition of which of the following improves machining of copper?

- (a) Sulphur
- (b) Vanadium
- (c) Tin
- (d) Zinc

IES-1992

Cartridge brass can be

- (a) Cold rolled into sheets
- (b) Drawn into wires
- (c) Formed into tubes
- (d) Any of the above.

Copper-tin alloys (Bronze)

- The alloys of copper and tin are usually termed as bronzes.
- The useful range of composition is 75 to 95% copper and 5 to 25% tin.
- The metal is comparatively hard, resists surface wear and can be shaped or rolled into wires, rods and sheets very easily.
- In corrosion resistant properties, bronzes are superior to brasses.

Contd...

- The hardness and strength of bronze increase with an increase in tin content.
- The ductility is also reduced with the increase in tin percentage above 5.
- When aluminium is also added (4 to 11%), the resulting alloy is termed **aluminium bronze**, which has a considerably higher corrosion resistance.
- Bronzes are comparatively costly compared to brasses due to the presence of tin which is an expensive metal.
- The colour of aluminium bronze is similar to that of 22 carat gold and it is frequently called '**imitation gold**'.

IES 2011

Aluminium Bronze is also known as :

- (a) Muntz metal
- (b) White metal
- (c) Duraluminium
- (d) Imitation gold

Phosphor bronze

- When bronze contains phosphorus, it is called phosphor bronze.
- Phosphorus increases the strength, ductility and soundness of castings.
- This alloy possesses good wearing qualities and high elasticity.
- A common type of phosphor bronze has the following composition according to Indian standards Copper = 87–90%, Tin = 9–10%, and Phosphorus = 0.1–3%.
- The material is specified for pump parts, gears, springs, power screw nuts and bearings.

IES-2006

In case of power screws, what is the combination of materials used for the screw and the nut?

- (a) Cast iron screw and mild steel nut
- (b) Carbon steel screw and phosphor bronze nut
- (c) Cast iron screw and cast iron nut
- (d) Aluminium screw and alloy steel nut

IES-1992

The percentage of phosphorous in phosphor bronze is

- | | |
|----------|--------|
| (a) 0.1 | (b) 1 |
| (c) 11.1 | (d) 98 |

Gun Metal

- It is an alloy of copper, tin and zinc.
- It usually contains 88% copper, 10% tin and 2% zinc.
- This metal is also known as **Admiralty gun metal**.
- The zinc is added to clean the metal and to increase its fluidity.
- It is not suitable for being worked in the cold state but may be forged when at about 600°C.
- It is extensively used for casting boiler fittings, bushes, bearings, glands, etc.

IES-2003

Gunmetal, which is used in journal bearings, contains

- (a) 88% Cu, 10% Sn, 2% Zn
- (b) 80% Cu, 10% Zn, 10% Al
- (c) 85% Cu, 5% Mg, 10% Al
- (d) 85% Cu, 5% Sn, 10% Pb

IES-1994

Which of the following pairs are correctly matched?

1. Silicon steelsTransformer stampings
2. DuraluminCooking utensils.
3. Gun metal..... Bearings

Select the correct answer using the codes given below.

Codes:

- (a) 1, 2 and 3 (b) 1 and 2
(c) 1 and 3 (d) 2 and 3

IES 2011

Match List –I with List –II and select the correct answer using the code given below the lists :

List –I	List –II
A. Gun Metal	1. Worm wheel
B. Phosphor bronze	2. Cylinder block
C. Gray cast iron	3. Piston
D. Al alloy	4. Bushings

	A	B	C	D		A	B	C	D
(a)	3	1	2	4	(b)	4	1	2	3
(c)	3	2	1	4	(d)	4	2	1	3

Monel metal

- It is an important alloy of nickel and copper.
- It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon. It is superior to brass and bronze in corrosion resisting properties.
- It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.

Name	Per cent of metal						Uses
	Cu	Zn	Sn	Pb	Al	Ni	
Admiral metal	71	28	1.0	-	-	-	Steam condenser tubes
Aluminium brass	76	22	-	-	2.0	-	High strength brass
Aluminium bronze	79	-	-	5.0 (Fe)	11.0	5.0	Bushings, gears, bearings, valve guides, pistons, Shock absorbers.
Ambrac	65	5	-	-	-	30	
Brass red	84	10.0	3.0	3.0	-	-	Sheet, Wire shapes, tubes, valve bodies, plumbing parts, pipe fittings.
Brass yellow	62	35	1.0	2.0	-	-	Spur gears, bear-ings, screw down nuts
Beryllium copper	98	-	-	-	-	2.0 beryllium	Diaphragms, high duty gears, valve sleeves, valve vents, Springs of electrical contacts and watch movements.

Gear bronze	86.5	-	-	3.3 (Fe)	10.2	-	Gears of high strength
Gun metal	88	2.0	10.0	-	-	-	Boiler fittings, bushes, bearings, glands
Manganese bronze	90	5.8	-	2.0 (Fe)	2.0	-	Bushes, plungers, feed pump rods, worm gears
Monel metal	30	-	-	-	-	67	Steam turbine blades, high temperature valves, impeller of centrifugal pump, springs.
K - monel	29.0	-	-	-	2.75	66	-do-
Muntz metal	60.0	40.0	-	-	-	-	Water fittings, condenser tubes, household articles
Phosphor bronze	80	-	20	1.0 (P)	-	-	Bearings, pump parts, worm gears, springs
	-90		-10				

IES 2011

Admiralty Brass is used for

- (a) Condenser Tubes
(b) Rivets
(c) Piston rods
(d) Utensils

IES-2006

Match List-I (Composition) with List-II (Application) and select the correct answer using the code given below the Lists:

- List- I**
A. Commercial bronze (10% Zn)
B. Red brass (15% Zn)
C. Aluminium brass (22% Zn, 2% Al)
D. P-bronze (11 % tin) small amount of P)

- List -II**
1. Radiator
2. Spring metal
3. Forging and stamping
4. Power plant and chemical equipment

Codes:	A	B	C	D	A	B	C	D
(a)	2	4	1	3	(b)	3	1	4
(c)	2	1	4	3	(d)	3	4	1

IES-2003

Monel metal is an alloy of

- (a) Iron and carbon
(b) Copper and zinc
(c) Aluminium and copper
(d) Copper and nickel

IES-2004

Match List I (Alloy) with List II (Application) and select the correct answer using the codes given below the Lists:

- | List I | List II |
|----------------------|----------------------------|
| A. Silicon steel | 1. Marine bearings |
| B. High carbon steel | 2. Cutting tools |
| C. High speed steel | 3. Springs |
| D. Monel metal | 4. Transformer laminations |

Codes:	A	B	C	D	A	B	C	D
(a)	1	2	3	4	(b)	4	3	2
(c)	4	2	3	1	(d)	1	3	2

Inconel

- It consists of 80% nickel, 14% chromium, and 6% iron.
- This alloy has excellent mechanical properties at ordinary and elevated temperatures.
- It can be cast, rolled and cold drawn.
- It is used for making springs which have to withstand high temperatures and are exposed to corrosive action.
- It is also used for exhaust manifolds of aircraft engines.

Nichrome

- It consists of 65% nickel, 15% chromium and 20% iron.
- It has high heat and oxidation resistance.
- It is used in making electrical resistance wire for electric furnaces and heating elements.

Nimonic

- It consists of 80% nickel and 20% chromium.
- It has high strength and ability to operate under intermittent heating and cooling conditions.
- It is widely used in gas turbine engines.

Babbitt metal

- The tin base and lead base babbitts are widely used as a bearing material, because they satisfy most requirements for general applications.
- The babbitt is generally used as a thin layer, 0.05 mm to 0.15 mm thick, bonded to an insert or steel shell. The composition of the babbitt metals is as follows:
- **Tin base babbitts** : Tin 90% ; Copper 4.5% ; Antimony 5% ; Lead 0.5%.
- **Lead base babbitts** : Lead 84% ; Tin 6% ; Antimony 9.5% ; Copper 0.5%.

IES 2011

Babbitt is an alloy of
(a) Sn, Cu, Sb and Pb
(b) Sn and Cu
(c) Sn, Cu and Pb
(d) Sn, Cu and Sb

IES-1995

Babbitt lining is used on brass/bronze bearings to
(a) Increase bearing resistance
(b) Increase compressive strength
(c) Provide anti-friction properties
(d) Increase wear resistance.

IES-2009

Why are babbitt alloys used for bearing material?

- (a) They have excellent embeddability
- (b) They are relatively stronger than other bearing materials
- (c) They do not lose strength with increase in temperature
- (d) They have high fatigue strength

IES-2008

Which one of the following is correct?

Babbitt are used for

- (a) Gears
- (b) Bearings
- (c) Bolts
- (d) Clutch liners

IES

Tin base white metals are used where the bearings are subjected to

- (a) Large surface wear
- (b) Elevated temperatures.
- (c) Light load and pressure
- (d) High pressure and load.

IES-1998

Match List-I (Alloys) with List-II (Applications) and select the correct answer using the codes given below the lists:

List-I				List-II					
A.	Chromel			1.	Journal bearing				
B.	Babbitt alloy			2.	Milling cutter				
C.	Nimonic alloy			3.	Thermocouple wire				
D.	High speed steel			4.	Gas turbine blades				
Code:	A	B	C	D	A	B	C	D	
(a)	3	1	4	2	(b)	3	4	1	2
(c)	2	4	1	3	(d)	2	1	4	3

IES-2005

Match List I (Alloy) with List II (Major Constituent) and select the correct answer using the code given below the Lists:

List I				List II					
A.	Babbitt			1.	Nickel				
B.	Invar			2.	Tin and lead				
C.	Gun Metal			3.	Aluminium				
D.	Duralumin			4.	Copper				
Code:A	B	C	D	A	B	C	D		
(a)	2	4	1	3	(b)	3	1	4	2
(c)	2	1	4	3	(d)	3	4	1	2

IES 2007

Match List I with List II and select the correct answer using the code given below the Lists:

List I (Component)					List II (Required Property)				
A.	Blades of bulldozer				1.	High wear resistance and high toughness			
B.	Gas turbine blades				2.	Low Young's modulus and high fatigue strength			
C.	Drill bit				3.	High wear and abrasion resistance			
D.	Springs of automobiles				4.	High creep strength and good corrosion resistance			
Code:	A	B	C	D	A	B	C	D	
(a)	3	2	1	4	(b)	1	4	3	2
(b)	3	4	1	2	(d)	1	2	3	4

Columbium/Niobium

- Columbium finds much use in large-scale applications, such as steel for automobile bodies and pipelines. The use that probably will consume most of the columbium is microalloying.
- Relatively small amount of columbium lend high strength to steel. The microalloyed, or high-strength, low-alloy (HSLA) steels, are used for automobile bodies, structures of all kinds, and high-pressure pipe, particularly in the oil and gas industry.
- Columbium with oxygen as dominant substitutional alloying atoms is used in the nuclear fusion reactor.
- Nuclear material refers to the metals uranium, plutonium, and thorium, in any form, according to the IAEA

IES 2011

Columbium is a :

- Nuclear material
- Automobile material
- Film material
- Foam material

Nimonic 90

- A precipitation hardenable nickel-chromium-cobalt alloy, having high stress-rupture strength and creep resistance at elevated temperatures up to about 950 °C.
- For springs exposed to lower loads, the material can be used up to 700 °C.
- Nimonic 90 offers good resistance to corrosion and is non-magnetic.
- Applications include the aircraft industry, gas turbines, vehicle components and springs in high temperature environments, and thermal.
- Operating temperature: -100 – + 550 °C

Ferro-electricity

- Ferro-electricity is defined as the spontaneous alignment of electric dipoles by their mutual interaction in the absence of an applied electric field.
- This arises from the fact that the local field increases in proportion to the polarization. Thus, ferro-electric materials must possess permanent dipoles. Ex.: BaTiO₃, Rochelle salt (NaKC₄H₄O₆·4H₂O), potassium dihydrogen phosphate (KH₂PO₄), potassium niobate (KNbO₃).
- These materials have extremely high dielectric constants at relatively low applied field frequencies.
- Thus, capacitors made from ferro-electric materials are smaller than capacitors made of other dielectric materials.

For-2015 (IES, GATE & PSUs)

Piezo-electricity

- Piezo-electricity, or pressure electricity, is defined as polarization induced by the application of external force.
- Hence, by reversing the direction of external force, direction of the field can be reversed i.e. the application of an external electric field alters the net dipole length and causes a dimensional change.
- This property is characteristic of materials having complicated structures with a low degree of symmetry.
- Thus, piezoelectric materials can be used as transducers – devices that convert mechanical stress into electrical energy and vice versa.
- Application for these materials includes microphones, ultrasonic generators, sonar detectors, and mechanical strain gauges. Ex.: Barium titanate, lead titanate, lead zirconate (PbZrO₃), ammonium dihydrogen phosphate (NH₄H₂PO₄), and quartz.

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IES-1993

Quartz is a

- Ferroelectric material
- Ferromagnetic material
- Piezoelectric material
- Diamagnetic material

Rev.0

Welding cracks

- Cracks may occur at the following locations :-
 - In the weld (Fuse) Metal Zone
 - In the Base metal zone
 - Sometimes, the cracks originate in one Zone and then spread to the other Zone.

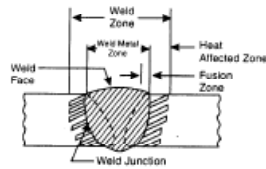


Fig. 5.49. Welding Zones.

Contd...

- Cracks in the base metal usually occur at low temperatures (around 200°C) and are known as Cold cracks.
- On the other hand, the cracks in the weld metal zone occur while the metal is still very hot. Such cracks are called Hot cracks.
- Cracks in the weld may be due to structural stresses in the metal (for example, the formation of martensite), heavy shrinkage, extra high amount of sulphur, phosphorous or carbon in the metal, excessively rigid clamping of the parts being welded or the presence of gases in the weld metal.

Contd...

- Cold cracking can occur due any to the following several factors :- improper welding conditions, the presence of gas and other impurities in the weld, wrong choice of filler rod and metallurgical factors such as excessive cooling rate resulting in the formation of martensite and formation of brittle phases in the weld when cold or the formation of phases which are brittle at high temperatures [Allotropic transformations].
- Cracks in the base metal can occur due to the following reasons :- Corrosion, Base metal defects, Base metal composition variations, hydrogen embrittlement and internal stresses set up due to restrained shrinking after welding.

IES-2005

Hot cracks occur in the weld and fusion zone as the metal solidifies. Which of the following are the causes for hot cracks?

- Presence of sulphur and phosphorus in the base metal
- High carbon or alloy content of the base metal
- Moisture in the joint or electrode
- Joint restraint

Select the correct answer using the code given below:

- | | |
|----------------|-------------------|
| (a) 1, 2 and 4 | (b) 1, 2 and 3 |
| (c) 3 and 4 | (d) 1, 2, 3 and 4 |

H-embrittlement and Passivity

- Hydrogen embrittlement** is form of failure than corrosion, but occurs as a result of hydrogen produced during corrosion. Atomic hydrogen diffuses into crystals and inhibits dislocation motion, causing failure.
- Counter measures: heat treatment; removal of hydrogen source.
- Passivity**: It is form protection against corrosion. It results from thin, strong adherent oxide layer formed over the surface. Usually observed in Al, Cr, Fe, Ni, Ti and their alloys. Passive layers may get damaged during mechanical vibrations, and so these metals are prone to erosion corrosion.

IES-1992

Presence of hydrogen in steel causes

- Reduced neutron absorption cross-section
- improved weldability
- Embrittlement
- corrosion resistance

Other questions

IES-2006

In case of power screws, what is the combination of materials used for the screw and the nut?

- Cast iron screw and mild steel nut
- Carbon steel screw and phosphor bronze nut
- Cast iron screw and cast iron nut
- Aluminium screw and alloy steel nut

IES-1992

For the pipe fitting like elbow, tee, union etc. which of the following is preferred?

- Pig iron
- Malleable iron
- Spheroidal graphite cast iron
- High carbon steel

IES-1992

Which of the following display properties similar to that of steel

1. Black-heart cast iron
 2. White-heart cast iron
 3. Gray cast iron
 4. Pig iron
- (a) 1 and 2 only (b) 3 and 4 only
(c) 2 and 4 only (d) 1 and 3 only

IES-1992

Addition of which of the following improves machining of copper?

- (a) Sulphur
- (b) Vanadium
- (c) Tin
- (d) Zinc

IES-2006

Disruptive strength is the maximum strength of a metal, when

- (a) Subjected to 3 principal tensile stresses at right angles to one another and of equal magnitude
- (b) Loaded in tension
- (c) Loaded in compression
- (d) Loaded in shear

IAS-1996

Match List I with List II and select the correct answer using the codes given below the lists:

List I (Cutting tools)

- A. Stellite
- B. H.S.S.
- C. Ceramic
- D. DCON

List II (Major constituent)

1. Tungsten
2. Cobalt
3. Alumina
4. Columbium
5. Titanium

Codes: A	B	C	D	A	B	C	D
(a) 5	1	3	4	(b) 2	1	4	3
(c) 2	1	3	4	(d) 2	5	3	4

IAS-1998

Which of the following methods are suitable for the production of super alloys?

1. Atomization from molten state using inert gas.
2. Atomization using plasma arc and rotating electrode.
3. Reduction and crushing.

Select the correct answer using the codes given below:

Codes:

- (a) 1 and 2 (b) 2 and 3
(c) 1 and 3 (d) 1, 2 and 3

IES-1996

The limit to the maximum hardness of a work material which can be machined with HSS tools even at low speeds is set by which one of the following tool failure mechanisms?

- (a) Attrition
- (b) Abrasion
- (c) Diffusion
- (d) Plastic deformation under compression.

GATE-2002

The ductility of a material with work hardening

- (a) Increases (b) Decreases
- (c) Remains unaffected (d) Unpredictable

IES-2009

Nano composite materials are highly preferable in design consideration for their

- (a) High resistance to crack propagation
- (b) Vibration resistance
- (c) Impact resistance
- (d) High resilience

IES-1992

Machine tool frame should have

- (a) High rigidity to weight ratio
- (b) Graphite in the form of nodules
- (c) Low hardness
- (d) High work hardness

GATE-1995

Machine tool structures are madefor high process capability. (tough/strong/rigid)

IES-2009

Which one of the following possesses the property of nonsparking character?

- (a) Hadfield's manganese steel (b) Spring steel
(c) Stellite (d) Invar

JWM 2010

Consider the following properties of engineering materials

1. Density
2. Conductivity
3. Elasticity
4. Hardness
5. Ductility

Which of these are mechanical properties of a material ?

- (a) 1, 2 and 4 only (b) 1, 2, 3 and 4
(c) 3, 4 and 5 (d) 2, 4 and 5

IES 2011

Materials which show direction dependent properties are called:

- (a) Homogeneous
(b) Visco-elastic
(c) Isotropic
(d) Anisotropic

IES 2011

Lead is widely used in:

- (a) Transformers
(b) Switch gear
(c) Galvanized pipes
(d) Batteries

IES 2011

Match List –I with List –II and select the correct answer using the code given below the lists :

List –I	List –II
A. System	1. Free energy is a minimum
B. Phase	2. Chemical elements or chemical compounds
C. Phase equilibrium	3. Consists of solids, liquids or gasses or their combination
D. Components	4. Homogeneous portion of a system that has uniform physical characteristics
(a) 2 1 4 3	(b) 3 1 4 2
(c) 2 4 1 3	(d) 3 4 1 2

GATE-2005

When the temperature of a solid metal increases

- (a) Strength of the metal decreases but ductility increases
(b) Both strength and ductility of the metal decrease
(c) Both strength and ductility of the metal increase
(d) Strength of the metal increases but ductility decreases

IAS-1998

Magnesium is extruded and not rolled because

- (a) It has a low melting point
(b) It has a low density
(c) Its reactivity with roll material is high
(d) It has a dose-packed hexagonal structure

IES 2011

Match List –I with List –II and select the correct answer using the code given below the lists :

List –I	List –II
A. Elasticity	1. Deform non elastically without fracture
B. Malleability	2. Undergo plastic deformation under tensile load
C. Ductility	3. Undergo plastic deformation under compressive load
D. Plasticity	4. Return to its original shape on unloading
A B C D	A B C D
(a) 1 2 3 4	(b) 4 2 3 1
(c) 1 3 2 4	(d) 4 3 2 1

Rev.0

IES 2011

Injection moulding process used to produce thermoplastic matrix composites with fibre reinforcement normally gives:

- (a) Short fibre composites
- (b) Two layer structure composites
- (c) Continuous fibre composites
- (d) Single layer composites

IES 2011

Assertion (A) : Solid solutions of metal are crystal whose properties are close to those of the solvent.

Reason (R) : They retain the same crystal lattice and type of bond.

- (a) Both A and R are individually true and R is the correct explanation of A
- (b) Both A and R are individually true but R is NOT the correct explanation of A
- (c) A is true but R is false
- (d) A is false but R is true

IES 2010

The correct statement is

- (a) Characteristic of any series of alloys cannot be found by phase diagram.
- (b) Phase diagram does not give amount of phases which are a function of composition, temperature and pressure.
- (c) The phase may be liquid or vapour with ordered crystal structure.
- (d) Phase diagram provides the information on how rapidly equilibrium is reached.

JWM 2010

Assertion (A) : Electric arc furnace can be used for acid and basic method of steel making.

Reason (R) : Impurities are eliminated extensively in acid are process.

IES 2010

Consider the following:

1. Water
2. Ice
3. Brine solution
4. Oil

Which of these is/are used as quenching media in case of Alloy steels?

- (a) 1, 2 and 3 only (b) 2, 3 and 4 only
- (c) 1 and 4 only (d) Only

The End