Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q.1**a)**	Stiffness:It is the resistance of a material for elastic deformation it is expressed in Youngs modulus. Toughness:It is the total energy absorbed by the material prior to its fracture. 1 mark each
b)	Y-Alloy Composition Al-92.5%,Cu-4%,Ni-2%,Mg-1.5% 2 marks
c)	Phenolics,ureas,melamine,epoxides,polysters 1 mark each
d)	1.It deals with the production of metal and nonmetal powders and subsequently manufacture of components by using these powders. 2.steps involved are powder production, Blending or mixing,compacting,sintering,sizing or impregnation,testing & inspection Definition 1 mark Explanation 1 mark
e)	It is an alloy of iron & carbon containing carbon percentage in the range of 2% to 6.67% 2 marks
f)	Alloy: It is a macroscopically mixture of two or more elements of which at least one element is a metal Bronze, Brass, Cast Iron etc…it exhibits metallic properties 01 and 2 examples 1 mark
g)	1.Mechanical Properties 2.Optical Properties 1 mark each
h)	1.To relieve internal stresses induced due to cold working 2. To make the steel suitable for further cold working. 1 mark each

i)	As density is defined as ratio of Mass per unit volume. As density is directly proportional to mass and inversely proportional to volume, So depending on type of application density plays vital role. Density plays an important role in designing of components. It decides weight of the components in design 2 marks
j)	Annealing,Normalising,Hardening,Tempering,Secondary hardening,Surface hardening Any four 2 marks
k)	1.Mechanical Processes. 2.Physical Process. 3.Chemical Process. 4.Electro chemical process(Electrodeposition) Any four 2 marks
l)	Duralium composition: Al-94.5%,Cu-4.5%,Mg-0.5%,Mn-0.5% Uses:Aircraft industry, Ship applications **Composition 1 mark 2 examples 1 mark**
Q.2 a)	Solid Solution:A microscopically homogenous mixture of atoms of two or more elements on solid states is called a solid solution. The element present in largest proportion is called parent metal or solvent and other element are referred as alloying elements or solute. Solid solution is classified into 2 types namely 1.Substitutional solid solution. It is again classified into 1.Disordered 2.Ordered 2.Interstitial solid solution Definition 1 mark.Explaination 1 mark Classification 2 types 1 mark each
b)	i.Chromium:Improves wear ,oxidation,and scaling resistance and hardenability but increases grain growth and reduce ductility.improves corrosion resistance ii.Nickel:Improves strength,toughness,hardenability without affecting ductility. iii.Tungsten:Forms hard stable carbides and promotes grain refining with great hardness at high temperature. iv.Molybdenum:stabilizes carbides and promotes grain refinement and increases high temperature,strength,creep resistance and hardenability 1 mark each

c)

Heat treatment:it is an operation or combination of operations involving heating & cooling of a material to obtain desirable condition (modify internal structure) and properties.

Objectives:

1.Relieving internal stresses developed during cold working,welding,casting,forging etc..

2. Improves machinability.

3.Obtain desired microstructure.

4.Adjust its Mechanical,Physical,or chemical properties.

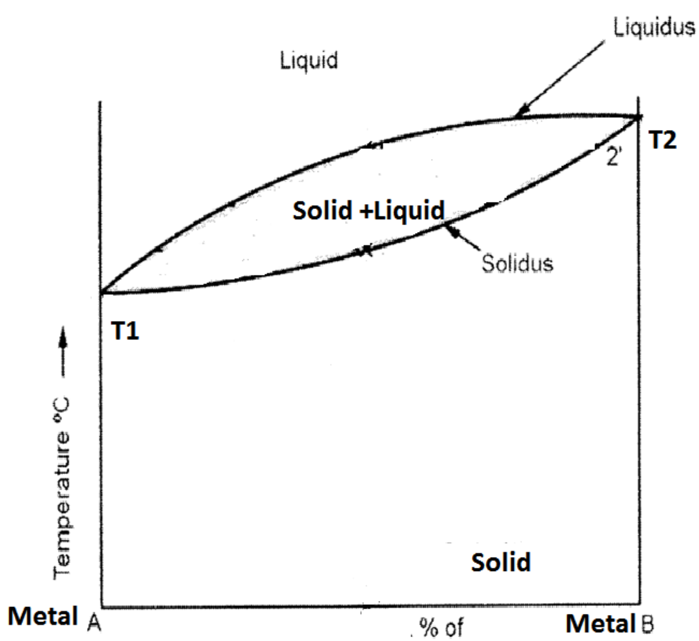
5.Increse hardness,wear,and abrasion resistance,and cutting ability of steel.

6.Decrese or increase the grain size.

7.Improve ductility and toughness.

8.Improve electrical & magnetic properties
Definition 1 mark.Any 6 objectives ½ mark each

d)



Isomorphous system represents all alloys wherein the two metals have complete solubility in solid and liquid states. These systems forms a loop type equilibrium diagram.

e.g.Copper-Nickel,antimony-bismuth etc..

T1 and T2 are melting points of metal A and Metal b respectively.the diagram represents three main regions.A liquid region at the top ,liquid+ solid region in the middle and solid at the bottom.A Liquidus line represents the temperature at which alloy becomes completely liquid while heating.similarly solidus line represents the temperature at which alloy starts to transform into liquid during heating.

In the solid region two metals are completely dissolved in each other and they have complete solid solubility **Diagram 1 mark.Definition 1 mark Example 1 mark.Explanation 1 mark.**

e)

Annealing	Normalizing
It is a process of heating a steel to a temperature which remove distortion and cooling to a room temperature to get stable structure.	It is a process of heating the steel to about fifty degrees centigrade above Ac3 line,holding and cooling to room temperature
Steels after annealing becomes very soft due to which lower strength & hardness	Steel after normalizing possess better strength and hardness than annealing
Very slow cooling rate (furnace cooling)	Faster cooling rate (Air cooling)
Large time consuming process	Less time consuming as compared to annealing
It refines the crystalline structure of steel	It refines the grain size of steel
Any four points 1 mark each	

f) Tempering:It is a heat treatment followed after hardening and involves heating the hardened steel to some temperature below the lower critical temperature(A1),soaking at this temperature for sufficient time followed by slow cooling in air. **Definition 1 Mark.Any three difference 1 mark each**

Austempering		Martempering	
1	It is not a hardening process	1	It is a type of hardening process
2	This process transforms austenite into bainite	2	This process transforms austenite to martensite.
3.	It is also called as isothermal quenching	3	It is also known as marquenching
4	Less warping & distortion	4	Better elongation & hardness
5.	Very few alloy steels are subjected to this treatment	5	Process is suitable for high hardenable steels

Q 3 a) **Carburizing:**

It is a method of introducing carbon into solid iron-base alloys such as low carbon steels in order to produce a hard surface. It is also called as Cementation. **2 marks**

It increases the carbon content of the steel surface by a process of absorption and diffusion.

Merits: 1 mark

1. Rapid heat transfer and hence process is quick.
2. Distortion of the component is small.
3. Work pieces of variety of shapes and sizes can be handled in a single bath.
4. After carburizing, parts can be directly quenched into water, oil or salt baths.

----------Any Two

Demerits: 1 mark

1. Liquid Carburizing salts are highly poisonous.
2. Salt bath fumes are also poisonous and proper arrangement for their disposal is necessary.
3. Cleaning for salt removal of complex parts is difficult.
4. Process is not clean

----------Any Two

b)

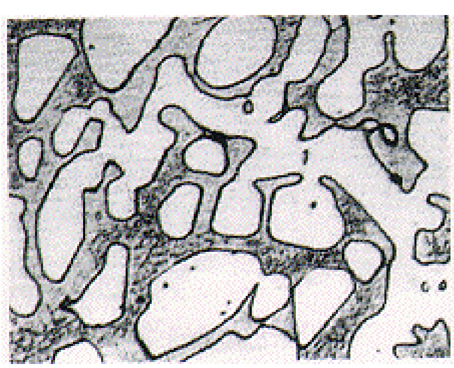
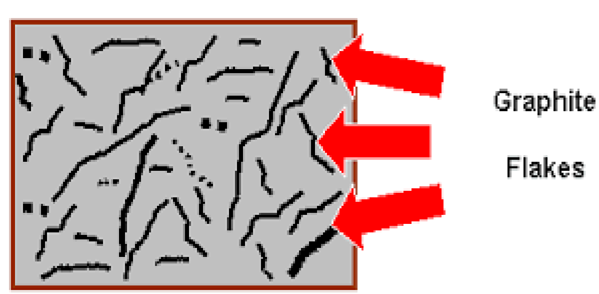
Desired properties of Bearing Materials:

1. The friction between the bearing and the rotating part should be as small as possible to reduce the power loss in transmission.
2. The affinity between the shaft and the shaft and the bearing material should be minimum.
3. It should be hard and wear resistant for longer life. However, it should not be harder than the shaft so as to avoid the damage of the shaft.
4. It should have sufficient load bearing ability i.e. the material should have good mechanical properties at ambient and elevated temperatures.
5. It should have sufficient plasticity and deformability to take care of large deflections and misalignment.
6. It should have high fatigue resistance.
7. It should have good resistance to galling and seizing.
8. It should have good thermal conductivity.
9. It should have a high oil retaining capacity.
10. It should have a good corrosion resistance.
11. It should be cheap and readily available.

----------Any Four 1 mark each

c)

Differentiate between White Cast Iron and Grey Cast Iron

White Cast Iron	Grey Cast Iron
1. Microstructure : 	1. Microstructure : 

(cementite +pearlite mixture)	
2. It is an alloy of carbon chemically bonded with iron as iron carbide.	2. It is an alloy of carbon and silicon with iron.carbon is present in the form of graphite flakes
3. It is obtained by rapid cooling.	3. It is obtained by allowing the molten metal to cool and solidify slowly.
4. It contains 1.75% - 2.3% carbon.	4. It contains 2.5% - 3.75% carbon.
5. It is very hard and brittle.	5. It is brittle and may be broken if a heavy hammer is used.
6. Hardness varies from 400 to 600 B.H.N.	6. Hardness varies from 150 to 240 B.H.N.
7. It cannot be machined.	7. It can be machined.
8. Applications: Used in weaving plates pump lines, grinding balls, dies etc.	8. Applications: Used in machine tool structure, frames for electric motors, cylinder blocks, heads for I.C. engine.

----------Any Four1 mark each

d) **Composition and Applications of Medium Carbon Steel and High Carbon Steel.**

Type of Steel	Composition	Applications
Medium Carbon Steel	0.30% - 0.80%	Drop forgings, boiler drums, marine shafts and axles, rotors and discs, agricultural tools and implements, aero engine cylinders, high tensile tubes and wires, castings for automobile engine components, laminated springs for automobiles, helical springs, locomotive tyres, wire ropes, steel spokes, clutch plates, large forging dies etc.
	0.8%	Spring, shear blades, chisels, cold sets, hammers, small forging dies, boiler maker's tools.
	0.9%	Cold chisels, cold working dies, punches and dies.
	1.0%	Springs, broaches, drift reamers.

	High Carbon Steel	1.1%	Press dies, punches, milling cutters, anvils, taps, wood working tools.
		1.2%	Taps, drills, screwing dies.
		1.3%	Files, razors, metal cutting tools for lathe, planer and slotter, mandrels and drawing dies.
		1.4 - 1.5%	Lathe tools for machining harder metals, gauges, engraving tools.
	1 mark each for each composition and each application		

e) **Ceramic:**

These are the materials containing phases that are compounds of metallic and non-metallic elements. It is the processing of earthly materials by heat. All metal oxides, carbides, nitrides, borides, silicates are considered as ceramics. The common examples are glass, cement, refractories etc**.** **2 marks**

Properties:

1. They are hard, strong and dense.
2. Have high resistance to the action of chemicals and to weather.
3. Possess high compression strength compared with tension.
4. Offer excellent dielectric properties.
5. Are good thermal insulators.
6. Are resistant to high temperature creep.
7. Have high fusion point.
8. At high temperature rigidity is high.

----------Any Two 1 mark

Applications:

1. Tiles.
2. Sanitary wares.
3. Low and high voltage insulators.
4. High frequency applications.
5. Heat resistant applications as pyrometers, burner, burner tips.
6. Chemical industry such as crucible, jars and components of chemical reactors.
7. In refractories for industrial furnaces.
8. In electrical and electronics industries as insulators, semiconductors, dielectric, porcelain alumina, quartz, mica etc.
9. In I.C. engines and turbines as armor plates.
10. In cutting tools

----------Any Two 1 mark

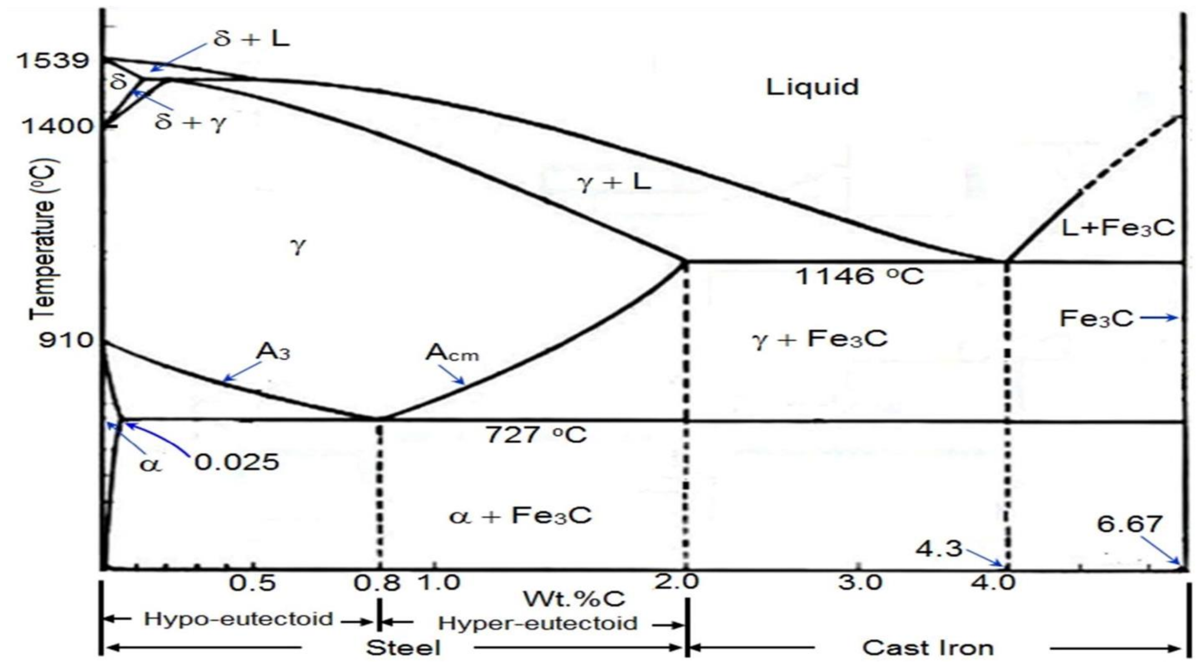
f) **Tool Steel: 2 marks**

The steels which are specially used for working, shaping and cutting of metals are termed as tool

	steels. Large number of steels are available for this purpose. They are classified and designated according to American Iron and Steel Institute (AISI) as below: i. Cold work tool steel. ii. Hot work tool steel. iii. High speed tool steel. iv. Special purpose tool steel. **High Speed Steel (H.S.S.): 2 marks** These steels maintain high hardness upto a temperature of about 550°C. So these steels can be used for cutting metals of high speeds. They have high wear resistance and cutting ability. This steel is heat resistance steel having properties like high hardness, good wear resistance and high compression strength. Tools operating at high speeds are made of high speed steel. These steels are divided into two types, depending upon principal alloying element: i. Tungsten High Speed Steel ii. Molybdenum Steels
Q 4 a)	**Chemical Composition: 1 mark each** i. Naval Brass: 60% Copper, 39% Zinc and 1% Tin. ii. Muntz Metal: 60% Copper and 40% Zinc. iii. Gun Metal: 88% Copper, 10% Tin and 2% Zinc. iv. Bronzes: It is an alloy of Copper containing elements other than zinc.
b)	**Cast Iron:** Cast irons are basically the alloys of iron and carbon in which the carbon varies from 2.0 to 6.67%. **1 mark** Classification of Cast Iron: **3 marks** i. On the basis of furnaces used in their manufacturing: 1. Cupola cast iron 2. Air furnace cast iron 3. Electric furnace cast iron 4. Duplex cast iron ii. On the basis of composition and purity 1. Low carbon, low silicon cast iron 2. High carbon, low sulphur cast iron 3. Nickel alloy cast iron iii. On the basis of microstructure and appearance of fracture: 1. White cast iron 2. Malleable cast iron 3. Grey cast iron 4. Nodular cast iron 5. Mottled cast iron 6. Chilled cast iron

	7. Alloy cast iron 8. Mechanile cast iron
c)	**Subcritical Annealing 2 marks** It is the process of annealing in which the cold worked steel is heated to some temperature below the critical temperature. Three methods of performing this process: i. Stress-relief annealing ii. Recrystallization annealing iii. Process annealing **Purpose: 2 marks** i. To relieve the internal stresses of the cold worked steel ii. To reduce the hardness and improve machinability. iii. To refine the grain structure. iv. To reduce the risk of distortion in machining and increase corrosion resistance. v. To make the steel soft and ductile.
d)	**Powder metallurgy process** **Advantages: 2 marks** i. A combination of metal and non-metallic powder is possible. ii. A close control on the amount of porosity is possible. iii. Components of any required compositions can be achieved. iv. Production of refractory metals and heavy metals is possible without melting. v. High density parts can be produced. vi. Production of components from metals which are insoluble in each other during melting is possible. vii. Complicated shaped parts can be manufactured easily. viii. Elimination of scrap. ix. Production of cemented carbide tools is possible only by this method. x. Fast and economical process for mass production. xi. Powder metallurgy parts can be welded, soldered or brazed easily. xii. Highly qualified or skilled operator is not required. **----------Any Four** **Limitations: 2 marks** -It is very difficult to produce high purity powder and also it is expensive to maintain purity. -Alloy powders are difficult to produce as simple method is not available. -Very large sized components cannot be produced. -Components of theoretical density cannot be produced. -Due to porosity, the specified mechanical properties are difficult to obtain. Porous metals tend to oxide rapidly. -Powder metallurgy parts show comparatively poor plastic properties. **----------Any Four**

e)	**Composite: 2 marks** Composite materials are combinations of two or more different materials combined together to achieve certain properties which they cannot achieve alone. **Properties: 1 mark** i. It has high stiffness, high specific strength. ii. It has elevated temperature strength and high fracture toughness. iii. It has resistance to corrosion, oxidation, electrical and thermal conductivity. **Applications: 1 mark** Used in aerospaces, underwater and transport applications, where conventional materials cannot fulfill the requirement.
f)	**Stainless Steel:** **Properties: 2 marks** i. Wide range of strength and hardness. ii. High ductility and formability. iii. High corrosion resistance. iv. Good creep resistance. v. Good thermal conductivity. vi. High resistance to scaling and oxidation at elevated temperatures. vii. Easy weld ability. viii. Good machinability. ix. High cold and hot workability. x. Excellent surface appearance and finish. **Uses: 2 marks** i. **Domestic** – cutlery, sinks, saucepans, washing machine drums, microwave oven liners, razor blades ii. **Architectural/Civil Engineering** – cladding, handrails, door and window fittings, street furniture, structural sections, reinforcement bar, lighting columns, lintels, masonry supports. iii. **Transport** – exhaust systems, car trim/grilles, road tankers, ship containers, ships chemical tankers, refuse vehicles iv. **Chemical/Pharmaceutical** – pressure vessels, process piping. v. **Oil and Gas** – platform accommodation, cable trays, subsea pipelines. vi. **Medical** – Surgical instruments, surgical implants, MRI scanners. vii. **Food and Drink** – Catering equipment, brewing, distilling, food processing. viii. **Water** – Water and sewage treatment, water tubing, hot water tanks. ix. **General** – springs, fasteners (bolts, nuts and washers), wire.

Q 5	**Attempt Any TWO:**
a)	**Explain with sketch of Iron & Iron Carbide Phase diagram .Show the Temperatures , Composition & Phases on it**
	 Fig: Iron – Iron Carbide Phase diagram

Sr. No.	Critical points (Symbols)	Temperature °C	Significance during heating
1.	A_0 (Curie temperature of cementite)	210	Cementite becomes paramagnetic
2.	A_1 (Lower critical temperature)	727	Pearlite starts transforming to austenite
3.	A_2 (Curie temperature of ferrite)	768	Ferrite becomes paramagnetic
4.	A_3 (Upper critical temperature for hypoeutectoid steels)	727–910	Completion of ferrite to austenite transformation
5.	A_{cm} (Upper critical temperature for hypereutectoid steels)	727–1147	Completion of cementite to austenite
6.	A_4	1400–1492	Completion of austenite to δ – ferrite transformation.

Table : Critical Temperatures of Fe-C Phase Diagram

α Ferrite – Interstitial solid solution of C in BCC iron. Max solubility of C is 0.025%. Exists from 273ºC to 910ºC.

Austenite γ - Interstitial solid solution of C in FCC iron. Max solubility of C is 2.1%. Exists from 910ºC - 1394ºC.

δ Ferrite (BCC) exists over the temp range of 1394ºC to 1539ºC. Max solubility of C is 0.09%.

Cementite, Fe_3C - is an intermetallic compound. C content in Fe_3C is 6.67%.

Graphite, the free form of C, also exists in the Fe-C system.

Bainite is another phase which forms in steels at higher cooling rates.

The hard phase Martensite forms below the Bainitic temperature range at high cooling rates.

(Detail diagram - 04 marks ; Depiction of temperature 02 mark either on the diagram or separate Table; Description of Phase 02 marks)

b) i) **How the engineering material are classified & give example of each**

Engineering material is classified into following types:

a.Metal : i. Ferrous ii) Non Ferrous

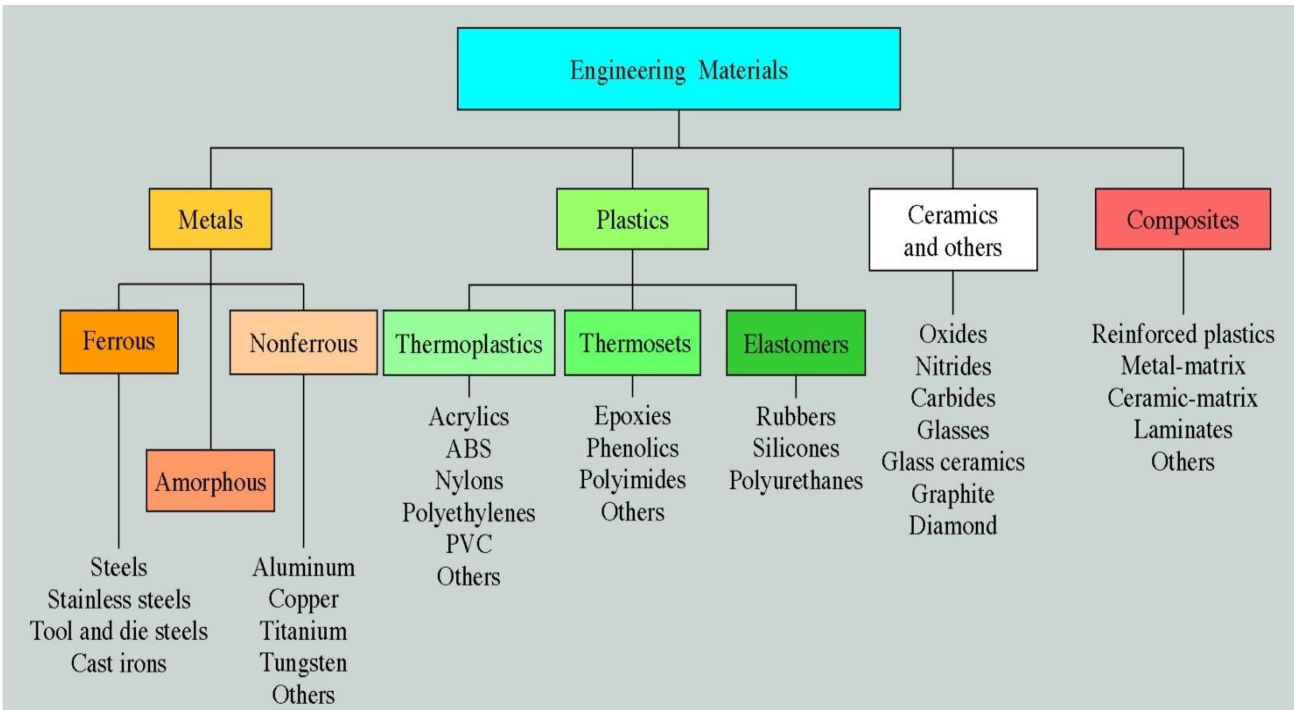
b. Plastics.

c. Ceramics.

d. Composites .

e. Organics

f. Semi Conductors.



(04 marks)

b) ii) **State & Explain steels which are used as 'Tool Steels'**

Tool steels are specially used for working, shaping and cutting of metals.

Types of Tool steel are :

1. Cold work Tool steel Steel.
2. Hot work Tool steel
3. High Speed Tool steels.
4. Special Purpose Tool steels.

Cold work Steel :

- Mainly used for cold working of steel.
- They have good hardness & wear resistance at low temperatures.
- They are sub classified into Water hardening Steel (W-series) Oil hardening (O-series), air hardening (A-series) & high carbon high chromium steels (D-series).

Hot Work Tool Steel

- Mainly used for hot working of metals such as stamping, drawing, forming, piercing, extruding, upsetting & swaging.
- Possess good strength, toughness, hardness & wear resistance at elevated temperature.

	High Speed Tool Steel : • They maintain hardness upto 550 º C & can be used for cutting of metal at high speed. • Principal Alloying elements W, Cr, V & Co. • Depending upon composition there are T series & W series Special Purpose Tool Steel : • They are shock resisting tool steel (S-series) , Low alloy tool steel (L-series) carbon-tungsten tool steels (F –series) & mould steel (P-series) . • Used for Punches , chisels , concrete breakers, rivet sets , forming dies , shear blades etc. **(01 mark each for types of tool steel & their explanation ; total 04 marks)**
c)	**Explain with neat sketches the process of flame hardening with its advantages & limitation**
	Process : Flame Hardening is a process of heating the surface layer of a hardenable steel to above its **Upper critical temperature** . It is done through the medium of **oxyacetylene flame** followed by water spray quenching or immersion quenching to transform **austenite to martensite.** It can be done in different ways : i) Spot hardening. ii) Progressive Method iii) Spinning Method iv) Combination of progressive & spinning method. In Spot hardening a spot or local area of the component is heated by one or more flames followed by quenching water . In Progressive method heating & quenching devices are moved over the component surface at a controlled rate. Spinning method is used for parts having rotational symmetry. In combination method , the work is rotated & the flames are traversed for heating followed by water spray.

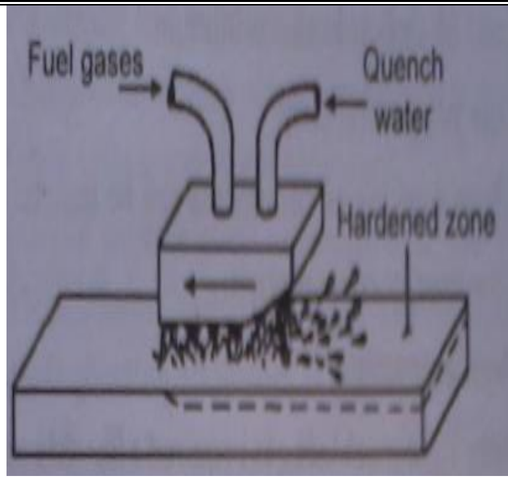


Fig: Flame Hardening of Flat plates

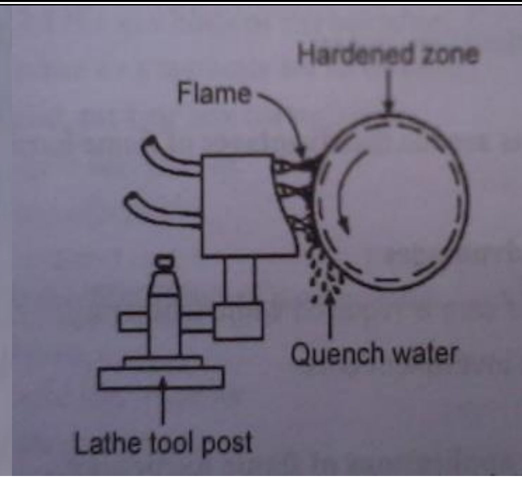


Fig: Flame Hardening of round bars in lathe

Advantages :

1. Depth of hardening can be easily controlled.
2. Less distortion of the material.
3. Oxidation & decarburization is minimum.
4. Loss of carbon is also minimum.
5. Low production cost.
6. Low energy consumption.
7. High output rate.

Disadvantages :

1. Process is required to be carried out with utmost care.
2. It requires high investment cost.

(02 Marks of Fig 04 marks for Description of Process 01 mark for advantages & 01 mark for limitation)

Q 6 **Attempt Any Four:**

a) **State the properties & application of the following :**

i) Neoprene
ii) Buna & Silicons.

Neoprene Properties :

Highly resistant to temperature

Highly resistant to oil.

Highly resistant to grease & ageing.

Applications:

Oil seals , gaskets

Adhesives

Tank lining

Low voltage insulation.

Buna Properties :

More resistant to weathering.

High strength

Resistant to tear, abrasion & flex cracking.

Readily attacked by solvents, gasolines etc.

Low hysteresis.

Applications :

Car tyres

Foot wear

Cable insulation

Moulded articles

Hose Pipes

Conveyor belts etc.

Silicons Properties :

Resistant to heat (-70 º to 250 º C), cold chemicals, solvents etc.

Low tensile strength at room temperature

Very strong at higher temperature

Application :

Vehicle tyres

Erasers

Seals.

Gaskets

Golves & Apron

Belt conveyors

Pipes & containers

Engine mounting

Vibration damping etc.

	(1/2 mark for each point ; Neoprene 02 marks ; Buna 01 mark & Silicons 01 mark)
b)	**What are different Non Destructive Tests ? What are the advantages of NDT in general?**
	NDT : The method of conducting tests on material without damage or reducing service life of the components. They do not directly measure Mechanical properties of material but locate the defects or flaws present in it. **Different Non Destructive Tests :** 1. Ultrasonic Inspection. 2. Magnetic Particle (Magna flux) Inspection. 3. Liquid Penetration Inspection. 4. Radiographic Inspection. 5. Remote visual inspection. 6. Eddy current testing. 7. Low coherence inferometry. **Advantages of Non Destructive Tests :** 1. It determines defects or flaws present in the material without damaging the component. 2. It provides high level of reliability. 3. It makes the component reliable, safe & economical. **(01 mark of NDT definition ; 02 marks for describing different NDT; 01 mark for Advantages)**
c)	**State any four properties & uses of copper**
	Properties of Copper : 1. It has good ductility & malleability. 2. It has high electrical & Thermal conductivity. 3. It is non magnetic. 4. It has fairly good corrosion resistance. Applications of Copper Electrical conductors Bus bars Automobile radiators Roofing Pressure vessels Kettles, Utensils Heat exchangers, Relays, Switch gear etc. **(2 Marks for Each)**
d)	**Explain the solidification of pure metal**
	The Time versus Temperature graph is plotted under normal condition. From A to B, Metal is in Liquid state; From B to C it is in Solid + Liquid state &; Below C it is in Solid state.

Above the Freezing point metal is in liquid state & below the freezing point the metal is in solid state.

From A to C if metal is cooled its Temperature drops & at Point C it starts to Solidify.

From B to C its Temperature remains constant but it liberates heat called Latent Heat of Fusion.

At point C it completely solidifies & From C to D metal is in solid state attaining room temperature.

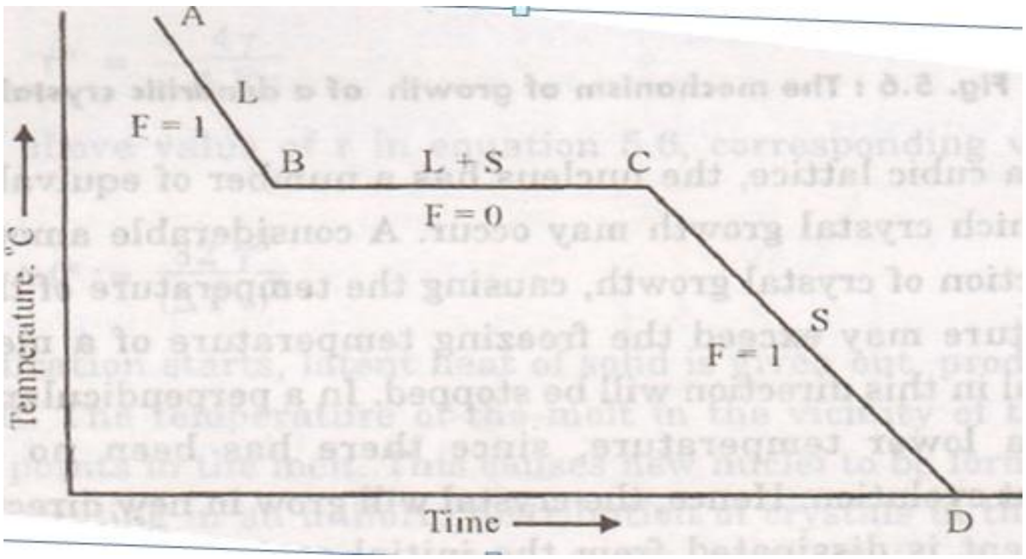


Fig: Cooling curve of Pure Metal

(2 Mark for Diagram , 02 Mark for Description)

e) **What is Normalising ?State its objectives & application.**

Normalising :

It is the process consists of heating to

i) above the upper critical temperature (A3) for hypoeutectoid steels &
ii) above Acm for hypereutectoid steel **by 30 º C to 50 º C**

holding long enough at this temperature for **homogeneous austenization** &

Cooling to room temperature **in still air.**

Objectives of of Normalising :

1. To relive the internal stresses induced due to welding, cold working etc.
2. To reduce hardness & to increase ductility.
3. To increase uniformity of phase distribution & to make material isotropic.
4. To refine grain size.
5. To make material homogeneous.
6. To increase machinability.
7. To make steel suitable for subsequent heat treatment.

Applications of Normalising :

1. It is usually used for steel parts that require maximum amount of strength & impact strength.

2. Using Normalisation , modification can be made to grain structure.
3. Ductile performance of steel can be improved without reducing hardness or strength.
4. Compared to other heat treatment , Normalisation can improve strength of the component.

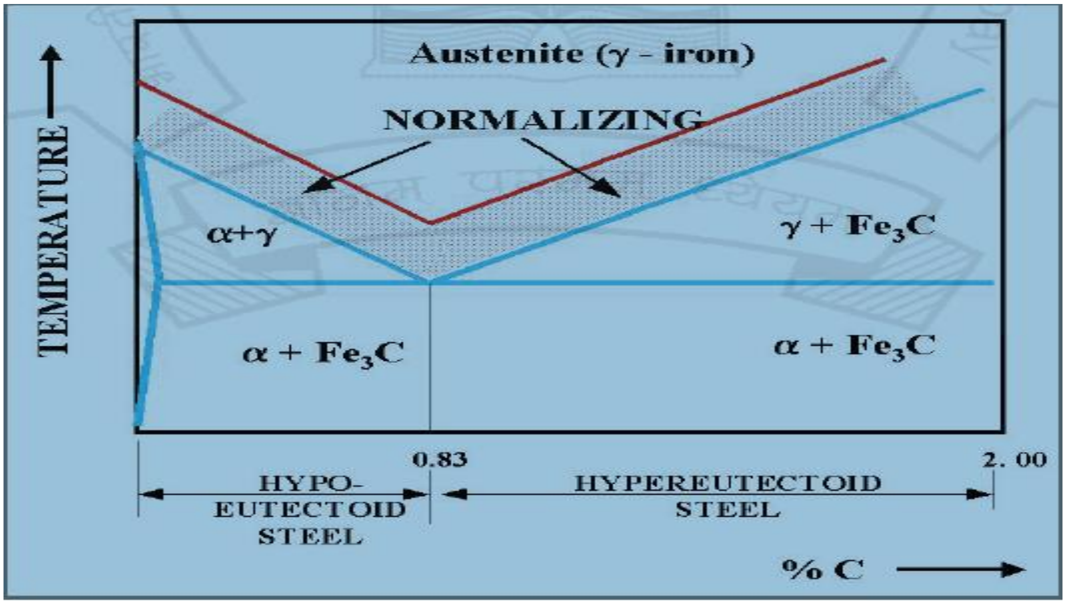


Fig : Normalising Process

(01 mark for each for Definition , Objective , Application & sketch)

f) **Define packing efficiency. Calculate packing efficiency any one crystal structure.**

Packing Efficiency :

The fractional amount of volume or space occupied by atoms in an unit cell is called as

Atomic Packing Factor (APF) or Atomic Packing Density or Atomic Packing Efficiency.

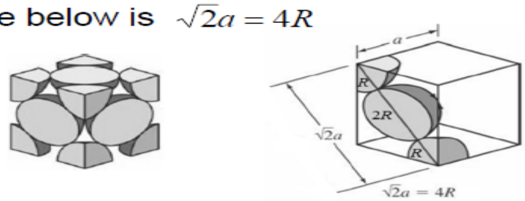
So , Packing Efficiency $= \frac{\text{Volume of atoms in unit cell}}{\text{Volume of the unit cell}}$

FCC lattice

Considering the atoms as hard spheres of radius R

Total volume of atoms $= 4 \times \frac{4}{3}\pi R^3$

The relation between R and the FCC cell side a as shown in the figure below is $\sqrt{2}a = 4R$

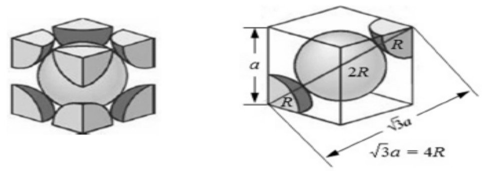


$$APF(FCC) = \frac{4 \times \frac{4}{3}\pi R^3}{a^3} = \frac{16 \times 2\sqrt{2}\pi a^3}{3 \times 64 a^3} = 0.74$$

BCC

For BCC crystals effective number of atoms per unit cell is 8 x 1/8 + 1 = 2 and the relation between R and a is

$$\sqrt{3}a = 4R$$



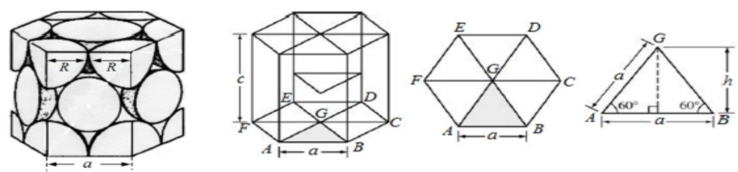
$$APF(BCC) = \frac{2\times\frac{4}{3}\pi R^3}{a^3} = \frac{8\times3\sqrt{3}\pi a^3}{3\times64a^3} = 0.68$$

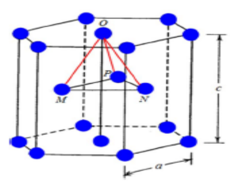
Hexagonal lattice

In the Hexagonal unit cell, number of atoms = 12 corner atoms x 1/6 (shared by six unit cells) + Two face atoms x 1/2 + 3 interior = 6.

$$2R = a$$

Unit cell volume = (6 x ½ x a x h) x c = (3 x a x a sin60°) x c = 3a^2 c sin60°





The face-centered atom and the three mid-layer atoms form a tetrahedron MNOP which has sides equal to a (as atoms at vertices touch each other) and height of c/2. Using this tetrahedron it can be shown that for an ideal hexagonal crystal c/a ratio = 1.633

$$APF(HCP) = \frac{6\times\frac{4}{3}\pi R^3}{3a^2c\sin60^\circ} = \frac{8\pi a^3}{3\times8\times1.414a^3} = 0.74$$

(1 Mark for Definition & 03 Marks for Calculation of Packing efficiency from any FCC , BCC or HCP structure)