LECTURE NOTES

ON

ENGINEERING MATERIAL
(TH-3)

FOR

3RD SEM MECHANICAL ENGG

(SCTEV&VT SYLLABUS)

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CHAPTER-1

ENGINEERING MATERIALS AND THEIR PROPERTIES

Engineering materials refers to the group of materials that are used in the construction of manmade structures and components. The primary function of an engineering material is to withstand applied loading without breaking and without exhibiting excessive deflection.

1.1 Classification of Engineering Materials

Basically **Engineering Materials** can be classified into two categories-

1. **Metals**
2. **Non-Metals**

Metals

Metals are polycrystalline bodies which are having number of differentially oriented fine crystals. Normally major metals are in solid states at normal temperature. However, some metals such as mercury are also in liquid state at normal temperature. All metals are having high thermal and electrical conductivity. All metals are having positive temperature coefficient of resistance. Means resistance of metals increases with increase in temperature.Examples of metals – Silver, Copper, Gold, Aluminum, Iron, Zinc, Lead, Tin etc. Metals can be further divided into two groups-

1. **Ferrous Metals –**
   All ferrous metals are having iron as common element. All ferrous materials are having very high permeability which makes these materials suitable for construction of core of electrical machines. Examples: Cast Iron, Wrought Iron, Steel, Silicon Steel, High Speed Steel, Spring Steel etc.
2. **Non-Ferrous Metals –**
   All non-ferrous metals are having very low permeability. Example: Silver, Copper, Gold, Aluminum etc.

Non-Metals

Non-Metal materials are non-crystalline in nature. These exists in amorphic or mesomorphic forms. These are available in both solid and gaseous forms at normal temperature.

Normally all non-metals are bad conductor of heat and electricity.

Examples: Plastics, Rubber, Leathers, Asbestos etc.

As these non-metals are having very high resistivity which makes them suitable for insulation purpose in electrical machines.

Difference between Metals and Non Metals

Sl. No.	Property	Metals	Non-Metals
1.	Structure	All metals are having crystalline structure	All Non-metals are having amorphic & mesomorphic structure
2.	State	Generally metals are solid at normal temperature	State varies material to material. Some are gas state and some are in solid state at normal temperature.
3.	Valance electrons and conductivity	Valance electrons are free to move within metals which makes them good conductor of heat & electricity	Valence electrons are tightly bound with nucleus which are not free to move. This makes them bad conductor of heat & electricity
4.	Density	High density	Low density
5.	Strength	High strength	Low strength
6.	Hardness	Generally hard	Hardness is generally varies
7.	Malleability	Malleable	Non malleable
8.	Ductility	Ductile	Non ductile
9.	Brittleness	Generally non brittle in nature	Brittleness varies material to material
10.	Lustre	Metals possess metallic lustre	Generally do not possess metallic lustre (Except graphite & iodine)

Other classification of engineering materials:

Engineering materials can also be classified as below-

1. **Metals and Alloys**
2. **Ceramic Materials**

3. **Organic Materials**

Metals and Alloys

Metals are polycrystalline bodies which are have number of differentially oriented fine crystals. Normally major metals are in solid states at normal temperature. However, some metals such as mercury are also in liquid state at normal temperature.
Pure metals are having very a low mechanical strength, which sometimes does not match with the mechanical strength required for certain applications. To overcome this draw back alloys are used.
Alloys are the composition of two or more metals or metal and non-metals together. Alloys are having good mechanical strength, low temperature coefficient of resistance.
Example: Steels, Brass, Bronze, Gunmetal, Invar. Super Alloys etc.

Ceramic Materials

Ceramic materials are non-metallic solids. These are made of inorganic compounds such as Oxides, Nitrides, Silicates and Carbides. Ceramic materials possess exceptional Structural, Electrical, Magnetic, Chemical and Thermal properties. These ceramic materials are now extensively used in different engineering fields.
Examples: Silica, glass, cement, concrete, garnet, Mgo, Cds, Zno, SiC etc.

Organic Materials

All **organic materials** are having carbon as a common element. In organic materials carbon is chemically combined with oxygen, hydrogen and other non-metallic substances.
Generally organic materials are having complex chemical bonding.
Example: Plastics, PVC, Synthetic Rubbers etc.

1.2 PROPERTIES OF MATERIALS

1. Physical Properties

A. The Melting or Freezing Point:

I. The melting or freezing point of pure metal is defined as the temperature at which the solid and liquid phases can exist in stable equilibrium. When a metal is heated to melting point, the liquid phase appears, and if more heat is supplied, the solid melts completely at constant temperature.

B. Boiling Point:

The boiling point of a liquid is the temperature at which its vapour pressure equals to one atmosphere. The boiling points of the metals except mercury are high. The boiling point of zinc

(907°C) and cadmium (865°C) are sufficiently low so that in recovery of these metals from their ores the metals are vapourised and condensed.

C. Density:

Mass per unit volume is termed as “density.” In metric system it is stated in kg/m^3. The low densities of aluminium and magnesium and of their alloys make them particularly valuable in aeronautic and transportation fields.

D. Linear Co-Efficient of Expansion:

The linear coefficient of expansion of a solid is defined as the increase in length, for each degree rise in temperature. These coefficients are important when metals are to be exposed to a considerable range of temperatures as in engine pistons, and other accurately fitting mechanisms.

E. Thermal Conductivity:

I. The thermal conductivity of a metal is defined as the number of kilojoules of heat that would flow per second through a specimen one sq. metre in cross-section and I metre in length when the temperature gradient is 1°C. Silver and copper show the highest thermal conductivities of all metals. Some metals like German silver exhibit very low conductivity and hence find applications where heat losses by metallic conduction should be kept to a minimum.

II. All metals are conductors of electricity; silver is the best conductor and copper is next. It should be noted that while volume aluminium has only 61% of the conductivity of copper, nevertheless weight for weight aluminium because of its low density, shows a conductivity nearly twice that of copper.

2. Mechanical Properties of Metals

Strength:

The strength of metal is its ability to withstand various forces to which it is subjected during a test or in service. It is usually defined as tensile strength, compressive strength, proof stress, shear strength, etc. Strength of materials is a general expression for the measure of capacity of resistance possessed by solid masses or pieces of various kinds to any cause tending to produce in them a permanent and disabling change of form or positive fracture.

Materials of all kinds owe their strength to the action of the forces residing in and about the molecules of the bodies (the molecular forces) but mainly to that one’s of these known as cohesion; certain modified results of cohesion as toughness or tenacity, hardness, stiffness and elasticity are also important elements, and strength is in relation of the toughness and stiffness combined.

Elasticity:

A material is said to be perfectly elastic if the whole of the stress produced by a load disappears completely on the removal of the load, the modulus of elasticity of Young’s modulus (E) is the proportionally constant between stress and strain for elastic materials.

Young's modulus is the indicative of the property called stiffness; small values of E indicate flexible materials and large value of E reflect stiffness and rigidity. The property of spring back is a function of modulus of elasticity and refers to the extent to which metal springs back when an elastic deforming load is removed. In metal cutting, modulus of elasticity of the cutting tools and tool holder affects their rigidity.

Plasticity:

I. Plasticity is the property that enables the formation of permanent deformation in a material. It is reverse of elasticity; a plastic material will retain exactly the shape it takes under load, even after the load is removed. Gold and lead are the highly plastic materials. Plasticity is used in stumping images on coins and ornamental work.

II. During plastic deformation there is the displacement of atoms within metallic grains and consequently the shapes of the metallic components change. It is because of this property that certain synthetic materials are given the name "plastics". These materials can be changed into required shape easily

Ductility:

It is the ability of a metal to withstand elongation or bending. Due to this property, wires are made by drawing out through a hole. The material shows a considerable amount of plasticity during the ductile extension. This is a valuable property in chains, ropes etc., because they do not snap off, while in service, without giving sufficient warning by elongation.

Malleability:

This is the property by virtue of which a material may be hammered or rolled into thin sheets without rupture. This property generally increases with the increase of temperature.

Toughness:

Toughness (or tenacity) is the strength with which the material opposes rupture. It is due to the attraction which the molecules have for each other; giving them power to resist tearing apart. The area under the stress-strain curve indicates the toughness (i.e., energy which can be absorbed by the material upto the point of rupture). Although the engineering stress-strain curve is often used for this computation, a more realistic result is obtained from a true-stress curve. Toughness is expressed as energy absorbed (Nm) per unit volume of material participating in absorption (m^3) or Nm/m^3. This result is obtained by multiplying the ordinate by the abscissa (in appropriate units) of stress-strain plot.**.**

Brittlenss:

Lack of ductility is brittleness. When a body breaks easily when subjected to shocks it is said to be brittle.

Hardness:

I. Hardness is usually defined as resistance of material to penetration. Hard materials resist scratches or being worn out by friction with another body.

II. Hardness is primarily a function of the elastic limit (i.e., yield strength) of the material and to a lesser extent a function of the work hardnening co-efficient. The modulus of elasticity also exerts a slight effect on hardness

Fatigue:. When subjected to fluctuating or repeating loads (or stresses), materials tend to develop a characteristic behaviour which is different from that (or materials) under steady loads. Fatigue is the phenomenon that leads to fracture under such conditions.

Fracture takes place under repeated or fluctuating stresses whose maximum value is less than the tensile strength of the material (under steady load). Fatigue fracture is progressive, beginning as minute cracks that grow under the action of the fluctuating stress.

Creep:.

"Creep" is the slow plastic deformation of metals under constant stress or under prolonged loading usually at high temperature. It can take place and lead to fracture at static stresses much smaller than those which will break the specimen by loading it quickly. Creep is specially taken care of while designing I.C. engines, boilers and turbines.

Chemical Properties of Materials

A study of chemical properties of materials is necessary because most of the engineering materials, when they come in contact with other substances with which they can react, tend to suffer from chemical deterioration.

The chemical properties describe the combining tendencies, corrosion characteristics, reactivities, solubilities, etc., of substances.

Some of the chemical properties are

(i) Corrosion resistance.

(ii) Chemical composition.

(iii) Acidity or alkalinity

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1.3 Performance requirement

A material performance establishes a level of expected performance of a material to ensure the long term use of the material. The construction of a material can also significantly affect its properties. Material is selected considering the design constraints and performance requirements e.g. loads acting on the member, size & weight constraints, environmental conditions, desired reliability & durability etc.

1.4 Material's reliability and safety

Reliabiliy is the degree of probability that a product, and the material of which it is made, will remain stable enough to function in service for the intended life of the product without failure.A material if it corrodes under certain conditions, then, it is neither stable nor reliable forthose conditions.

A material must safely perform its function, otherwise, the failure of the product made out of it may be catastrophic in air-planes and high pressure systems. As another example, materials that gives off spark when struck are safety hazards in a coal mine.

CHAPTER-2

FERROUS MATERIALS AND ALLOYS

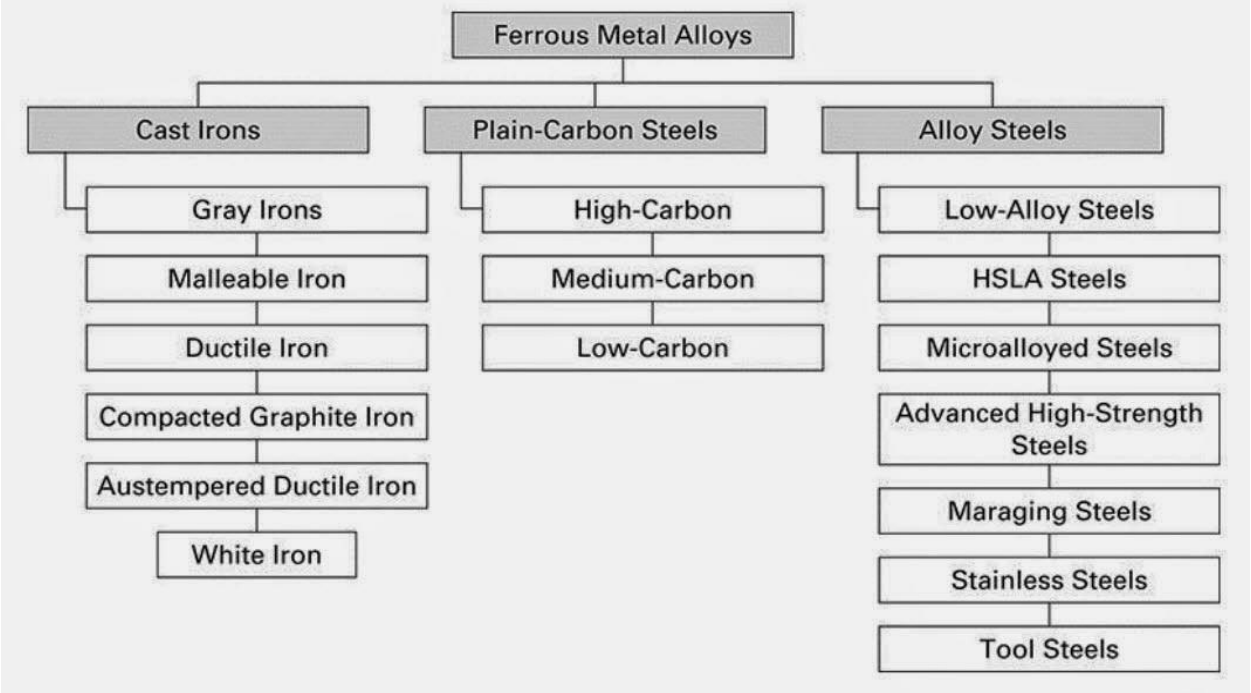
2.1 Ferrous Metal

Ferrous metals are those which contain iron as their main constituent or base metal. Iron (Fe) is the principal element of Ferrous Metals. The ferrous metals includes all the types of Iron, Steel, and their alloys. In the present, their role in the engineering industries can be easily described as “most dominating.”In all the jobs ranging from the manufacture of a primitive type of agricultural implements to advanced types of Air Crafts, ferrous metals and their alloys occupy a prominent position

Characteristics of Ferrous Metals

- Durable.
- Great tensile strength.
- Usually magnetic.
- Low resistance to corrosion.
- A silver-like colour.
- Recyclable.
- Good conductors of electricity.

2.2 classification



Different Ferrous metals,compositions and applications

1. Pig Iron:

Pig Iron is the first or basic form in which Iron is prepared as the metal from its It is, therefore, impure and crude and requires subsequent processing to develop Cast, Wrought Iron, and Steel, which are the common Ferrous Metals *used* in construction and industries ores*.*

Types of pig iron

i. Grey Pig Iron:

It is also called *foundry pig*. It is soft in character and rich in carbon. It is produced when the raw material is burnt at a very high temperature.

ii. White Pig Iron:

It is also called forge Pig Iron, as it is hard and brittle and can be converted only by using pressure. This type contains sulfur as the main impurity and hence is considered *inferior* in grade.

iii. Bessemer Pig Iron:

It is specially used in the manufacture of Steel in the Bessemer process, because of its freedom from sulfur and phosphorous

2. Cast Iron:

Cast Iron is derived from the Pig Iron. Pig Iron, because of its impurities, is weak and hence very difficult to shape into various forms.Therefore, Pig Iron is remolded in a furnace and cast or poured into molds of the desired shape to get the Iron known as Cast Iron**.**

General Properties of Cast Iron;

1. It is hard and brittle.
2. It can be hardened but cannot be tempered.
3. It cannot be forged, welded, or riveted.
4. It cannot be magnetized.
5. It does not rust easily.
6. It becomes soft in saltwater.
7. It shrinks easily.
8. It is weak in tension and strong in compression.
9. It is not suitable for shock and impact loads.
10. It has a specific gravity of 7.5, and it has a melting point of 1250°C.
11. **It has good machinability property**

Uses of Cast Iron;

1. Used for water and gas pipes.
2. Used in manufacturing of cisterns, sewer and drain pipes, manhole covers and fittings.

3. Used for rail chairs, carriage wheels, etc.
4. Used in compression members, bed plates, etc.
5. Used for making parts, bodies, and beds of machines

Types of Cast Iron

i. Grey Cast Iron:

Grey Cast Iron is produced by melting the foundry Pig Iron or grey Pig Iron in the cupola furnace. It shows grey color when fractured. The grey color is due to the presence of free graphite.

The usual composition of Grey Cast Iron is:

- Iron – 92 percent.
- Carbon – 3 to 3.5 percent (as graphite).
- Carbon – 0.5 percent (combined).
- Silicon – 1 to 2.75 percent.
- Manganese – 1 percent.
- Phosphorus – 0.5 to 1 percent.
- Sulfur – 0.02 to 0.15 percent.

It is soft and ductile. It is commonly used in castings, dies, molds, machine frames, and pipes, etc.

Properties of Grey Cast Iron

1. It is gray in color.
2. It is soft compared to other Cast Irons and has good machinability.
3. It has high compressive strength.
4. It is poor in tensile strength and impact strength with almost no ductility.

Uses of Grey Cast Iron

1. It is used for machine tool bodies.
2. It is used for pipe and pipe fittings.
3. It is used for automobile cylinder blocks, heads, housings, etc.
4. It is used in flywheels and agricultural implements.

ii. White Cast Iron:

It is white in color as there is no free graphite. In white Cast Iron, the entire carbon is in combined state. i.e., in the form of cementite, also known as Iron carbide.

White Cast Iron is produced by melting the low phosphorus Pig Iron along with the Steel scraps in a cupola furnace.

The Cast Iron thus obtained is in a molten state, and it is chilled, i.e., it is cooled rapidly. Therefore, it is also known as chilled Cast Iron.Due to rapid cooling, its outer surface becomes harder while its interior remains softer.

It has a shiny white color and a bright metallic white luster. It is very strong, hard, and resistant to Wear and Tear. And quite brittle as well.
Its usual composition is as follows:

- Iron – 94 percent.
- Carbon – 1.75 to 2.3 percent.
- Silicon – 0.85 to 1.2 percent.
- Manganese – 0.1 to 0.4 percent.
- Phosphorous – 0.05 to 0.2 percent.
- Sulfur – 0.12 to 0.35 percent.

Properties of White Cast Iron
1. It is white in color.
2. It is hardest of all Cast Irons and is wear-resistant.
3. It is brittle.
4. It has high tensile strength but weak compressive strength.
5. It is not easily machinable due to its hardness, hence, require special tools for machining.

Uses of White Cast Iron:
It is used for car wheels, rollers for crushing grains, crusher jaw plates, etc.

iii. Malleable Cast Iron:
Malleable Cast Iron is the annealed White Cast Iron, i.e., white Cast Iron is heated slowly up to 900 to 950°C temperature for several days and then cooled at a slower rate.

The Iron obtained is malleable as well as ductile. It possesses useful properties of both Cast Iron and mild Steels.

The tensile strength of malleable Cast Iron is higher than that of grey Cast Iron and has good machinability.

It is used for hubs of wagon wheels, railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks, etc.

Uses of Malleable Cast Iron
1. It is used in Automobile industries for making rear-axle housing, steering-gear housing, hubs, and pedals, etc.
2. It is used in Railways equipment of a great variety.
3. It is used in Agricultural machinery making and carpentry tools.

iv. Ductile Cast Iron:
It is a modified Grey Cast Iron. It is also called as nodular or spheroid graphite Cast Iron or high strength Cast Iron.

Ductile Cast Iron is produced by adding any one of the elements of magnesium, calcium, cerium, bismuth, zinc, cadmium, titanium, and boron into the molten Grey Cast Iron.

Composition of ductile Cast Iron is;

- Carbon – 3.2 to 4.5%.
- Silicon – 1 to 4%.
- Magnesium – 0.1% to 0.8%.
- Phosphorus – 0.1%.
- Iron – the rest % is Iron.

Properties of Ductile Cast Iron
1. It has high fluidity.
2. It has high tensile strength, toughness, and wear resistance.

Uses of Ductile Cast Iron
1. It is used for castings where shock and impact loads are operating.
2. It is used in rolls for rolling mills, hydraulic cylinders, cylinder heads, etc.

v. Alloy Cast Iron

Alloy Cast Irons are also called as plain Cast Irons. Alloyed Cast Irons are produced by adding the alloying elements to the Pig Iron in the cupola furnace itself or adding the same into the molten Cast Iron taken out of the furnace.

Better results are obtained when Pig Iron with alloying elements are heated in an electric furnace or air furnace. The alloying elements used are; nickel, chromium, molybdenum, and vanadium.The usual alloying elements are *Nickel* and *Chromium*. *Nickel* is added to effect an increase in the hardness and resistance to wear. Chromium makes the Cast Iron extremely tough, strong and ductile.

The alloy Cast Irons are used for gears, sprockets, wheels, I.C engine cylinders, piston, piston rings, crankcases, crankshafts, camshaft, brake drums and shoes, parts of grinding machines, etc

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3. Wrought Iron:

It is the purest form of Iron, containing all impurities below a limit of 0.5 percent. And carbon is included in these impurities, its proportion being generally less than 0.12 percent.Besides, Wrought Iron always contains a small proportion of slag in the silicate component.The source material for the manufacture of Wrought Iron is PIG IRON. There are two processes for the manufacture of Wrought Iron:

- Puddling Process.
- Aston Process.

Properties and Uses of Wrought Iron:

Strength*:* It has a tensile strength varying between 2500 to 4000 kg/cm^2. The strength will be greater in the longitudinal direction.
The ultimate compressive strength ranges between 1500-2000 kg/cm^2.

Physical property: Wrought Iron is bluish in color, has a silky luster and fibrous structure. It is malleable, ductile, tough, and resistant to corrosion.
Density: The metal has a density of 7.8 gm/cm^3 and a melting point of 1500 centigrade. Wrought Iron shows good resistance to fatigue and sudden shock. Moreover, it can be welded with ease.

Because of the above set of properties, Wrought Iron is extensively used as a material for making plates, sheets, pipes, tubes, etc.

It is also used in buildings, railways, and marine industries.

2.4 Steel:

Steel is an alloy of Iron and carbon, where the carbon content is less than 1.7%. If the carbon content in Steel exceeds 1.7%, it does not combine with the Iron, but it is present as free graphite.Besides carbon, many other metals may also be present in addition to Iron, giving rise to great varieties of Steel.The hardness and toughness of Steel increase with the increase in carbon content up to 1.7%.On the other hand, with the decrease in the carbon content (lower than 0.1%), the material would resemble more to Wrought Iron or pure Iron.

The best thing about Steel is that it has both properties of Cast and Wrought Iron – Compressive Strength of Cast Iron and Tensile Strength of Wrought Iron.Due to these properties, Steel is used as a structural material in all types of situations.Steel is a versatile material of modern age. Its properties can be varied over a wide range by varying its composition and by subjecting it to various mechanical and heat treatment processes.

As we noted earlier, Cast Iron is better in resisting compressive stresses, while Wrought Iron is suited to tensile stresses. Steel is superior in resisting both compressive and tensile stresses.Hence, Steel finds most of the applications for all purposes in places of Cast Iron and Wrought Iron.The elements of the composition of Steel apart from carbon are sulfur, silicon, phosphorus, manganese, etc.

Classification of Steels:

Steels can be classified in many ways such as on the basis of the methods used in their manufacture, on the carbon content, or according to their use.It is, however, the classification on the basis of their chemical composition is commonly adopted. Following are the major groups of Steels.

i. Plain Carbon Steels:

This is the first major group of Steels. Carbon is the only controlling component in them besides Iron. They are further subdivided into 3 subcategories.

- Low Carbon Steels (C=0.05-0.25%)
- Medium Carbon Steels (C=0.25-0.50%)
- High Carbon Steels (C=0.50-1.50%)

ii. Alloy Steels:

An alloy is the purposeful mixture of two or more elements of which one being in largest proportion is called as base metal, and other elements are called as alloying elements.

However, the Steel, containing Iron and carbon, is not referred to as an alloy. But if elements are added other than Iron and carbon, the Steel is known as alloy Steel.

Thus all the Steels, in addition to Iron and carbon-containing other elements such as; nickel, chromium, manganese, silicon, vanadium, molybdenum, tungsten, sulfur, phosphorus, etc., are called as alloy Steels.

The purpose of alloying is to improve the properties of Steel, like imparting the fine grain size, to improve the hardness, toughness, strength, corrosion resistance, etc.

These are Steels made with the addition of a definite proportion of a selected element or elements in addition to carbon at the manufacturing stage.

Benefits of alloying are as follow:

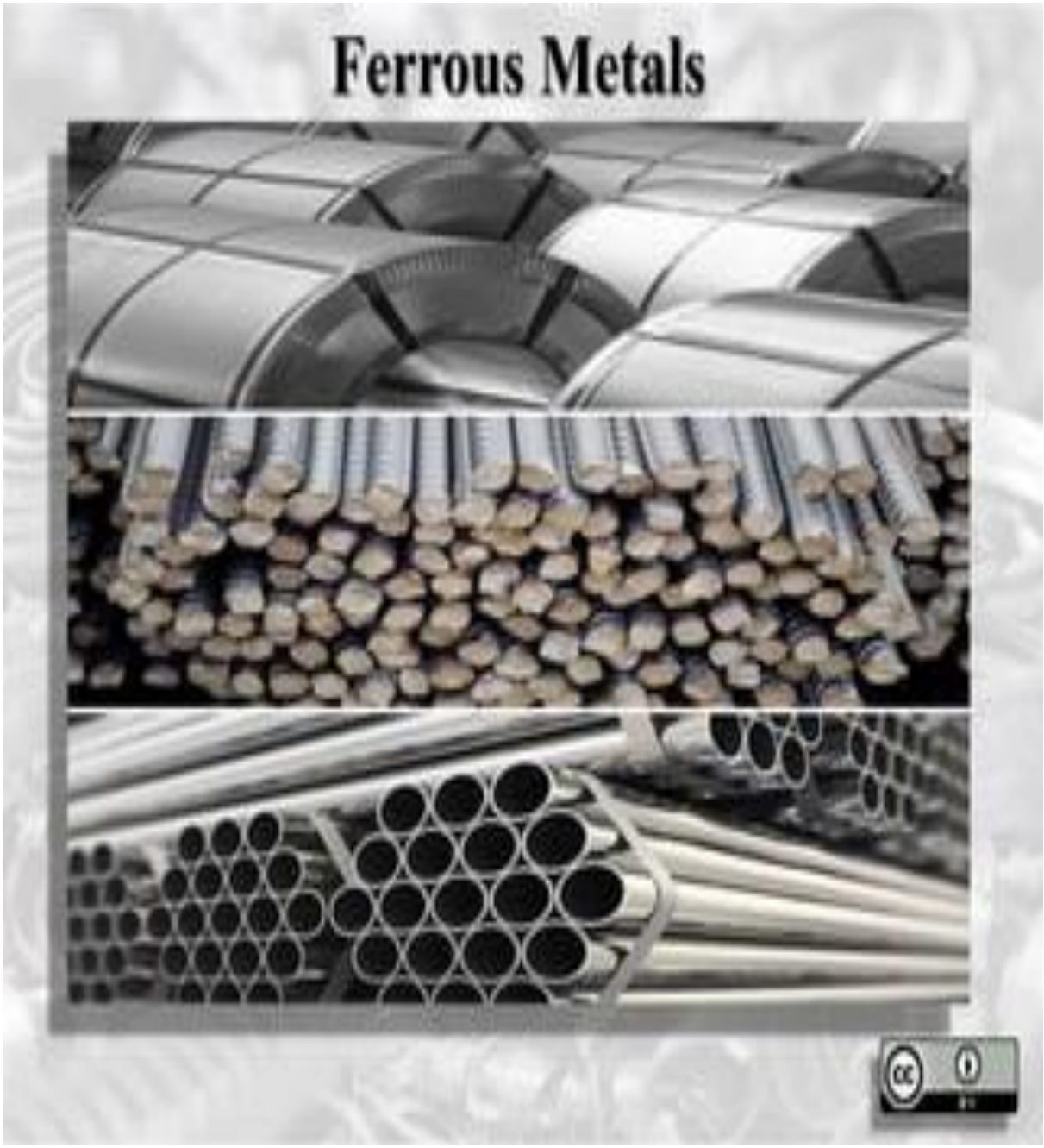
- The tensile strength of the Steel may be increased without affecting its workability.
- The resistance against very high temperature, abrasion and corrosion may be improved considerably.
- The electrical, magnetic, and thermal properties may be modified in the desired direction.

They can be sub-divided into 2 types on the basis of the proportion of alloying elements, which are the following:

- Low Alloy Steels.
- High Alloy Steels.



Ferrous Metals



Examples of Ferrous Metal Applications



Skyscrapers



Bridge



Shipping Containers



Industrial Piping

CHAPTER – 3

IRON CARBON SYSTEM

3.1 INTRODUCTION

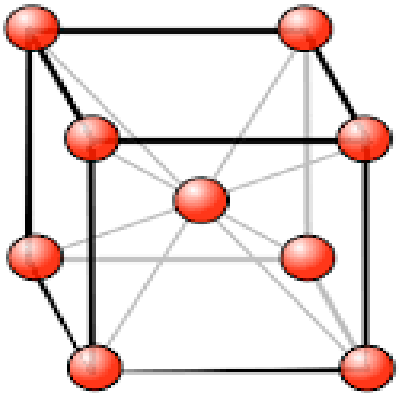
The Fe - C diagram (also called the iron - carbon phase or equilibrium diagram) is a graphic representation of the respective microstructure states of the alloy iron - carbon (Fe-C) depending on temperature and carbon content. The iron-carbon phase diagram is widely used to understand the different phases of steel and cast iron.

To explain this diagram, an introduction about metal structures and pure iron must be done.

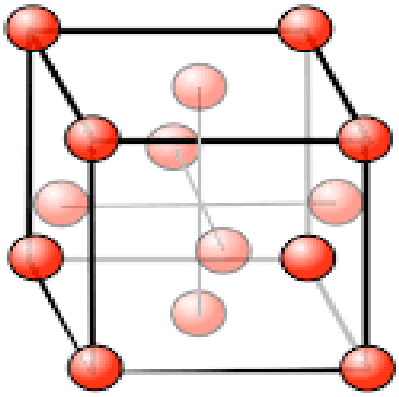
UNIT CELL CUBIC STRUCTURES

Before to explain the Fe-C diagram we've to introduce the two structures that are involved in the diagram and precisely:

1. BODY-CENTERED CUBIC (BCC) structure, in which there's an atom at each corner of the cube and one in the center;
2. FACE-CENTERED CUBIC (FCC) structure, in which there's an atom at the corner of each unit cell and one in the center of each face, but there's no atom at the center of the cube.



(BCC)



(FCC)

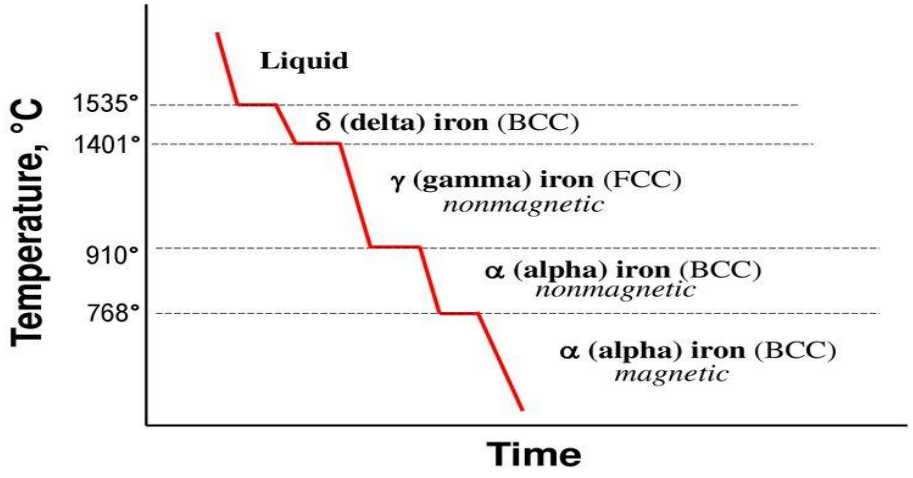
IRON

Iron (Fe) is an allotropic metal that change behavior based on temperature. It's a relatively soft and ductile metal. It exists in more than one type of lattice structure (BCC/FCC). In fact there're four allotropic transformations and five phases that

iron can assume. All of these can be easily represented using a COOLING CURVE where the following phases can be identified:

1. LIQUID PHASE (L), above 1539 °C iron is in the liquid phase.
2. DELTA FERRITE (δ-Fe), if we slowly cooling down the pure iron below his melting point (1539 °C) it will crystallize into a phase, which has a body-centered cubic (BCC) structure;
3. GAMMA FERRITE (γ-Fe), cooling down further until 1400 °C, iron assume a new phase called gamma (austenite), which has a face-centered cubic (FCC) structure;
4. ALFA FERRITE non magnetic (α-Fe), at 910 C an below the iron assume a new structure called alfa ferrite, which is again a BCC structure;
5. ALFA FERRITE magnetic (α-Fe), under 770 C, iron assume a magnetic properties maintaining the BCC structure of alfa ferrite;

Allotropic Transformation of Pure Iron



Cooling Curve of Pure Iron

3.2 Fe-C PHASE DIAGRAM

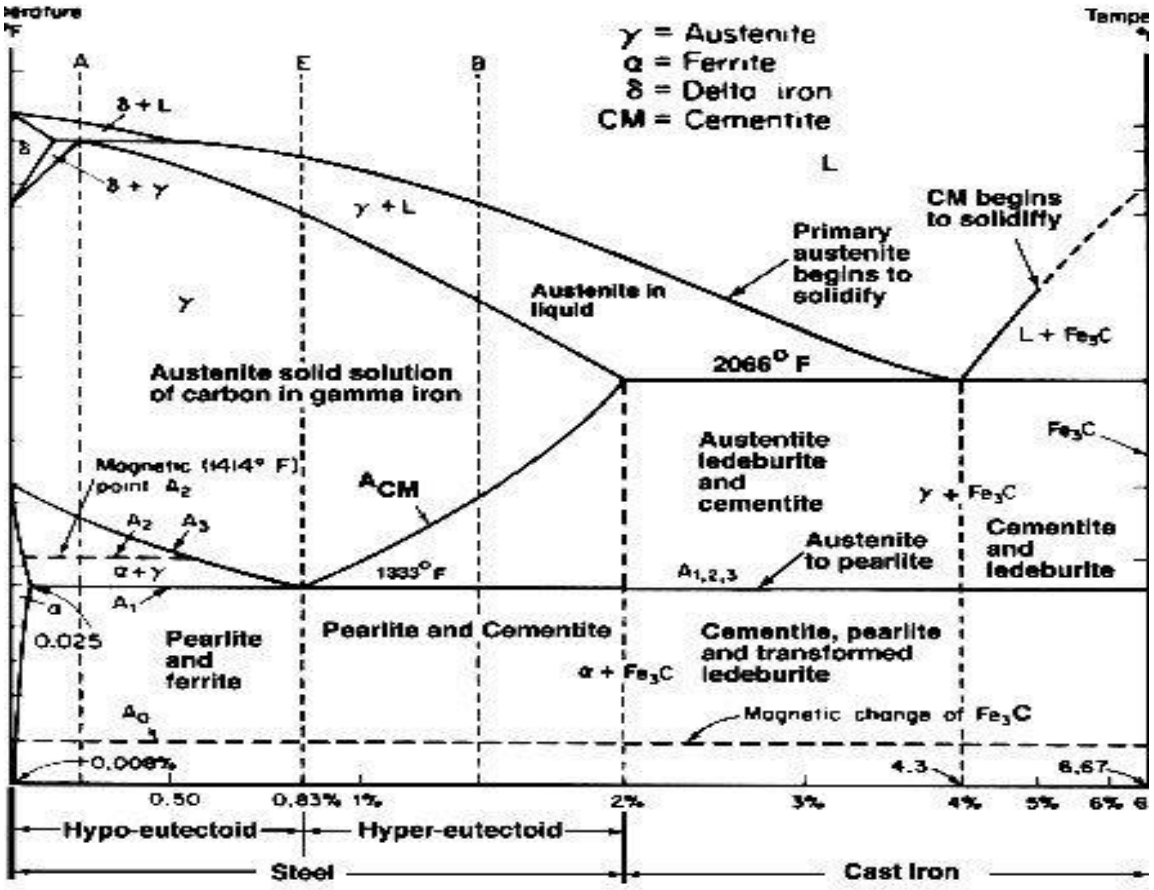
As mentioned before the Fe-C phase diagram is the representation of all the phases and structures of the alloy iron - carbon based on the different temperature and carbon content.

This diagram is particular important in order to:

- Classify the alloy into different groups like steel and cast iron
- Identify the different phases of iron
- Identify the microstructure of the different phases
- Provide the information regarding solidification and heat treatments

We're going to see how build the diagram step by step starting to the essential temperatures indicated regarding the pure iron.

Temperature (°C) is indicated in the y-axis and weight carbon content (wt % C) is indicated in the x-axis. In the diagram is represented a maximum value of 6.67% C as there's no particular application in engineering for carbon content above this value.



Boundaries

Multiple lines can be seen in the diagram titled A1, A2, A3, A4, and ACM. The A in their name stands for the word ‘arrest’. As the temperature of the metal increases or decreases, a phase change occurs at these boundaries when the temperature reaches the value on the boundary.

Normally, when heating an alloy, its temperature increases. But along these lines (A1, A2, A3, A4, and ACM) the heating results in a realignment of the structure into a different phase and thus, the temperature stops increasing until the phase has changed completely. This is known as thermal arrest as the temperature stays constant.

Different chemical reactions

1. **Peritectic reaction,** the liquid (at 0.5% C) and δ-Fe (at 0.1% C) phases transform into a austenite (with 0.2% C) at temperature of 1493 °C
2. **Eutectic reaction,** the liquid solidifies as a phase mixture of austenite (with 2.1% C) and cementite (with 6.67% C) at temperature of 1147 °C.
3. **Eutectoid reaction,** austenite (at 0.8% C) transforms into a phase mixture of ferrite (with 0.02% C) and cementite (with 6.67% C) at temperature of 727 °C.

Different phases OF Fe-C diagram

1. **Liquid phase (L)**
2. **Delta ferrite phase (δ-fe),** is an interstitial solid solution of C in δ-Fe (BCC) in the high temperature region of the diagram. It's stable at temperature above 1400 °C and melts at temperature above 1539 °C;
3. **Gamma ferrite phase (γ-fe),** is an interstitial solid solution of C in γ-Fe (FCC). It's also called austenite. Is not stable below 910 °C. The max solubility of C is about 2.1% at 1147 °C. It's has high formability;
4. **Alfa ferrite phase (α-fe),** is an interstitial solid solution of C in α-Fe (BCC). It's a stable form of iron at room temperature. The max solubility of C is about 0.02% at 727 °C. It's a fairly and ductile phase, actually the softest one structure of the diagram;
5. **Cementite (fe3c),** also called as iron carbide. It's an inter metallic compound of iron and carbon with orthorhombic crystal system. It's very hard and brittle phase, actually the hardest structure of the entire diagram

CHAPTER- 4

CRYSTAL IMPERFECTIONS

4.1 crystal

It is definen as any solid material in which the component atoms are arranged in a definite pattern and whose surface regularity reflects its internal symmetry.





Crystals are classified into seven crystallographic systems based on their symmetry: isometric, trigonal, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic.
An ideal crystal has a perfect order of its constituent particles while a real crystal has less order because of some defects.

Crystal imperfections

Crystal Imperfections are the defects in the regular geometrical arrangement of the atoms in a Crystalline solid. A Perfect Crystal is an idealization; there is no such thing in nature.

Any deviation from the perfect atomic arrangement in a crystal is said to contain imperfections or defects. Or a crystalline defect is a lattice irregularity having one or more of its dimensions on the order of an atomic dimension. There are 4 major categories of crystalline defects:

Zero dimensional: Point defects occurring at a single lattice point.

One dimensional: Linear defects (dislocations) occurring along a row of atoms.

Two dimensional: Planar (surface) defects occurring over a two-dimensional surface in the crystal.

Three dimensional: Volume (bulk) (void) defects

4.2 Classification of Crystal Defects

1.Point defects

a. Vacancy

b. Schottky

c. Self interstitial

d. Frenkel

e. Colour centers

f. Polarons

g. Excitons

2. Line defects

a. Edge dislocation

b. Screw dislocation

3. Surface defects

a. Grain boundaries

b. Tilt boundaries

c. Twin boundaries

d. Stacking faults

4. Volume defects

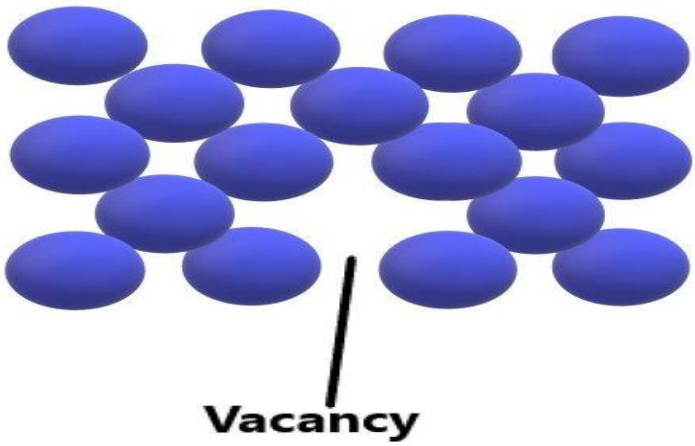
a. Inclusions

b. Voids

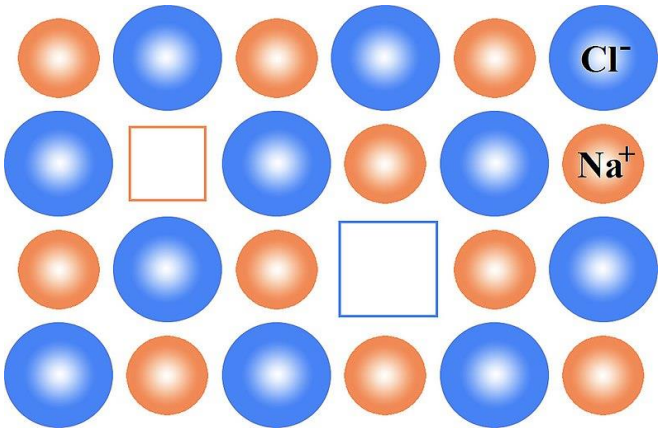
4.3 Point Defects

Point defects are where an atom is missing or is in an irregular place in the lattice structure.

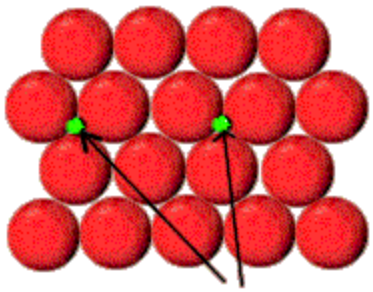
Vacancies A perfect crystal with regular arrangement of atoms can not exist. There are always defects, and the most common defects are point defects. This is especially true at high temperatures when atoms are frequently and randomly change their positions leaving behind empty lattice sites, called vacancies. Or Vacancies are empty spaces where an atom should be, but is missing. In most cases diffusion (mass transport by atomic motion) - can only occur because of vacancies.



Schottky This defect is a type of vacancy in which an atom being free from regular site, migrates through successive steps and eventually settles at the crystal surface. a pair of anion and cation vacancies.

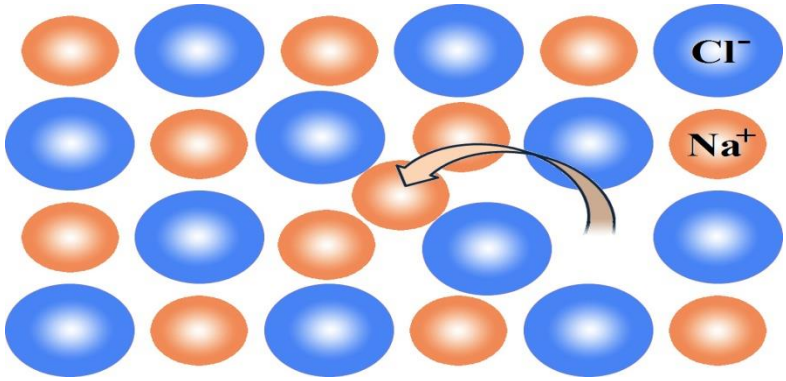


Self Interstitials Atoms are squeezed in between regular lattice sites. If the interstitial atom is of the same species as the lattice atoms, it is called self-interstitial. Creation of a self-interstitial causes a substantial distortions in the surrounding lattice and costs more energy as compared to the energy for creation of a vacancy and, under equilibrium conditions, selfinterstitials are present in lower concentrations than vacancies. Foreign, usually smaller atoms (carbon, nitrogen, hydrogen, oxygen) are called interstitial impurities. Interstitial impurity atoms are much smaller than the atoms in the bulk matrix. Interstitial impurity atoms fit into the open space between the bulk atoms of the lattice structure. An example of interstitial impurity atoms is the carbon atoms that are added to iron to make steel.



Interstitial Atoms

Frenkel defect It is a pair of cation (positive ion) vacancy and a cation interstitial. Or it may also be an anion (negative ion) vacancy and anion interstitial. Or the combination of a vacancy and interstitial is called a Frankel defect. However anions are much larger than cations and it is not easy for an anion interstitial to form. In both Frenkel and Schottky defects, the pair of point defects stays near each other because of strong coulombic attraction of their opposite charges.

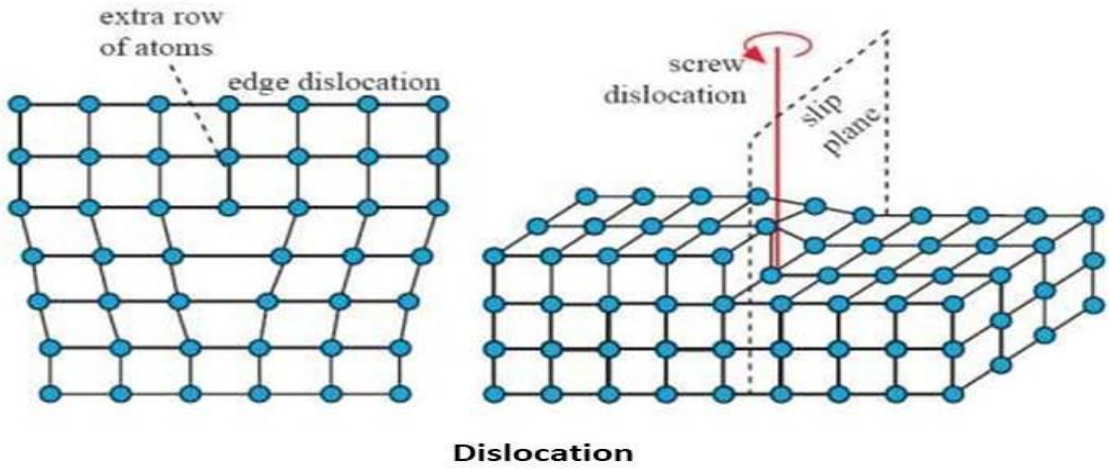


4.4 Line Defects (Dislocations)

In line defects groups of atoms are in irregular positions. Linear defects are commonly called dislocations. Any deviation from perfectly periodic arrangement of atoms along a line is called the line imperfection. A line defect is a lattice distortion created about a line formed by the solidification process, plastic deformation, vacancy condensation or atomic mismatch in solid solutions.

Two extreme types of dislocations are distinguish as

1. Edge dislocations and 2. Screw dislocations.



Dislocation

Edge Dislocations: The inter-atomic bonds are significantly distorted only in the immediate vicinity of the dislocation line. As shown in the set of images below, the dislocation moves similarly a small amount at a time. The dislocation in the top half of the crystal is slipping one plane at a time as it moves to the right from its position in image (a) to its position in image (b) and finally image (c). In the process of slipping one plane at a time the dislocation propagates across the crystal. Edge dislocation is considered positive when compressive stresses present above the stresses exist below the dislocation line, it is considered as negative edge dislocation.

Screw or Burgers dislocation:

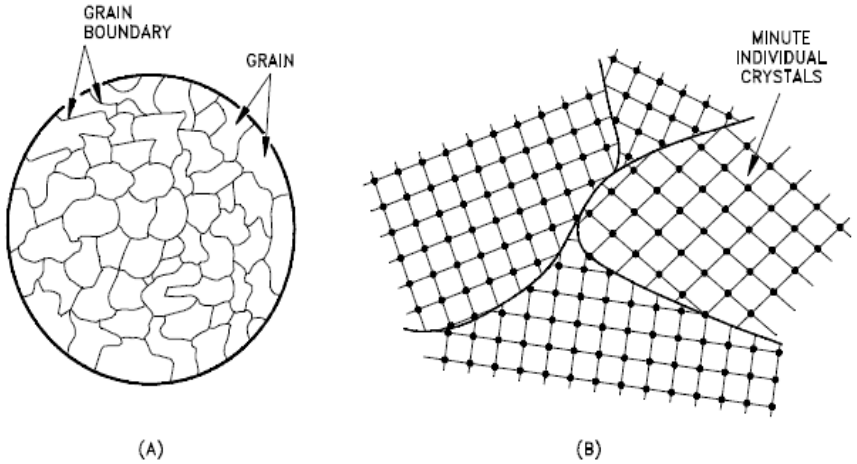
The screw dislocation is slightly more difficult to visualize. The motion of a screw dislocation is also a result of shear stress, but the defect line movement is perpendicular to direction of the stress and the atom displacement, rather than parallel.

Interfacial defects

Interfacial defects can be defined as boundaries that have two dimensional imperfections in crystalline solids, and have different crystal structures and/or crystallographic orientations on either side of them. They refer to the regions of distortions that lie about a surface having thickness of a few atomic diameters. For example: external surfaces, grain boundaries, twin boundaries, stacking faults, and phase boundaries. These imperfections are not thermodynamically stable, rather they are meta-stable imperfections. They arise from the clustering of line defects into a plane.

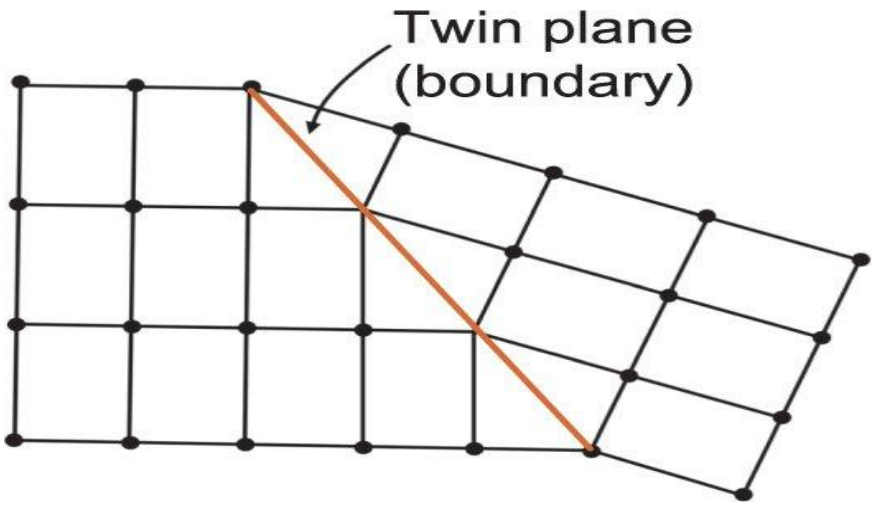
Grain boundaries

Crystalline solids are, usually, made of number of grains separated by grain boundaries. Grain boundaries are several atoms distances wide, and there is mismatch of orientation of grains on either side of the boundary as shown in figure below. When this misalignment is slight, on the order of few degrees (< 10°), it is called low angle grain boundary. These boundaries can be described in terms of aligned dislocation arrays. If the low grain boundary is formed by edge dislocations, it is called tilt boundary, and twist boundary if formed of screw dislocations. Both tilt and twist boundaries are planar surface imperfections in contrast to high angle grain boundaries. For high angle grain boundaries, degree of disorientation is of large range (> 15°). G rain boundaries are chemically more reactive because of grain boundary energy.



Twin boundaries

It is a special type of grain boundary across which there is specific mirror lattice symmetry. Twin boundaries occur in pairs such that the orientation change introduced by one boundary is restored by the other (figure below). The region between the pair of boundaries is called the twinned region. Twins which forms during the process of recrystallization are called annealing twins, whereas deformation twins form during plastic deformation. Twinning occurs on a definite crystallographic plane and in a specific direction, both of which depend on the crystal structure. Annealing twins are typically found in metal.



CHAPTER–5

HEAT TREATMENT

Definition

Heat Treatement is the process of heating and cooling metals to achieve desired physical and mechanical properties through modificationof their crystalline structure.

5.1Purpose of Heat Treatement

To increase hardness and strength
To increase wear and abrasion resistance
To reduce or eliminate internal residual stresses
To eliminate gases particularly hydrogen.
To induce controlled compressive residual stress on the surface
To improve corrosion resistance of the surface

5.2Heat Treatement Processes

1-Annealing
- Full annealing
- Iso-thermal annealing
- Diffusion annealing
- Recrystallisation annealing
- Process annealing
- Stress relief annealing

2-Normalising
3-Hardening
4-Carburising
5-Cyniding
6-Nitriding
7-Flame hardening
8-Induction hardening

Annealing

Annealing involves heating to a predetermined temperature, holding at this temperature and finally cooling at a very slow rate. The temperature to which steel is heated and the holding time are determined by various factors such as chemical composition of steel, size and shape of steel component and final properties desired.

Purpose of annealing:

(1) Relieve internal stress
(2) Improve or restore ductility
(3) Enhance machinability
(4) Eliminate chemical non-uniformity
(5) Refine grain size
(6) Reduce the gaseous contents in steel

Depending on the heat treatment temperature annealing treatment can be subdividedinto three classes:

(1) Full annealing
(2) Partial annealing
(3) Subcritical annealing

Full annealing steel is heated above the upper critical temperature (A3) and thencooled slowly.
Partial annealing invovles heating steel to temperature lying between lower critical temperature (A1) and upper critical temperature (A3 or Acm).
Subcritical annealing is a process in which the maximum temperature to which steel is heated is always less than the lower critical temperature (A1).

Full annealing

Steel is heated to about 30-50°C above the upper critical temperature for hypo- eutectoid steels. The steel is held at this temperature for predetermined time, followed by cooling at a very slow rate as cooling in the furnace.

Isothermal annealing

In hypo-eutectoid steel is heated above the upper critical temperature and held for some time at this temperature. The steel is then cooled rapidly to a temperature less than the lower critical temperature (A1). This temperature is usually chosen between 600-700°C. Fast cooling can be achieved by rapidly transferring steel to another furnace maintained at the desired

temperature.

Diffusion annealing

This process is also known as homogenizing annealing, is employed to remove any structural non-uniformity. Dendrites, columnar grains and chemical inhomogeneties are observed in the case of ingots, heavy plain carbon steel castings and high alloy steel castings. Steel is heated sufficiently above the upper ctical temperature (1000-1200°C) and held at this temperature for prolonged periods, 10-20 hours, followed by slow cooling.

Partial annealing

Partial annealing is also refered to as intercritical annealing or incomplete annealing. Steel is heated between the lower critical temperature and the upper critical annealing. It is followed by slow cooling. Hypoeutectoid steels are undergoes this process. The resultant microstructure consists of fine pearlite and cementite instead of coarse pearlite and a network of cementite at the austenite grain boundaries as observed in the case of full annealing**.**

Recrystallization annealing

Heavily cold worked are subjected to this treatment. The process consists of heating steel above the recrystallization temperature, holding at this temperature and cooling thereafter. The temperature for recrystallizing annealing is not fixed. Recrystallization temperature and also recrystallization annealing temperature depends on chemical composition, amount of prior deformation, holding time and initial grain size.

Process annealing

In this process steel is heated to a temperature below the lower critical temperature and is held at this temperature for sufficient time and then cooled. As it is subcritical annealing, coolin rate is of little importance. Purpose of this process is to reduce the hardness and increase ductility of cold worked steel so that further working cab be carried out easily. It differs from recrystallization annealing in the sense that complete recrystallization of cold worked steel may or may not take place in this treatment.

Normalizing

Normalizing is a process of heating steel to about 40-50°C above the upper critical temperature, holding for proper time and then cooling in still air or slightly agitated air to room temperature. In special cases, cooling rate can be controlled either by changing air temperature or air volume. After normalizing the resultant microstructure should be pearlitic. This is particularly important for some alloy steels which are air hardening by nature.

Since the temperature involved in this process is more than that for annealing, the homogeneties of austenite increases and it increases and it results in better dispersion of ferrite and cementite in the final microstructure. This dispersion results in enhanced mechanical properties.

Application:

Refinement of grain size is one of the most important objectives of normalizing. Rolled and forged steel, possessing coarse grains due to high temperatures involved in these operations are subjected to normalizing treatment for grain refinement.

Another important application is adoption as post treatment after achieving a homogeneous structure. Generally heavy castings, including ingots, suffer from chemical inhomogeneity.

Difference between Annealing and normalising

Annealing	Normalising
1. Metal is heated and is left at the same furnace for cooling.	Metal is heated and held at for same time and then allowed to cool down freely in the air.
2. Annealing is done before machining.	Normalising is done after forging or wrong heat treatment.
3. Tensile strength is reduced after annealing.	Tensile strength is increased after normalizing.
4. Grain size is changed to larger in the internal structure.	Grain size is changed to very small in the internal structure.

5.3 Hardening

For heavy duty purposes high hardness is required. The process by which high hardness can be obtained is known as hardnening. Hardening treatment consists of heating to hardening temperature, holding at that temperature followed by rapid cooling such as quenching in water, oil or salt baths. The high hardness developed by this process is due to the phase transformation accompanying rapid cooling.

Hardening temperature depends on chemical composition, for plain carbon steel it depend on carbon content alone. Hypoeutectoid steels are heated to about 30-50°C above the upper critical temperature, where as eutectoid s and hypereutectoid steels are heated to about 30- 50°C above the lower critical temperature. Ferrite and pearlite transform to austenite at hardening temperature for hypoeutectoid steels. This austenite transforms to martensite on rapid quenching from hardening temperature. The presence of martensite accounts for high hardness of quenched steel. If hypoeutectoid steel is heated to a hardening temperature equivalent to that of hypereutectoid steel, the structure will consist of ferrite and austenite. This will transform to ferrite and martensite on quenching. The preferred hardening temperature for hypereutectoid steel lies between the lower critical and upper critical temperature.

Advantages

1. The first is related to the presence of cementite in hardened steel which improves the wear resistance of the steel.
2. Hardening temperature is the attainment of fine martensite in the final microstructure.

Because of rapid cooling internal stresses are developed, so hardened parts are followed by another treatment known as tempering which reduces internal stresses and improves the ductility of the material.

FACTORS AFFECTING HARDENING PROCESS

Properties improved by hardening are depends on various factors:

1. Chemical composition of steel
2. Size and shape of the steel part
3. Hardening cycle i.e heating rate, hardening temperature, holding time and cooling rate
4. Homogeneity and grain size of austenite
5. Quenching media
6. Surface condition of steel part

Hardening Methods

Rapid cooling is carried out in order to obtain martensite in hardened steel. Austenite to pearlite transformation is surpressed in this process.

(i) conventional or direct quenching

(ii) quenching in stages

(iii) spray quenching

(iv) quenching in self tempering

(v) austempering or iso thermal quenching

(vi) martempering

Heating the steel to the austenitizing temperature followed by quenching in a constant temperature bath maintained above Ms point. The usual temperature of the bath is lies between 180 and 250°C. Steel

is held in the bath till a uniform temperature is achieved through out the section and then cooled in air. The cooling rate should be sufficiently high and holding time is short to prevent transformation of austenite to pearlite or to bainite. Marteniste is formed in the second stage. The resultant microstructure of martempered steel is martensite. In order to improve properties, martempered steels are generally tempered.

Tempering

Heating hardened steel below the lower critical temperature, followed by cooling in air or at any other desored rate, is known as tempering. It is already mentioned that hardening process is followed by tempering to improve the ductility of the steel. Tempering treatments lowers

hardness, strength and wear resistance. However this is compensated by the advantages gained by relieving internal stresses, restoration of ductility and transformation of retained austenite.

STRUCTURAL CHANGES DURING TEMPERING

A number of structural changes take place during tempering treatment. These changes include isothermal transformation of retained austenite, ejection of carbon from body centred tetragonal lattice of martensite, growth and spheroidization of carbide particles and formation of ferrite-carbide mixture.

1. First stage of tempering is also referred to as low temperature tempering. The maximum temperature at this stage is 250°C and this results a low carbon martensite and a carbide by transformation of high carbon martensite. The carbide precipitation from the high carbon martensite during the first stage of tempering is not cementite. This carbide is known as epsilon carbide which has a hexagonal closed packed

structure. The carbon content of epsilon carbide is more than that of cementite and the chemical formula Fe2.4C. This carbide is forms at low temperature range in which martensite is metastable.

2. The second stage of tempering consists of heating steels in the temperature range (350- 500°C) In this stage retained austenite is transformed to bainite. It consists of ferrite and epsilon carbide.

3. The third stage of tempering is known as high temperature tempering (500-680°C). At this high temperature a mixture of ferrite and cementite forms. Martensite changes to ferrite by losing its carbon. The release carbon combines with epsilon carbide which forms cementite.

Effect of alloying elements on tempering

Almost all alloying elements enhance the ability of steel to softening during tempering. Alloying elements is divided by carbide (Cr, Mo, W, V, Ti) and non carbide (Ni, Al, Mn) forming elements. Non carbide forming elements enters into ferrite and/or martensute hence they have less impact on tempered hardness of steel. In case of carbide forming elements they form their respective alloy carbides and the martensite formed in the alloy steel are more stable.

Surface hardening

Surface hardening is the process of hardening the surface of a metal object while allowing the metal deeper underneath to remain soft, thus forming a thin layer of harder metal (called the "case") at the surface. For iron or steel with low carbon content, which has poor to no hardenability of its own, the case hardening process involves infusing additional carbon into the case. Case hardening is usually done after the part has been formed into its final shape, but can also be done to increase the hardening element content of bars to be used in a pattern welding or similar process.

Carburizing Carbon is diffused into the part's surface to a controlled depth by heating the part in a carbonaceous medium. The resulting depth of carburization, commonly referred to as case depth, depends on the carbon potential of the medium used and the time and temperature of the carburizing treatment. The steels most suitable for carburizing to enhance toughness are those with sufficiently low carbon contents, usually below 0.3 percent. Carburizing temperatures range from 1550 to 1750°F (843 to 954°C), with the temperature and time at temperature adjusted to obtain various case depths. Steel selection, hardenability, and type of quench are determined by section size, desired core hardness, and service requirements.

Three types of carburizing are most often used: -

1. **Liquid carburizing** involves heating the steel in molten barium cyanide or sodium cyanide. The case absorbs some nitrogen in addition to carbon, thus enhancing surface hardness.
2. **Gas carburizing** involves heating the steel in a gas of controlled carbon content. When used, the carbon level in the case can be closely controlled.
3. **Pack carburizing**, which involves sealing both the steel and solid carbonaceous material in a gas-tight container, then heating this combination.

With any of these methods, the part may be either quenched after the carburizing cycle without reheating or air-cooled followed by reheating to the austenitizing temperature prior to quenching. The case depth may be varied to suit the conditions of loading in service. However, service characteristics frequently require that only selective areas of a part have to be case hardened. Covering the areas not to be cased, with copper plating or a layer of commercial paste, allows the carbon to penetrate only the exposed areas. Another method involves carburizing the entire part, then removing the case in selected areas by machining, prior to quench hardening

Nitriding

The steel part is heated to a temperature of 900-1150°F (482 to 621°C) in an atmosphere of ammonia gas and dissociated ammonia for an extended period of time that depends on the case depth desired. A thin, very hard case results from the formation of nitrides. Strong nitride-forming elements (chromium and molybdenum) are required to be present in the steel, and often special nonstandard grades containing aluminum (a strong nitride former) are used. The major advantage of this process is that parts can be quenched and tempered, then machined, prior to nitriding, because only a little distortion occurs during nitriding.

Cyaniding This process involves heating the part in a bath of sodium cyanide to a temperature slightly above the transformation range, followed by quenching, to obtain a thin case of high hardness.

5.5 Hardenability of steels

When a peice of steel is heated to austenitizing temperature and then quenched, the cooling rate varies across the cross section. Since different grades of steel has its own depth of penetration of hardness across the cross section. Hardenability of steel is a measure of this property. It may be defined as the susceptibility of the steel to hardening when quenched and is related to the depth and distribution of hardness across a cross-section.

The maximum hardness depends on the carbon content in the steel. It can be achieved byfulfilling the following conditions:

(i) All the carbon is in solution in austenite
(ii) Crtical cooling rate is achieved
(iii) No retained austenite is present after quenching
(iv) No auto tempering of martensite takes place

CHAPTER -6

NON FERROUS ALLOYS

6.1 Duralumin

It an alloy of aluminum that contains copper, manganese, magnesium, iron, and silicon and is resistant to corrosion by acids and seawater.

Duralumin Properties

Duralumin is a strong, light-weighted, and hard alloy of aluminum. It is also reflective and impermeable. It is a malleable metal and can be easily shaped. It is a very good conductor of heat and electricity. It is odorless, and reacts with the oxygen that is around, and forms aluminum oxide. It is resistant to corrosion. It has a thin surface, which is made up of a layer of pure aluminum, which is corrosion-resistant and covers the core of the strong duralumin. Generally, Duralumin alloys are soft, ductile, and workable when they are in a normal state. They can be easily rolled, folded, or forged. They can also be drawn into a variety of shapes and forges. It has a high strength, which can be easily lost during wielding. So it can be easily transformed, and hence is used in aircraft construction. It is suited for aircraft construction because of its lightweight and high strength.
It is an important wrought alloy. Its composition contains following chemical contents.
Copper = 3.5-4.5 %
Manganese = 0.4 - 0.7 %
Magnesium = 0.4- 0.7 %
Aluminium = 94 %

Duralumin Uses Duralumin has the following uses:

- It is used for making wire, bar, and rods for screw machine products. It is used in places where good strength and good machinability are required.

It is used in heavy-duty forgings, wheels, plates, extrusions, aircraft fittings, space booster tankage and truck frame, and other suspension components. It finds applications in places where high strength is required, and services at elevated temperatures.

Y – Alloy

Y-Alloy is also called copper-aluminium alloy. The addition of copper to pure aluminium increases its strength and machinability. Its composition contains following chemical content.

Copper = 3.5-4.5 %
Manganese = 1.2 - 1.7 %
Nickel = 1.8 - 2.3 %
Silicon, Magnesium, Iron = 0.6 % each
Aluminium = 92.5 %

Properties

The addition of copper in aluminium increases its strength and machinability. Y-alloy can be easily cast and hot worked. Like duralumin, this alloy is heat treated and age hardened. The age-hardening process of Y-alloy is carried out at room temperature for about five days.

Applications

Y-Alloy is mainly used for cast purposes, but it can also be used for forged components like duralumin. Since Y -alloy has better strength than duralumin at high temperatures, therefore it is much used in aircraft engines for cylinder heads, pistons, cylinder heads, crank
cases of internal combustion engines die casting, pump rods etc.

6.2 Properties of Copper Alloys

Copper is a tough, ductile and malleable material. These properties make copper extremely suitable for tube forming, wire drawing, spinning and deep drawing. The other key properties exhibited by copper and its alloys include:

- Excellent heat conductivity
- Excellent electrical conductivity
- Good corrosion resistance
- Good biofouling resistance
- Good machinability
- Retention of mechanical and electrical properties at cryogenic temperatures
- Non-magnetic

Copper-Tin Alloys: The Bronzes

Properties

Copper tin alloy can be divided into two categories—high-tin bronzes, where the tin content is greater than 10%, and low-tin bronzes, where the tin content is between 0% and 10%. High-tin bronzes are known for their strength and corrosion resistance, while low-tin bronzes are known for their malleability and flexibility. Depending on your needs, you can customize your alloy by adjusting both the amount of tin in your mixture as well as the temperature at which it is heated to obtain different properties.

Uses

Bronze alloys have countless applications thanks to their strength and malleability. They have been used in many industries throughout history—from creating coins to making musical instruments like cymbals or bells. Modern times, they are still commonly used in manufacturing industries such as aerospace engineering or automotive engineering due to their weight-to-strength ratio. In addition to industrial applications, bronze alloys can also be used for decorative purposes, such as creating sculptures or jewelary.

Brass

Brass is an alloy of copper (Cu) and zinc (Zn). Due to its unique properties, which include **corrosion resistance**,

common uses for brass include applications that require low friction. These applications can include fittings (fasteners and connectors), tools, appliance parts, and ammunition components.

Babbit material

Babbitt metal, also spelled Babbit Metal, is tin- or lead-based alloys used as bearing material for axles and crankshaftsThey may be made of:

(1) high-tin alloys with small quantities of antimony and copper;
(2) high-lead alloys containing antimony, arsenic, and tin; and
(3) intermediate tin-lead alloys with antimony and copper

The alloy mentioned in the patent was **89% Tin, 9% Antimony and 2% Copper**, which is amazingly close to today's very popular ASTM B-23 Grade 2 “Babbitt” was originally applied to Tin-base alloys, it is now used to describe bearing metals with Lead or other metals as the major element

6.3 Lead and Lead Alloys

Lead was one of the first metals known to man. Probably the oldest lead artifact is a figure made about 3000 BC. All civilizations, beginning with the ancient Egyptians, Assyrians, and Babylonians, have used lead for many ornamental and structural purposes. Many magnificent buildings erected in the 15th and 16th centuries still stand under their original lead roofs.

Lead is very soft and ductile, it is normally used Commercially as lead alloys. Antimony, tin, arsenic, and calcium are the most common alloying elements. Antimony generally is used to give greater hardness and strength, as in storage battery grids, sheet, pipe, and castings. Antimony contents of lead-antimony alloys can range from 0.5 to 25%, but they are usually 2 to 5%.

Properties of Lead

The properties of lead that make it useful in a wide variety of applications are density, malleability, lubricity, flexibility, electrical conductivity, and coefficient of thermal expansion, all of which are quite high; and elastic modulus, elastic limit, strength, hardness, and melting point, all of which are quite low. Lead also has good resistance to corrosion under a wide variety of conditions. Lead is easily alloyed with many other metals and casts with little difficulty.

The high density of lead (11.35 g/cm3, at room temperature) makes it very effective in shielding against x-rays and gamma radiation. The combination of high density, high limpness (low stiffness), and high damping capacity makes lead an excellent material for deadening sound and for isolating equipment and structures from mechanical vibrations.

Malleability, softness, and lubricity are three related properties that account for the extensive use of lead in many applications.

The low tensile strength and low creep strength of lead must always be considered when designing lead components. The principal limitation on the use of lead as a structural material is not its low tensile strength but its susceptibility to creep. Lead continuously deforms at low stresses and this deformation ultimately results in failure at stresses far below the ultimate tensile strength. The low strength of lead does not necessarily preclude its use. Lead products can be designed to be self-supporting, or inserts or supports of other materials can be provided.

Alloying with other metals, notably calcium or antimony, is a common method of strengthening lead for many applications. In general, consideration should always be given to supporting lead structures by lead-covered steel straps. When lead is used as a lining in a structure made of a stronger material, the lining can be supported by bonding it to the structure. With the development of improved bonding and adhesive techniques, composites of lead with other materials can be made. Composites have improved strength yet also retain the desirable properties of lead.

Products and Applications

The most significant applications of lead and lead alloys are lead-acid storage batteries (in the grid plates, posts, and connector straps), ammunition, cable sheathing, and building construction materials (such as sheet, pipe, solder, and wool for caulking). Other important applications include counterweights, battery clamps and other cast products such as: bearings, ballast, gaskets, type metal, terneplate, and foil.

Zinc Alloys

Zinc alloys have excellent electrical conductivity. High thermal conductivity. Low cost raw material. High dimensional accuracy and stability

Applications

Zinc alloy applications vary widely based on industry. In addition, the purity level of the zinc will also dictate which application that the zinc will be used in.

- Automotive: Zinc alloys are often used coatings for galvanized steel. Galvanizing steel parts and components in vehicles helps to prevent corrosion.
- Medical: Zinc alloys are used for medical devices as zinc is considered environmentally safe.
- Construction and Buildings: Zinc alloys are used throughout the construction industry in a wide range of products and applications. It can be used a solder, household fittings, and as coating on roofing and cladding products.
- Marine: Zinc alloys are often used as sacrificial anodes for marine vessels and other applications that will be exposed to saltwater environments.

Nickel alloys

Nickel alloys are characterized by **strength, ductility, and resistance to corrosion and heat**. About 65 % of the nickel consumed in the Western World is used to make stainless steel, whose composition can vary but is typically iron with around 18% chromium and 8% nickel.

Applications

Alloys containing 72-83% nickel have the best soft magnetic properties and are used in transformers, inductors, magnetic amplifiers, magnetic shields and memory storage devices.

Low alloy and High alloy materials

Both low and high alloy steel have enhanced properties than carbon steel. However, the key difference between low alloy steel and high alloy steel is that low alloy steels have less than 0.2% alloying element, whereas high alloy steels have more than 5% alloying element. When considering the chemical composition, low alloy steel contains iron, carbon (less than 0.2%), and other alloying elements such as Ni, Cr, Mo, V, B, W and Cu, while high alloy steel contains iron chromium, nickel, carbon, manganese.

6.4 Duplex and Super Duplex stainless steel

Duplex Stainless Steel is named as such because its metallurgical structure consists of two duel phases – austenitic (face-covered cubic lattice) and ferrite (body-centred cubic lattice). Unlike traditional austenitic stainless steels, super duplex stainless steels have a 20 – 28% higher chromium content, up to a 5% molybdenum content, 9% lower nickel, and only 0.05 – 0.5% Nitrogen

Super Duplex stainless steels are based around an alloying addition of 25% chromium, whereas duplex stainless steels are based around an alloying addition of 22% chromium. By increasing the chromium content, the level of pitting corrosion resistance is also increased. However, there are other variables than these.

CHAPTER – 7

BEARING MATERIAL



Bearing steel is **special steel featuring high wear resistance and rolling fatigue strength**. High-carbon chromium bearing steel, engineering steel and some types of stainless steel and heat resistant steel are used as materials of bearings and for other purposes.

Properties of bearing material.

A bearing material
Possess low co-efficient of friction
Provide hard ,wear resistance surface with a tough core.
Have high compressive strength
Have high fatigue strength
Be able to bear shocks and vibration.

Classifications of bearing materials

Bearing metals are

- Lead or metals are Example – White metal,Babbitt's metal
- (ii) Cadmium –based alloys . Ex: Automobiles and air craft industries

- (iii) Aluminum –based alloys Example –Bearing is diesel engines and tractors.
- (iv) Silver-based alloys Examples:-Connecting rod bearing of air craft engine.
- (vi)Sintered bearing materialsExamples:-sintering iron bearing .
- (v) Copper- based alloys Examples:-Bronze,bearing in railway.
- (vi) Non metallic bearing materialsExamples:-Teflon and nylon

Copper based bearing metal:-

Composition:typical composition of bearing bronze are;¬
Cu 80% 85%
Sn 10% 15%
Pb 10%

The term bronze covers a large number of copper alloys with varying percentages of Sn, Zn, and Pb.bronze is one of the oldest known bearing materials

Bronze:

- Is easily worked.
- Has good corrosion resistance andIs reasonably hard
- Tin bronze (10 to 14% tin, remainder copper) is used in the machine and engine industry for bearing bushes made from thin walled drawn tubes.
- Copper based alloy are employed for making bearing required to resist heavier pressures such as in railways.

Tin base bearing material:

Composition: Sn -88% Sb - 8% Cu - 4%

Tin based alloys preferred for higher load and speeds.

- They posses low co-efficient of friction.
- They also posses good ability to embed dirt
- Good conformability to journal.
- Good corrosion resistance
- Very good seizure resistance etc.
- Tin based alloys are used in high speed engines steam turbines.

CHAPTER -8

SPRING MATERIALS

Spring materials are **high strength alloys**, which often exhibit the greatest strength in the alloy system. For example: In steels, medium and high-carbon steels are regarded as spring materials

Properties of Spring Materials

1. It should possess high modulus of elasticity.
2. It should have high elastic limit
3. It should have high fatigue strength
4. It should have high creep strength
5. It should have high notch toughness
6. It should have good resistance to corrosion
7. It should have high electrical conductivity

Iron- based alloy

i) High Carbon Spring Steel

(C 0.7-1.0,Mn 0.3-0.6& remaining Fe) These spring steels are the most commonly used of all spring materials because they are the least expense, are easily worked, and are readily available. They are not suitable for springs operating at high or low temperature or for shock or impact loading

ii) Alloy Spring Steel

EN-45(C 0.5,Mn 1.0,Cr 0.2-0.9,V0.12 &remaining Fe),EN-60(C0.5-0.75,Mn0.6- 1.2&remaning Fe). These spring steels are used for conditions of high stress, and shock or impact loadings. They can withstand a wider temperature variation than high carbon spring steel and are available in either the annealed or pre-tempered conditions.

iii) Stainless Spring Steel

(Cr18,Ni8,C 0.1-0.2&remaining Fe)The use of stainless spring steels has increased and there are compositions available that may be used for temperatures up to 288°C.

They are all corrosion resistant but only the stainless 18-8 compositions should be used at sub-zero temperatures. They are suitable for valve springs.

Copper Base Spring Alloys

Copper base alloys are more expensive than high carbon and alloy steels spring material. However they are frequently used in electrical components because of their good electrical properties and resistance to corrosion.

i) Brasses(Cu67,Zn33): Switch control, electrical application.
ii) Nickle Silver(Cu56,Ni18,Zn18): Electrical relays.
iii) Pb Bronze (Cu92,Sn8,Pb 0.1): Bushes.
Iv) Beryllium Copper(Cu98,Be2.0): Relays and Bushes

CHAPTER – 9

POLYMERS

9.1 **Polymer**

A polymer is a large molecule or a macromolecule which essentially is a combination of many subunits. The term polymer in Greek means ‘many parts’. Polymers can be found all around us. From the strand of our DNA, which is a naturally occurring biopolymer, to polypropylene which is used throughout the world as plastic.

Polymers may be naturally found in plants and animals (**natural polymers**) or may be man-made (**synthetic polymers**). Different polymers have a number of unique physical and chemical properties, due to which they find usage in everyday life.

Classification

Natural, Synthetic, and Semi-synthetic Polymers.

Natural Polymers:

They occur naturally and are found in plants and animals. For example, proteins, starch, cellulose, and rubber. To add up, we also have biodegradable polymers called biopolymers.

Semi-synthetic Polymers:

They are derived from naturally occurring polymers and undergo further chemical modification. For example, cellulose nitrate, and cellulose acetate.

Synthetic Polymers:

These are man-made polymers. Plastic is the most common and widely used synthetic polymer. It is used in industries and various dairy products. For example, nylon-6, 6, polyether’s etc.

Classification Based on Molecular Forces

- **Elastomers:** These are rubber-like solids weak interaction forces are present. For example, Rubber.
- **Fibres:** Strong, tough, high tensile strength and strong forces of interaction are present. For example, nylon -6, 6.

- **Thermoplastics:** These have intermediate forces of attraction. For example, polyvinyl chloride.
- **Thermosetting polymers:** These polymers greatly improve the material's mechanical properties. It provides enhanced chemical and heat resistance. For example, phenolics, epoxies, and silicones.

Properties of Polymers

Physical Properties

- As chain length and cross-linking increase, the tensile strength of the polymer increases.
- Polymers do not melt, and they change state from crystalline to semi-crystalline.

Chemical Properties

- Compared to conventional molecules with different side molecules, the polymer is enabled by hydrogen bonding and ionic bonding resulting in better cross-linking strength.
- Dipole-dipole bonding side chains enable the polymer for high flexibility.
- Polymers with Vander Waals forces linking chains are known to be weak but give the polymer a low melting point.

Optical Properties

- Due to their ability to change their refractive index with temperature, as in the case of PMMA and HEMA: MMA, they are used in lasers for applications in spectroscopy and analytical applications.

Thermoplastic polymers	Thermosetting polymers
These are formed by addition polymerisation	These are formed by condensation polymerization
Monomer used in these is generally bifunctional	In this monomer used is tri, tetra or polyfunctional
They are long chain linear polymer with negligible cross links	These have three- dimensional network structure with number of cross links
They have low molecular wt.	They have high molecular wt
They are soft, weak , brittle	They are hard, strong and more brittle
They can be softened and reshaped and reused.	They cannot be softened and reshaped again once again.
e.g.- polyethylene, polystyrene,PVC,PVA etc.	e.g.- phenol formaldehyde, ureaformaldehyde, nylon 6:6 etc.

9.2 Elastomers

Elastomers are polymers that have viscosity and elasticity and therefore are known as viscoelasticity. The molecules of elastomers are held together by weak intermolecular forces and generally exhibit low Young's modulus and high yield strength or high failure strain. They inherit the unique property of regaining their original shape and size after being significantly stretched.

Elastomers Examples

Following are examples of elastomers with their applications:

1. **Natural rubber:** These are used in the automotive industry and in the manufacture of medical tubes, balloons, adhesives.
2. **Polyurethanes:** These are used in the textile industry for manufacturing elastic clothing like lycra.
3. **Polybutadiene:** These are used for providing wear resistance in wheels of vehicles.
4. **Silicone:** These are used in the manufacture of medical prostheses and lubricants as they have excellent chemical and thermal resistance.
5. **Neoprene:** These are used in the manufacture of wet-suits and in industrial belts.

Properties of Elastomers

- **Temperature:** The specific working temperature of elastomers vary depending on the factors like media compatibility, seal design, and dynamic and static operation.
- **Low-temperature flexibility:** The rate of recovery of elastomeric material can be studied by subjecting the material to low-temperature retraction.
- **Hardness:** The measurement of the material's resistance towards the deforming force for a defined length of time is done by measuring the hardness. It differs from material to material. The soft compounds deform easily and have high friction, while the harder compounds have high resistance and low friction.
- **Ageing:** This property helps to understand the behaviour of a material when exposed to heat. If the elastomers are pushed beyond their ageing resistance, they will suffer from hardening, cracking, and splitting.
- **Colour:** Colouring is used mainly to differentiate between the compound grades based on their usage.
- **Elongation at break:** This property is used for testing the moment of rupture when the material is under tensile stress.

CH – 10

COMPOSITES AND CERAMICS

10.1 composites.

Composites are simply **a combination of two or more constituent materials with different physical or chemical properties**. When combined, they produce a material with characteristics different from their original properties. The two main components within a composite are the matrix and fiber.

Types of Composite Material

Currently, composites are widely used in consumer goods and construction materials as a lightweight, economical replacement for metals. Composite materials are being used to create parts that are as massive as passenger aeroplane fuselages. The various types of composite materials are as follows:

- Ceramic matrix composite
- Metal matrix composite
- Reinforced concrete
- Glass fibre reinforced concrete
- Translucent concrete
- Engineered wood
- Plywood
- Engineered bamboo
- Parquetry
- Wood-plastic composite
- Cement-bonded wood fibre
- Fibreglass
- Carbon Fiber reinforced polymer
- Sandwich panel
- Composite honeycomb
- Papier-mache
- Plastic coated paper

Properties of Composite Materials

Each of the different forms of composites includes a broad and expanding range of materials; however, composites as a class of materials typically exhibit the following qualities: a low coefficient of thermal expansion, high strength, high modulus, low

density, and exceptional fatigue resistance, creep, creep rupture, corrosion, and wear.

Physical Properties

The physical properties of the composite are not isotropic in nature. But typically, they are anisotropic. For instance, the stiffness of the composite panel will often depend on the direction of the applied forces and/or moments. By applying the rule of mixtures, it is possible to find the condition that sets the upper limit for composite strength. There are two rules of mixture:

- Isostrain rule of mixtures
- Isostress rule of mixtures

Mechanical Properties of Composite Materials

High-strength, high-modulus fibres are incorporated into a matrix to create a composite material (polymer, metal, or ceramic). The fibres' orientation can result in various in-plane characteristics (longitudinal, transverse-stress, strain, and modulus of elasticity).

- **Particle Reinforcement:** Particle reinforcement generally strengthens composites less than fibre reinforcement. It improves the composites' stiffness while boosting their toughness and strength. They are utilised in applications that demand resistance because of their mechanical characteristics.
- **Continuous Fiber Reinforcement:** Generally, a matrix with a weak phase and a fiber acting as the strong phase is used to accomplish continuous fiber reinforcement. The availability of materials in their fibre form, which can be obtained, accounts for the popularity of fiber utilisation. Due to the covalent nature of their linkages, non-metallic fibers typically exhibit a relatively high strength to density ratio when compared to metal fibers. The most well-known example of this is carbon fibers, which have numerous uses in the space industry, sports gear, and protective gear.

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10.2 Ceramics

Types of Ceramics

A ceramic is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures

There are different material categories into which ceramics can be divided. Ceramics are mainly divided into two categories:

- Traditional
- Advanced

These categories can all be evolved into distinctive material features. Let us see each of these categories in detail.

Traditional Ceramics

Objects made of clay and cement hardened by high-temperature heating are examples of traditional ceramics. Dishes, crockery, flowerpots, and roof and wall tiles are all made from traditional ceramics. Earthenware, stoneware, and porcelain pottery are the types of pottery displayed here.

- Structure clay product
- Whitewares

Advanced Ceramics

Carbides, such as silicon carbide, SiC; oxides, such as aluminium oxide, Al2O3; nitrides, such as silicon nitride, Si3N4; and many other materials, including mixed oxide ceramics that can act as superconductors, are examples of advanced ceramics. Modern processing techniques are required for advanced ceramics, and developing these techniques has led to advances in medicine and engineering. There are two types of advanced ceramics:

- Non-silicate oxide ceramics
- Non-oxide ceramics

Semiconductors are a type of ceramic; they are covalently bonded solids that include, in addition to the well-known Si and Ge, GaAs, CdTe ...etc. Outside of electronic materials, other semiconductors include SiC, TiO2, ZnO, and others. Atoms in solids, in general, and ceramics in particular, will be arranged in long-range order, short-range order, or a combination of both. Solids with long-range order are known as crystalline solids, while those without that periodicity are known as amorphous, glassy, or noncrystalline solids.

Advantages of Ceramics

There are numerous materials available to create a wide range of items. Every substance, from glass to metal, has advantages. Here, we'll list a few significant benefits of working with ceramic materials and using final ceramic products:

- Because they have high hardness, they are commonly used as abrasive powder and cutting tools.
- Because of their high melting point, they are excellent refractory materials.

- They are also good thermal insulators, which is why they are used as a refractory material.
- They have high electric resistivity, making them suitable for use as an insulator.
- Due to their low mass density, they produce lightweight components.
- They are generally chemically inert, making them long-lasting.

Disadvantages of Ceramics

Ceramic materials have a lot of high installation and transportation requirements, and their main drawback is fragility. It is easy for them to break when hard objects strike ceramic art. The following drawbacks are listed below:

- They have a brittle nature.
- They have a low degree of ductility.
- Their tensile strength is low.
- Even for identical specimens, there is a wide range of variation in strength.
- They are challenging to shape and machine.

Applications of Ceramics

Ceramics are harder, non-combustible, and inert than metals and plastics. As a result, they are suitable for use in high temperature, corrosive, and tribological applications.

- Because of their lightweight, they are used in the space industry.
- They serve as cutting instruments.
- They serve as refractory substances.
- As electrical insulators and thermal insulators, they are utilized.
- Photoelectrochemical devices or cells PEC are solar cells that produce electrical energy or hydrogen through a process similar to water electrolysis