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ENGINEERING MATERIAL (TH- 03)

THIRD SEMESTER

AUTOMOBILE ENGINEERING

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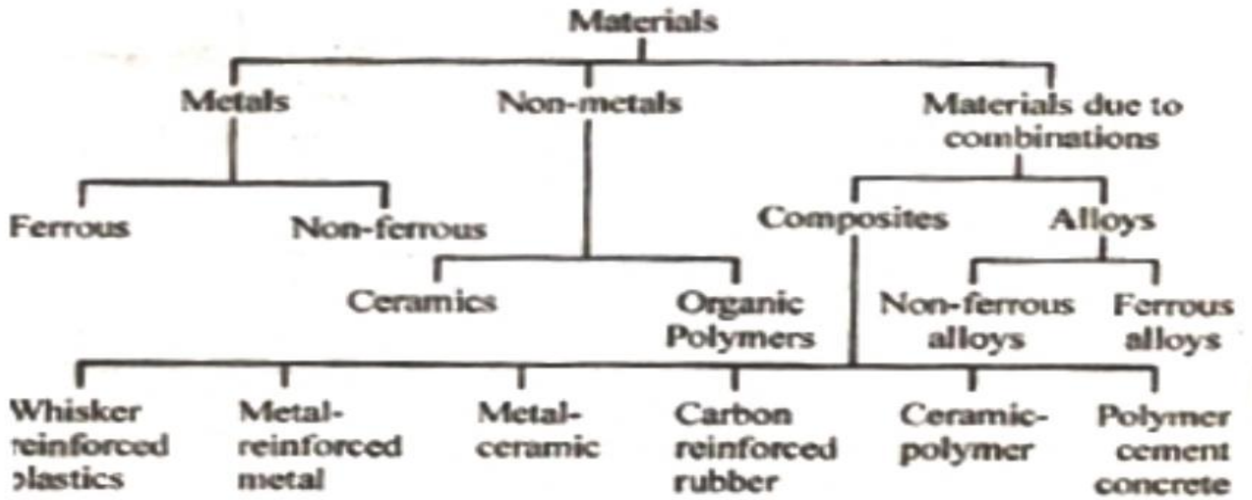
CHAPTER -1

ENGINEERING MATERIALS AND THEIR PROPERTIES

CLASSIFICATION OF ENGINEERING MATERIAL

Engineering materials are classified mainly three categories 1. Metals 2. Non-metals 3. Due to Combination



METALS:- Metals are substances capable of changing their shape permanently. They are composed of elements which readily give up electrons to provide a metallic bond and electrical conductivity. Metals may be ferrous or non ferrous type.

The ferrous metals contain Fe and C as their constituents. The behavior and properties of ferrous metals depend upon the percentage and the form of carbon present in them. They are iron and steel.

Non-ferrous metals not contain Fe and C as their constituents, examples of commonly used non-ferrous metals are AI, Cu, Ag, Zn, Ni, Sn, Cr, Pb etc. AI, Cu, Ag, and Au are good conductors of electricity, Ag is most malleable, Au is most ductile and Cr is corrosion resistant. Zn is used in the metal plating. Sn is used to make bushes and Ni imparts strength and creep resistance.

NON-METALS:-They can be further classified as ceramics and organic polymers. Ceramics are generally metallic or non metallic oxides. physically separable and chemically Homogeneous constituents of materials consisting of phases are also called ceramics. rocks, fireclay and firebricks, cements and limes are some commonly used ceramics. Ferrites, garnets, Ferro-electrics and ceramic superconductors are the latest development in this area. Organic polymers are derived mainly from the hydrocarbons. These consist of covalent bonds formed by carbon, chemically combined with oxygen and hydrogen. The polymers are obtained from monomers bonded by a chemical reaction (a process called polymerization). In this process, long molecular chain having high molecular weight is generated. Organic polymers are relatively inert and light, and generally have a high degree of plasticity. Bakelite, polyethylene, nylon, Teflon are some examples.

DUE TO COMBINATION:- They may be alloys or composites. An alloy is a combination of two or more metals. They possess properties which are quite different from those of their constituent metals. Alloys may be ferrous non-ferrous depending on the base metal used. An alloy is prepared for a specific purpose to meet the particular requirements of an application. Some common ferrous alloys are invar, stainless steel and high speed steel (HSS). Non-ferrous alloys include phosphor bronze, brass, duralumin, etc. Composites may be inorganic or organic. They have two or more constituents of dissimilar properties. The two major constituents may be metals and ceramics or metals and polymers, or ceramics and polymers or any other combination. Instead of metals, alloys may also be used to make composites. Constituent of composites called reinforcing constituent may be in particulate form, fibrous form or flake form.

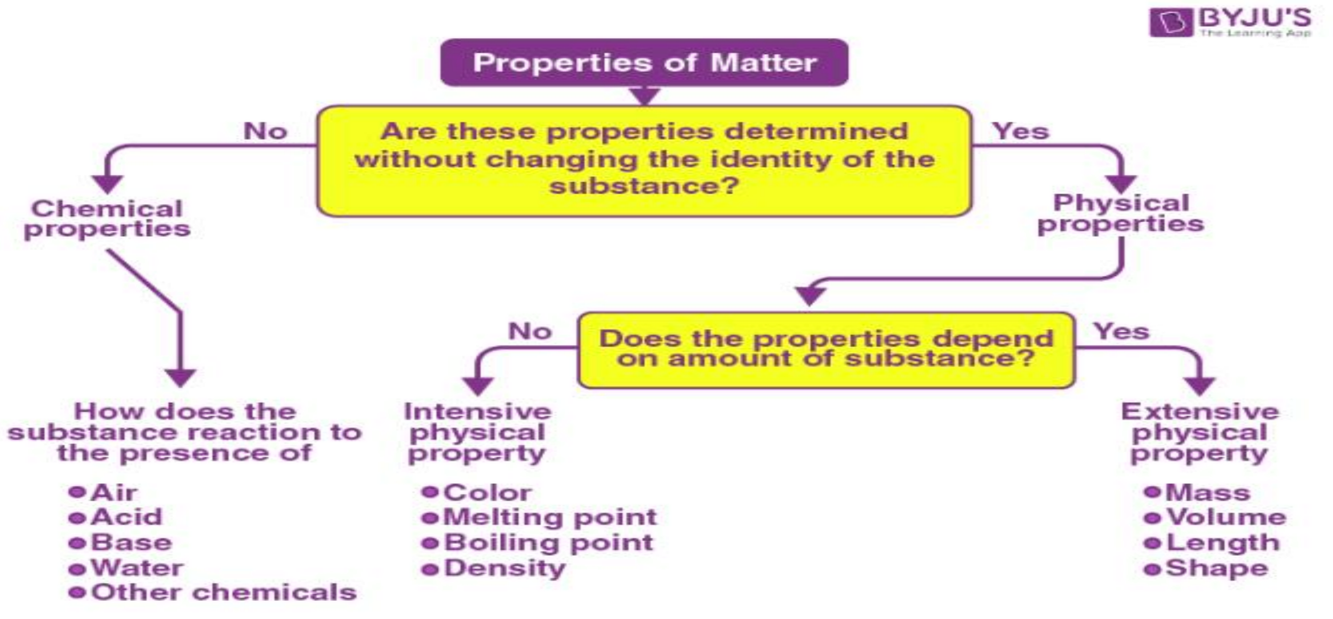
Difference between Ferrous & Non-Ferrous Metals

	Ferrous Metals	Non-Ferrous Metals
1.	Contains any amount of iron in its basic form.	Does not contains any amount of iron in its basic form.
2.	That's why they possesses magnetic property and makes them prone to corrosion.	They do not possess magnetic property, but resist corrosion much better than ferrous metals.
3.	They have a high tensile strength since they can carry a high amount of strain.	They have very low tensile strength.
4.	They have the ability for oxidation, known as corrosion. Oxidation of ferrous metals forms as a reddish-brown deposit on the surface & is oxide of iron.	They have typically lighter weights, higher melting points & are basically resistant to corrosion.
5.	Typically used when the magnetic attraction of iron may be a disadvantage. (used where strength is the primary focal point)	Ideal for electronic & electrical applications.
6.	Eg., pig iron, steel, cast iron, etc.	Eg., cobalt, aluminium, zinc, etc.

MATTER

Matter is any substance that has mass and takes up space by having volume.

Matter is described as something that has mass and occupies space. All physical structures are made up of matter, and the state or process of matter is an easily observed property of matter. Solid, liquid, and gas are the three basic states of matter.



Everything that exists is made up of matter. Atoms and substances are made up of minuscule pieces of matter. The atoms that make up the objects we see and touch every day are made up of matter. All that has mass and occupies space has volume is known as matter. The amount of matter in an object is measured by its mass.

PHYSICAL PROPERTIES OF MATTER

- Matter is made up of tiny particles called atoms and can be represented or explained as something that takes up space. It must display both the mass and volume properties.
- Properties are the characteristics that enable us to differentiate one material from another. A physical property is an attribute of matter that is independent of its chemical composition.
- Density, colour, hardness, melting and boiling points, and electrical conductivity are all examples of physical properties.
- Any characteristic that can be measured, such as an object's density, colour, mass, volume, length, malleability, melting point, hardness, odour, temperature, and more, are considered properties of matter.

[N.B:-Melting point-The point at which materials changes from solid to liquid.

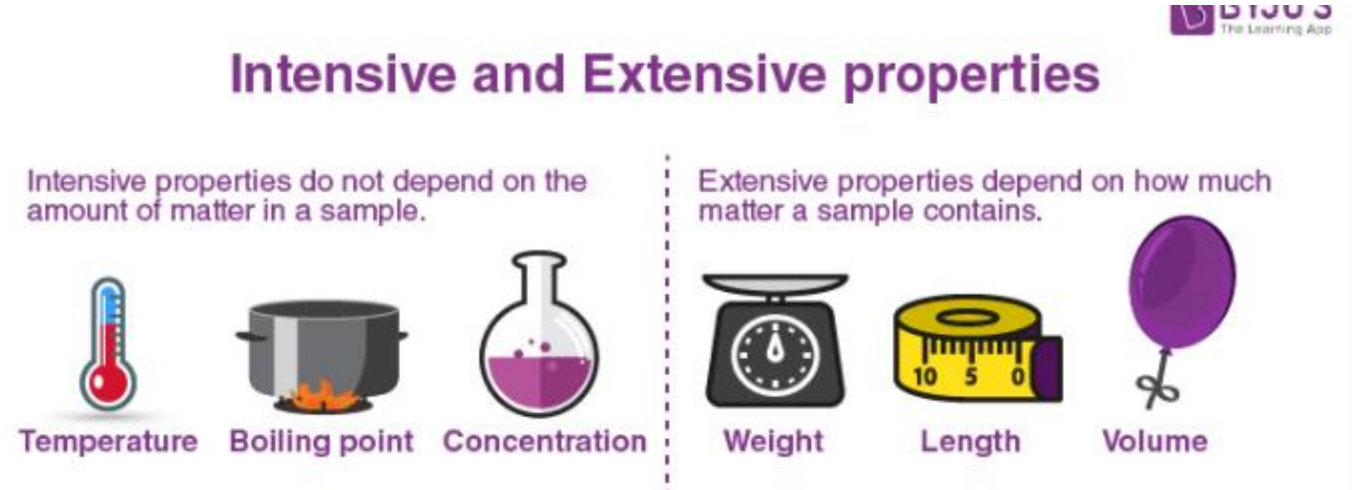
Boiling point- The temperature at which material changes from liquid to vapor.]

INTENSIVE AND EXTENSIVE PROPERTIES OF MATTER

Both the physical and chemical properties of matter are either extensive or intensive. Extensive properties including mass and volume are proportional to the amount of matter being weighed. Density and colour, for example, are not affected by the amount of matter present.

1. **Intensive properties of matter** – An intensive property is a bulk property, which means it is a system's local physical property that is independent of the system's size or volume of material. Intensive properties are those that are independent of the amount of matter present. Pressure and temperature, for example, are intensive properties.

2. **Extensive property of matter** – A property that is dependent on the amount of matter in a sample is known as an extensive property. Extensive properties include mass and volume. The scale of the system or the volume of matter in it determines the extensive property of the system. Extensive properties are those in which the value of a system's property is equal to the sum of the values for the parts of the system.



CHEMICAL PROPERTIES OF MATTER

Chemical properties are characteristics that can only be measured or observed as matter transforms into a particular type of matter. Reactivity, flammability, and the ability to rust are among them. The tendency of matter to react chemically with other substances is known as reactivity. Flammability, toxicity, acidity, the reactivity of various types, and heat of combustion are examples of chemical properties.

REACTIVITY – The tendency of matter to combine chemically with other substances is known as reactivity. Certain materials are highly reactive, whereas others are extremely inactive. Potassium, for example, is extremely reactive, even in the presence of water. A pea-sized piece of potassium reacts explosively when combined with a small volume of water.

FLAMMABILITY – The tendency of matter to burn is referred to as flammability. As matter burns, it reacts with oxygen and transforms into various substances. A flammable matter is anything like wood.

TOXICITY – Toxicity refers to the extent to which a chemical element or a combination of chemicals may harm an organism.

ACIDITY – A substance's ability to react with an acid is a chemical property. Some metals form compounds when they react with different acids. Acids react with bases to create water, which neutralizes the acid.

Chemical properties are extremely helpful when it comes to distinguishing compounds. Chemical properties, on the other hand, can only be detected when a material is in the process of being changed into another substance.

MECHANICAL PROPERTIES OF ENGINEERING MATERIALS

The mechanical properties of a material are those which are associated with the ability of the material to resist mechanical forces and load. These mechanical properties of the metal include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resilience, creep and hardness. We shall now discuss these properties as follows:

1. STRENGTH:-It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress.

2. STIFFNESS:- It is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. ELASTICITY:- It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines. It may be noted that steel is more elastic than rubber.

4. PLASTICITY:-It is property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. DUCTILITY:-It is the property of a material enabling it to be drawn into wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice (in order of diminishing ductility) are mild steel, copper,aluminium, nickel, zinc, tin and lead.

6. BRITTLENESS:-It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion. Brittle materials when subjected to tensile loads, snap off without giving any sensible elongation. Cast iron is a brittle material.

7. MALLEABILITY:-It is a special case of ductility which permits materials to be rolled or hammered into thin sheets. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice (in order of diminishing malleability) are lead, soft steel, wrought iron, copper and aluminum

8. TOUGHNESS:-It is the property of a material to resist fracture due to high impact loads like hammer blows. The toughness of the material decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed upto the point of fracture. This property is desirable in parts subjected to shock and impact loads.

9. MACHINABILITY:- It is the property of a material which refers to a relative case with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. It may be noted that brass can be easily machined than steel

10. RESILIENCE:-It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.

11.CREEP :-When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called creep .This property is considered in designing internal combustion engines, boilers and turbines.

12. FATIGUE:-When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as *fatigue. The failure is caused by means of a progressive crack formation which are usually fine and of microscopic size. This property is considered in designing shafts, connecting rods, springs, gears, etc.

13. HARDNESS:-It is a very important property of the metals and has a wide variety of meanings. It embraces many different properties such as resistance to wear, scratching, deformation and machinability etc. It also means the ability of a metal to cut another metal.

FACTORS AFFECTING MECHANICAL PROPERTIES

Mechanical properties of engineering materials refer to their ability to withstand applied forces and deformation without breaking or losing strength. These properties play a crucial role in determining the suitability of a material for various engineering applications. Several factors can affect the mechanical properties of engineering materials, including:

COMPOSITION: - The chemical composition of a material affects its mechanical properties. The presence of impurities or alloying elements can alter the material's strength, ductility, and other properties.

MICROSTRUCTURE: - The microstructure of a material refers to its crystal structure and the arrangement of its atoms and grains. The grain size, shape, and orientation can influence the mechanical properties of a material.

PROCESSING: - The method of processing a material, such as forging, casting, or extrusion, can affect its mechanical properties. The rate of cooling, heat treatment, and other processing parameters can also impact the material's properties.

TEMPERATURE: - The mechanical properties of materials can change significantly at different temperatures. At high temperatures, materials may lose strength and become more prone to deformation and failure.

LOADING CONDITIONS:- The way a material is loaded, such as tension, compression, bending, or torsion, can affect its mechanical properties. The rate of loading, duration of loading, and type of loading can also impact the material's properties.

IMPORTANCE OF MECHANICAL PROPERTIES IN MATERIAL SELECTION

Mechanical properties play a crucial role in material selection because they determine the ability of a material to withstand loads, stresses, and strains without failure or deformation. Different applications and environments require different mechanical properties, and the right choice of materials can make the difference between the success and failure of a product or structure.

Here are some examples of how different mechanical properties affect material selection:

STRENGTH: The strength of a material is its ability to resist external loads without breaking or deforming. High-strength materials are preferred for applications that involve high loads or stresses, such as in structural components of buildings or in heavy machinery. However, high strength may also mean that the material is brittle and prone to fracture under certain conditions.

DUCTILITY: Ductility is the ability of a material to deform under stress without breaking. Materials with high ductility are preferred for applications that require deformation without failure, such as in forming processes or in structural components that may experience bending or twisting.

TOUGHNESS: Toughness is the ability of a material to absorb energy without fracture. Materials with high toughness are preferred for applications that require resistance to impact or shock loading, such as in automotive parts or in structural components subjected to vibrations.

HARDNESS: Hardness is the ability of a material to resist indentation or scratching. Materials with high hardness are preferred for applications that require wear resistance, such as in cutting tools or in abrasive environments.

FATIGUE RESISTANCE: Fatigue resistance is the ability of a material to withstand cyclic loading without failure. Materials with high fatigue resistance are preferred for applications that involve repetitive loading, such as in rotating machinery or in structural components subjected to vibrations.

MATERIAL PERFORMANCE REQUIREMENTS

The material performance requirements can be divided into five broad categories: functional requirements, process ability requirements, cost, reliability, and resistance to service conditions

1. FUNCTIONAL REQUIREMENTS:- Functional requirements are directly related to the required characteristics of the product. For example, if the product carries a uniaxial tensile load, the yield strength of a candidate material can be directly related to the load-carrying capacity of the product. However, some characteristics of the part or product may not have simple correspondence with measurable material properties, as in the case of thermal shock resistance, wear resistance, reliability, etc. Under these conditions, the evaluation process can be quite complex and may most closely related to mechanical, physical, or chemical properties.

2. PROCESSABILITY REQUIREMENTS :-The processability of a material is a measure of its ability to be worked and shaped into a finished part. With reference to a specific manufacturing method, processability can be defined as castability, weldability, machinability, etc. Ductility and hardenability can be relevant to processability if the material is to be deformed or hardened by heat treatment, respectively. It is important to remember that processing operations will almost affect the material properties so that processability considerations are closely related to functional requirements.

3. COST:-Cost is usually an important factor in evaluating materials, because in many applications there is a cost limit for a given component. When the cost limit is exceeded, the design may have to be changed to allow for the use of a less expensive material or process.

4. RELIABILITY REQUIREMENTS:-Reliability of a material can be defined as the probability that it will perform the intended function for the expected life without failure. Material reliability is difficult to measure, because it is not only dependent upon the material's inherent properties, but it is also greatly affected by its production and processing history.

5. RESISTANCE TO SERVICE CONDITIONS:- The environment in which the product or part will operate plays an important role in determining the material performance requirements. Corrosive environments, as well as high or low temperatures, can adversely affect the performance of most materials in service.

SAFETY

Material safety is a very essential element to be considered in any engineering applications. Selection of material should be considered before construction of any engineering ideas. 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 give off spark when struck are safety hazards in a coal mine.

CHAPTER-2

FERROUS MATERIALS AND ALLOYS

2.1 FERROUS MATERIALS

A ferrous metal is any metal that is primarily composed of iron and has magnetic properties. A ferrous metal is known for its hardness, durability and tensile strength. Some common ferrous metals include:

- Alloy steel
- Carbon steel
- Cast iron
- Wrought iron

Ferrous metals are known and used for their strength. The properties that they possess make them perfect to be used in both the industrial and architectural sector for projects like skyscrapers, bridges, railroad projects and vehicles. Due to their magnetic properties, ferrous metals are also widely used in various appliances and engines. Ferrous metals, however, have high carbon content, which generally makes them more likely to rust; stainless steel is an exception due to its chromium content, as is wrought iron, due to the purity of its iron content. Ferrous metals are widely used in almost all industries such as in the manufacturing of shipping containers, industrial piping, automobiles, railroad tracks, ships and many commercial and domestic tools.

2.1 CHARACTERISTICS OF FERROUS MATERIALS:

Ferrous materials are metals or metal alloys that contain the iron as a base material. Steel is a ferrous alloy, and there are a number of other alloys that contain iron. Ferrous metals are good conductors of heat and electricity. Metal alloys have high resistance to shear, torque and deformation. The thermal conductivity of metal is useful for containers to heat materials over a flame. The principal disadvantages of many ferrous alloys are their susceptibility to corrosion.

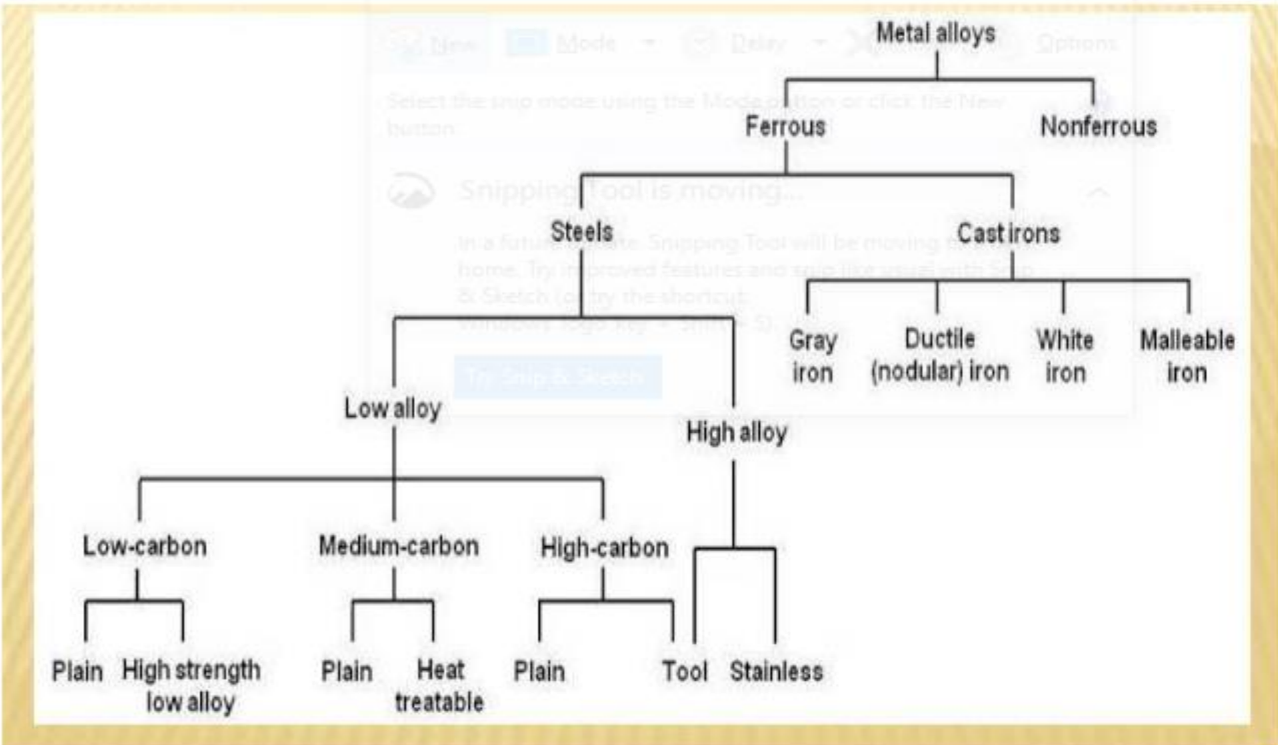
2.1 APPLICATION:

• Due to the strength and resilience of metals they are frequently used in high-rise building and bridge construction, most vehicles, many appliances, tools, pipes, no illuminated signs and railroad tracks.

• Corrosion resistance property makes them useful in food processing plants, e.g., steel.

• Cast iron is strong but brittle, and its compressive strength is very high. So used in castings, manhole covers, engine body, machine base etc.

• Mild steel is soft, ductile and has high tensile strength. It is used in general metal products like structural, workshop, household furniture etc. Carbon steels are used for cutting tools due to their hardness, strength and corrosion resistance properties.



STEEL

- It is an alloy of iron and carbon in which carbon content is upto 2%.
- It may contain other alloying elements.

TYPES OF STEEL:-

LOW CARBON STEEL-

- Carbon content in the range of 0 – 0.3%.
- Most abundant grade of steel is low carbon steel (greatest quantity produced; and least expensive).
- Not responsive to heat treatment; cold working needed to improve the strength. It has good weldability and machinability

MEDIUM CARBON STEEL-

- Carbon content in the range of 0.3 – 0.8%.
- It can be heat treated - austenitizing, quenching and then tempering.

- Most often used in tempered condition – tempered martensite Medium carbon steels have low hardenability and ductility.
- Addition of Cr, Ni, Mo improves the heat treating capacity

TYPICAL APPLICATIONS –

Railway wheels and tracks, gears, crankshafts.

HIGH CARBON STEELS –

- Carbon content 0.8 – 2%
- High Carbon content provides high hardness and strength.
- Hardest and least ductile.-
- Used in hardened and tempered condition.
- Strong carbide formers like Cr, V, W are added as alloying elements to from carbides of these metals.
- Used as tool and die steels owing to the high hardness and wear resistance property.

2.2 CARBON STEEL:-

Plain Carbon Steel is an alloy of iron and carbon with carbon content up to 1.5% although other elements such as Silicon, Manganese may be present. The properties of carbon steel are mainly due to its carbon content.

Carbon Steel is classified into

i) Low carbon steel or Mild steel

ii) Medium carbon steel

iii) High carbon steel

2.2 I) LOW CARBON STEEL OR MILD STEEL: Low carbon steel or mild steel is further classified in to three types basing on their composition i-e percentage of carbon.

a) Dead mild steel or mild steel containing 0.05 to 0.15% of carbon.

b) Mild steel containing 0.15 to 0.2% of carbon.

c) Mild steel containing 0.2 to 0.3% of carbon.

USE OF MILD STEEL:

i) Dead mild steel is used for making steel wire, sheet, rivets, screws, pipe, nail, chain, etc.
ii) Mild steel containing 0.15 to 0.2% carbon is used for making camshafts, sheets, strips for blades, welded tubing, forgings, drag lines, etc.

iii) iii) Mild steel containing 0.2 to 0.3% carbons is used for making valves, gears, crank shafts, connecting rods, railways axles, fish plates and small forgings, etc.

2.2 MEDIUM CARBON STEEL

Steel containing 0.3 to 0.7% carbon is known as Medium carbon steel. Medium carbon steel are of three categories.

i) Steel containing 0.35 to 0.45% carbon is used for connecting rod, wires & rod, spring ,clips, gear shaft, key stock, shafts & brakes lever, axle, small & medium forgings, etc.

ii) Steel containing 0.45 to 0.55% carbon is used for railways coach axles, axles & crank pins on heavy machines, splines shafts, crank shafts, etc.

ii) Steel containing 0.6 to 0.7% carbon is used for drop forging die & die blocks, clutch ,discs, plate punches, set screws, valve springs, cushion ring, thrust washers, etc.

2.2 HIGH CARBON STEEL

Steel containing 0.7 to 0.1.5% carbon is known as high carbon steel.

USES:-

i) Steel containing 0.7 to 0.8% carbon is used for making cold chisels, wrenches, jaws for vice, pneumatic drill bits, wheels for railway service, wire for structural work, shear blades, automatic clutch disc, hacksaws, etc.

ii) Steel containing 0.8 to 0.9% carbons is used for making rock drills, railway rail, circular saws, machine chisels, punches & dies, clutch discs, leaf springs, music wires, etc.

iii) Steel containing 0.9 to 1.0% carbon is used for making punches & dies, leaf & coil springs, keys, speed discs, pins, shear blades, etc.

iv) Steel containing 1.0 to 1.1% carbon is used for making railway springs, machine tools, mandrels, taps, etc.

v) Steel containing 1.1 to 1.2% carbon is used for making taps, thread metal dies, twist drills, knives, etc.

vi) Steel containing 1.2 to 1.3% carbon is used for making files, metal cutting tools, reamers, etc.

vii) Steel containing 1.3 to 1.5% carbons is used for making wire drawing dies, metal cutting saws, paper knives, tools for turning chilled iron, etc.

2.3 ALLOY STEEL

An alloy steel may be defined as a steel to which elements other than carbon are added insufficient amount to produce an improvement in properties. The alloying is done for specific purposes to increase wearing resistance, corrosion resistance and to improve electrical and magnetic properties, which cannot be obtained in plain carbon steels. The chief alloying elements used in steel are nickel, chromium, molybdenum, cobalt, vanadium, manganese, silicon and tungsten. Each of these elements confer certain qualities upon the steel to which it is added.

These elements may be used separately or in combination to produce the desired characteristic in steel. Following are the effects of alloying elements on steel:

2.3 LOW-ALLOY STEELS

Low-alloy steels typically undergo heat treatment, normalizing and tempering during production. They are also weldable. However, weld heat treatment is necessary in order to avoid weld cracking. Chromium-molybdenum low alloy steels are heat resistant steels which contain 0.5 % to 9 % chromium and 0.5 % to 1 % molybdenum. The carbon content is normally below 0.2 %. The chromium provides improved oxidation and corrosion resistance while the molybdenum increases strength at elevated temperatures.

ADVANTAGES OF LOW-ALLOY STEELS

- High yield strength
- Able to withstand high temperatures
- Good creep strength
- Oxidation resistance
- Hydrogen resistance
- Low temperature ductility

2.3 HIGH-ALLOY STEEL

High-alloy steels are defined by a high percentage of alloying elements. The most common high-alloy steel is stainless steel, which contains at least 12 percent chromium. Stainless steel is generally split into three basic types: martensitic, ferritic, and austenitic.

TYPES OF ALLOY

Alloy steel is often categorized based on the type of alloy and its concentration. These are a few of the most common additions to alloy steel:

- **Aluminum** removes oxygen, sulfur, and phosphorus from steel.
- **Bismuth** improves machinability.
- **Chromium** increases wear resistance, hardness, and toughness.
- **Cobalt** increases stability and encourages the formation of free graphite.
- **Copper** improves hardening and corrosion resistance.
- **Manganese** increases hardenability, ductility, wear resistance, and high-temperature strength.
- **Molybdenum** lowers carbon concentration and adds room-temperature strength.
- **Nickel** improves strength, corrosion resistance, and oxidation resistance.
- **Silicon** increases strength and magnetism.
- **Titanium** improves hardness and strength.
- **Tungsten** improves hardness and strength.
- **Vanadium** increases toughness, strength, corrosion resistance, and shock resistance.

2.3 TOOL STEEL

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures.

2.3 STAINLESS STEEL

Stainless steel, also known as inox or corrosion-resistant steel (CRES), is an alloy of iron that is resistant to rusting and corrosion. Stainless steel is an iron and chromium alloy. While stainless must contain at least 10.5% chromium, the exact components and ratios will vary based on the grade requested and the intended use of the steel. Other common additives include: Nickel.

2.4 TOOL STEEL

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into tools. Their suitability comes from their distinctive hardness, resistance to abrasion, their ability to hold a cutting edge, and/or their resistance to deformation at elevated temperatures.

Tool steel is generally used in a heat-treated state. Many high carbon tool steels are also more resistant to corrosion due to their higher ratios of elements such as vanadium. With carbon content between 0.7% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality. Stainless steel-Stainless steel does not readily corrode, rust or stain with water as ordinary steel does, but despite the name it is not fully stain-proof, most notably under low-oxygen, high-salinity, or poor-circulation environments. There are different grades and surface finishes of stainless steel to suit the environment the alloy must endure. Stainless steel is used where both the properties of steel and corrosion resistance are required. Stainless steel differs from carbon steel by the amount of chromium present.

1. NICKEL. It increases the strength and toughness of the steel. These steels contain 2 to 5% nickels and from 0.1 to 0.5% carbon. In this range, nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion. An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature. It has proved to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines. A nickel steel alloy containing 36% of nickel is known as invar. It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.

2. CHROMIUM. It is used in steels as an alloying element to combine hardness with high strength and high elastic limit. It also imparts corrosion-resisting properties to steel. The most common chrome steels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon. The chrome steel is used for balls, rollers and races for bearings. A nickel chrome steel containing 3.25%

nickel, 1.5% chromium and0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.

3. TUNGSTEN. It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour. It is usually used in conjunction with other elements. Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools. The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.

4. VANADIUM. It aids in obtaining a fine grain structure in tool steel. The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility. The chrome-vanadium steel containing about 0.5 to 1.5% chromium, 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility. These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.

5. MANGANESE. It improves the strength of the steel in both the hot rolled and heat treated condition. The manganese alloy steels containing over1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required. The principal uses of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

6. SILICON. The silicon steels behave like nickel steels. These steels have a high elastic limit as compared to ordinary carbon steel. Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.

7. COBALT. It gives red hardness by retention of hard carbides at high temperatures. It tends to decarburize steel during heat-treatment. It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

8. MOLYBDENUM. A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel. These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high-speed steels.

CHAPTER -3

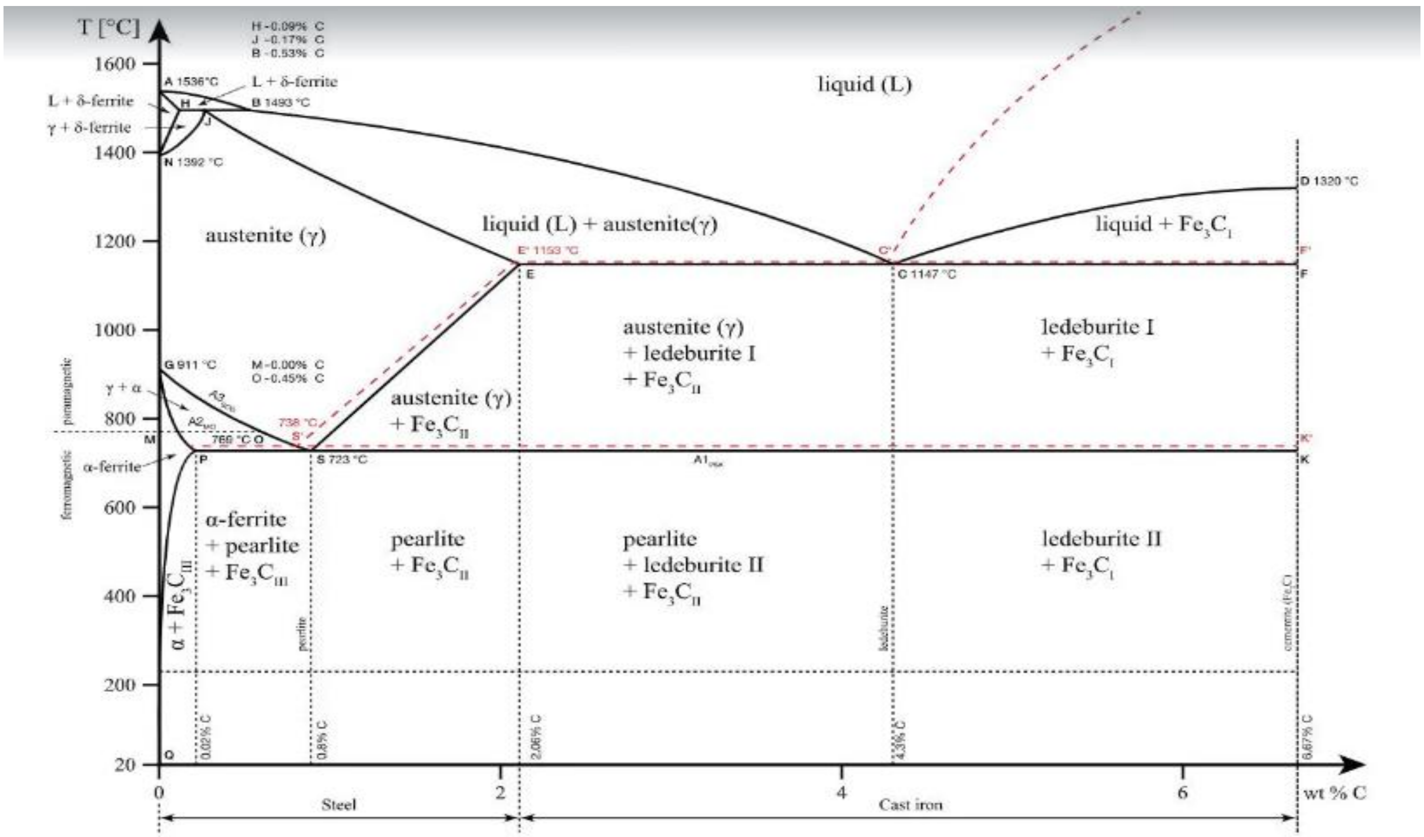
IRON –CARBON SYSTEM

CONCEPT OF PHASEDIAGRAM

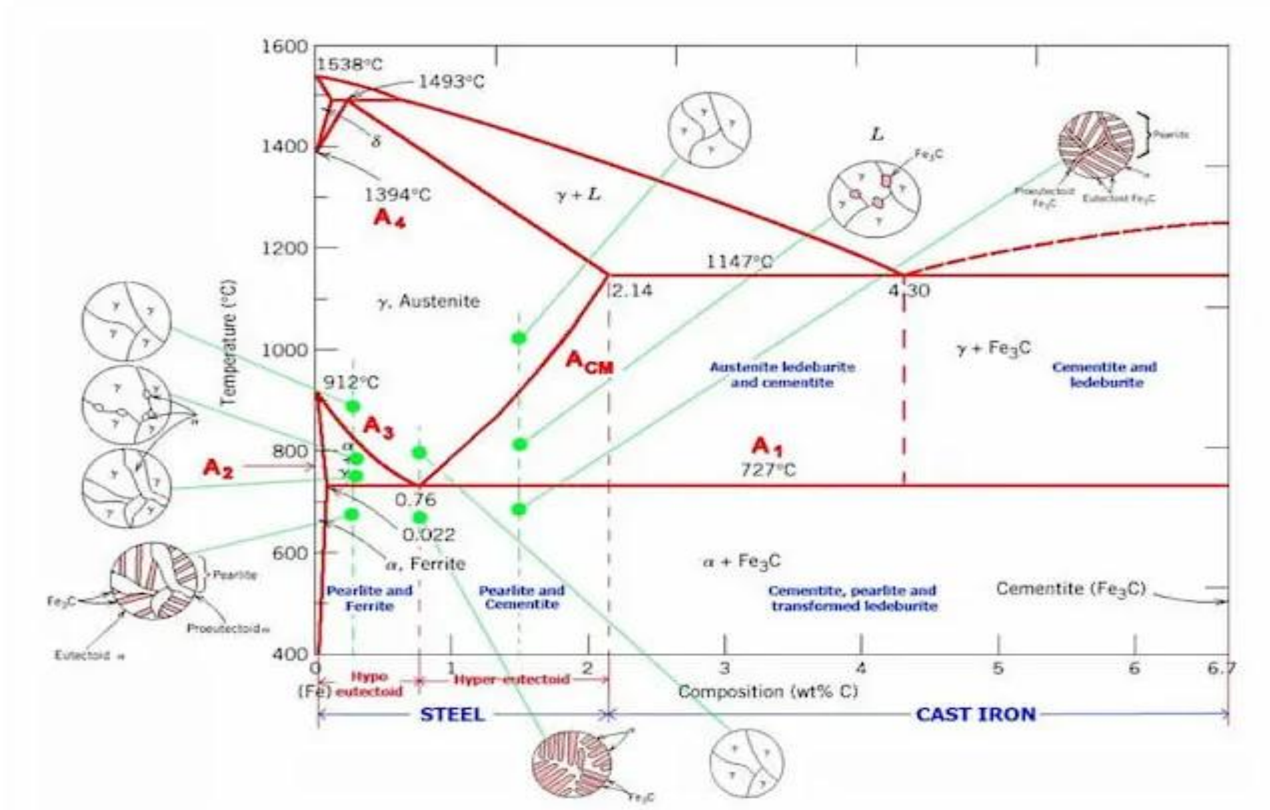
Phase diagrams plot pressure (typically in atmospheres) versus temperature (typically in degrees Celsius or Kelvin). The labels on the graph represent the stable states of a system in equilibrium. The lines represent the combinations of pressures and temperatures at which two phases can exist in equilibrium.

COOLING CURVE

A cooling curve is a line graph that represents the change of phase of matter, typically from a gas to a solid or a liquid to a solid. The independent variable (X-axis) is time and the dependent variable (Y-axis) is temperature.



IRON-CARBON PHASE DIAGRAM



The iron-carbon phase diagram is widely used to understand the different phases of steel and cast iron. Both steel and cast iron are a mix of iron and carbon. Also, both alloys contain a small amount of trace elements.The graph is quite complex but since we are limiting our exploration to Fe3C, we will only be focusing on up to 6.67 weight percent of carbon.This iron-carbon phase diagram is plotted with the carbon concentrations by weight on the X-axis and the temperature scale on the Y-axis.The carbon in iron is an interstitial impurity. The alloy may form a face-centred cubic (FCC) lattice or a body-centred cubic (BCC) lattice. It will form a solid solution with α, γ, and δ phases of iron.

TYPES OF FERROUS ALLOYS ON THE PHASE DIAGRAM

The weight percentage scale on the X-axis of the iron-carbon phase diagram goes from 0% up to 6.67% Carbon. Up to a maximum carbon content of 0.008% weight of Carbon, the metal is simply called iron or pure iron. It exists in the α-ferrite form at room temperature.

From 0.008% up to 2.14% carbon content, the iron-carbon alloy is called steel. Within this range, there are different grades of steel known as low-carbon steel (or mild steel), medium-carbon steel, and high-carbon steel.

When the carbon content increases beyond 2.14%, we reach the stage of cast iron. Cast iron is very hard but its brittleness severely limits its applications and methods for forming.

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.

Alloy steel elements such as nickel, manganese, chromium, and molybdenum affect the position of these boundaries on the phase diagram. The boundaries may shift in either direction depending on the element used. For example, in the iron-carbon phase diagram, the addition of nickel lowers the A3 boundary while the addition of chromium raises it.

EUTECTIC POINT

Eutectic point is a point where multiple phases meet. For the iron-carbon alloy diagram, the eutectic point is where the lines A1, A3 and ACM meet. The formation of these points is coincidental.

At these points, eutectic reactions take place where a liquid phase freezes into a mixture of two solid phases. This happens when cooling a liquid alloy of eutectic composition all the way to its eutectic temperature.

The alloys formed at this point are known as eutectic alloys. On the left and right side of this point, alloys are known as hypoeutectic and hypereutectic alloys respectively ('hypo' in Greek means less than, 'hyper' means greater than).

PHASE FIELDS

The boundaries, intersecting each other, mark certain regions on the Fe3C diagram.Within each region, a different phase or two phases may exist together. At the boundary, the phase change occurs. These regions are the phase fields.They indicate the phases present for a certain composition and temperature of the alloy. Let's learn a little about the different phases of the iron-carbon alloy.

DIFFERENT PHASES

α-FERRITE

Existing at low temperatures and low carbon content, α-ferrite is a solid solution of carbon in BCC Fe. This phase is stable at room temperature. In the graph, it can be seen as a sliver on the left edge with Y-axis on the left side and A2 on the right. This phase is magnetic below 768°C.

It has a maximum carbon content of 0.022 % and it will transform to γ-austenite at 912°C as shown in the graph.

γ-AUSTENITE

This phase is a solid solution of carbon in FCC Fe with a maximum solubility of 2.14% C. On further heating, it converts into BCC δ-ferrite at 1395°C. γ-austenite is unstable at temperatures below eutectic temperature (727°C) unless cooled rapidly. This phase is non-magnetic.

δ-FERRITE

This phase has a similar structure as that of α-ferrite but exists only at high temperatures. The phase can be spotted at the top left corner in the graph. It has a melting point of 1538°C.

Fe3C or CEMENTITE

Cementite is a meta-stable phase of this alloy with a fixed composition of Fe3C. It decomposes extremely slowly at room temperature into iron and carbon (graphite).

This decomposition time is long and it will take much longer than the service life of the application at room temperature. Some other factors (high temperatures and the addition of certain alloying elements for instance) can affect this decomposition as they promote graphite formation.

Cementite is hard and brittle which makes it suitable for strengthening steels. Its mechanical properties are a function of its microstructure, which depends upon how it is mixed with ferrite.

Fe-C LIQUID SOLUTION

Marked on the diagram as ‘L’, it can be seen in the upper region in the diagram. As the name suggests, it is a liquid solution of carbon in iron. As we know that δ-ferrite melts at 1538°C, it is evident that the melting temperature of iron decreases with increasing carbon content.

CHAPTER- 4.0

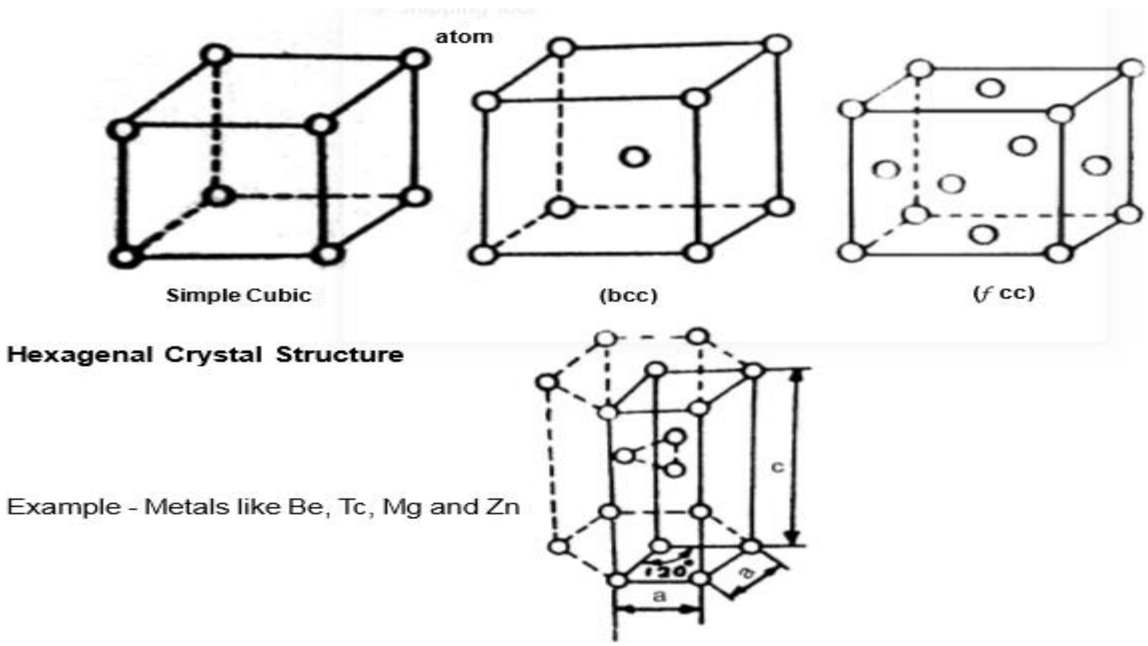
CRYSTAL IMPERFECTIONS

A crystal or crystalline solid is a solid material whose constituents are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions.

Crystals are classified into seven crystallographic systems based on their symmetry: isometric, trigonal, hexagonal, tetragonal, orthorhombic, monoclinic, and triclinic.

In crystal structure, the smallest unit is one unit cell which characterizes the specific arrangement and location of atoms.

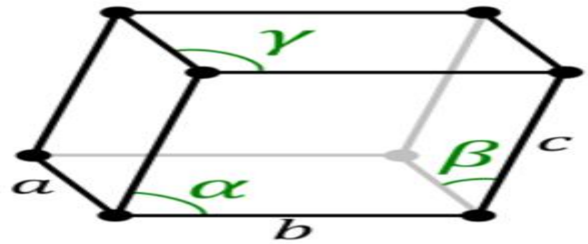
There are three types of unit cells with cubic crystal structure such as SC, BCC, FCC.



THE SEVEN CRYSTAL SYSTEMS

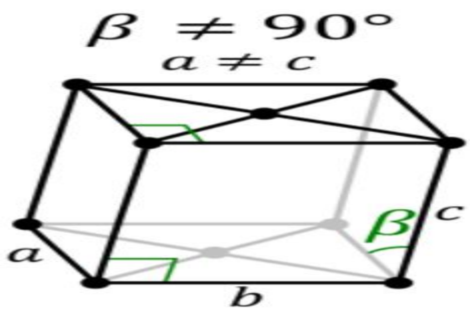
1. TRICLINIC SYSTEM:

It is the most unsymmetrical crystal system. All three axes are inclined towards each other, and they are of the same length. Based on the three inclined angles the various forms of crystals are in the paired faces. Some standard Triclinic Systems include Labradorite, Amazonite, Kyanite, Rhodonite, Aventurine Feldspar, and Turquoise.



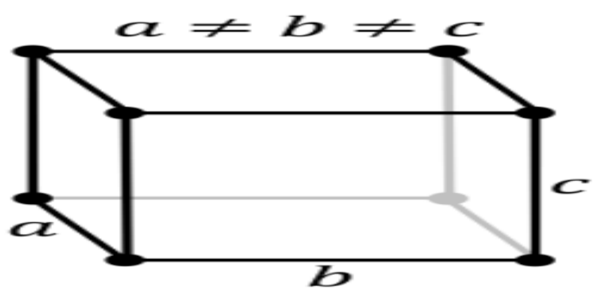
2. Monoclinic System:

It comprises three axes where two are at right angles to each other, and the third axis is inclined. All three axes are of different length. Based on the inner structure the monoclinic system includes Basal pinacoids and prisms with inclined end faces. Some examples include Diopside, Petalite, Kunzite, Gypsum, Hiddenites, Howlite, Vivianite and more.



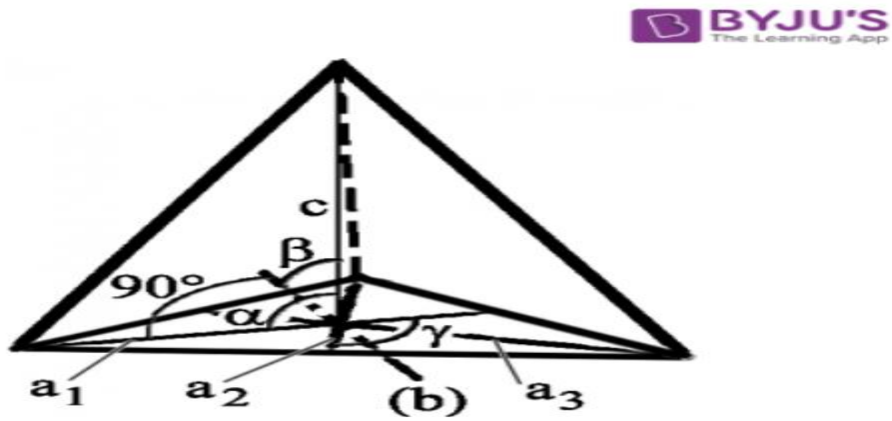
3. ORTHORHOMBIC SYSTEM:

It comprises three axes and is at right angles to each other. There are different lengths. Based on their Rhombic structure the orthorhombic system includes various crystal shapes namely pyramids, double pyramids, rhombic pyramids, and pinacoids. Some common orthorhombic crystals include Topaz, Tanzanite, Iolite, Zoisite, Danburite and more.



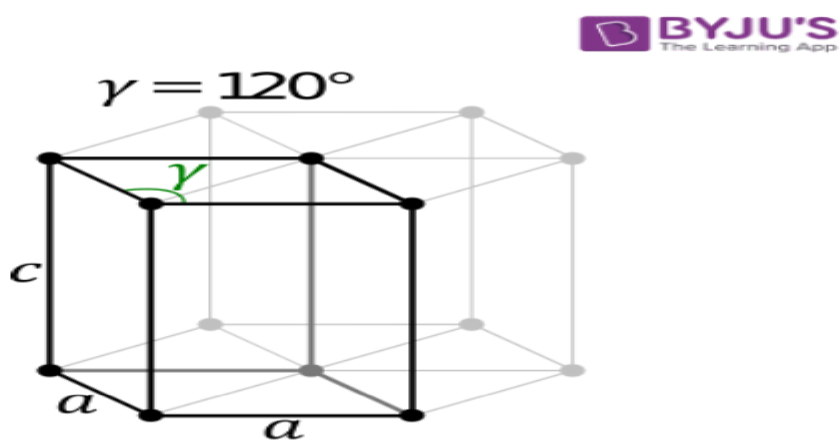
4. TRIGONAL SYSTEM:

Angles and axis in a trigonal system are similar to Hexagonal Systems. At the base of a hexagonal system (ross-section of a prism), there will be six sides. In the trigonal system (base cross-section) there will be three sides. Crystal shapes in a trigonal system include three-sided pyramids, Scalenohedral and Rhombohedra. Some typical examples include Ruby, Quartz, Calcite, Agate, Jasper, Tiger's Eyes and more.



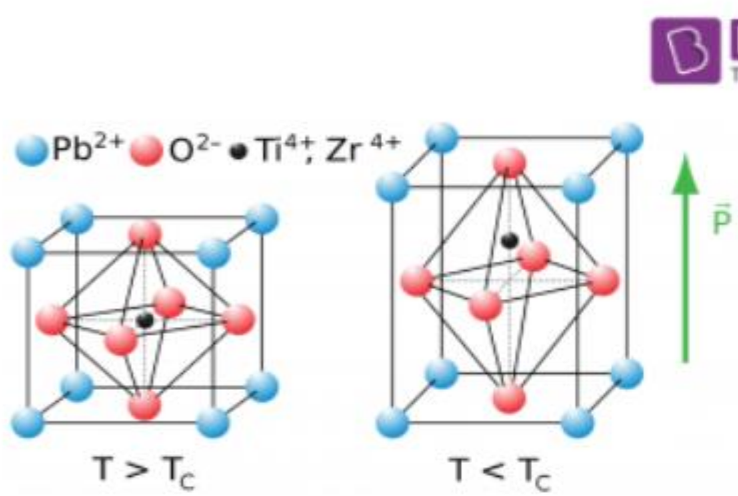
5. HEXAGONAL SYSTEM:

It comprises four axes. The three a1, a2 and a3 axes are all contained within a single plane (called the basal plane) and are at 120°. They intersect each other at an angle of sixty degrees. The fourth axis intersects other axes at right angles. Crystal shapes of hexagonal systems include Double Pyramids, Double-Sided Pyramids, and Four-Sided Pyramids. Example: Beryl, Cancrinite, Apatite, Sugilite, etc.



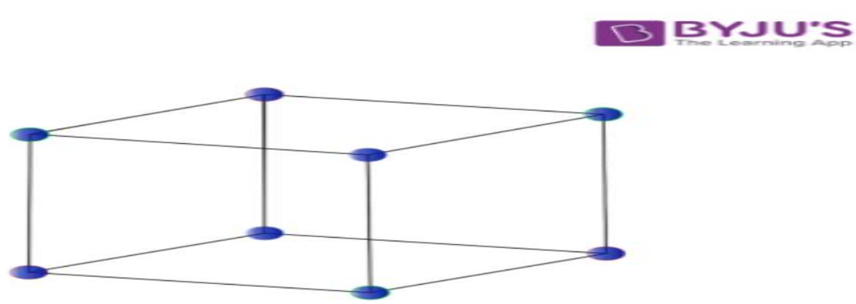
6. **TETRAGONAL SYSTEMS:**

It consists of three axes. The main axis varies in length; it can either be short or long. The two-axis lie in the same plane and are of the same length. Based on the rectangular inner structure the shapes of crystal in tetragonal include double and eight-sided pyramids, four-sided prism, trapezohedrons, and pyrite.



7. **CUBIC SYSTEM:**

Cubic system is the most symmetrical one out of the seven crystal system. All three angles intersect at right angles and are of equal length. Crystal shapes of a cubic system based on inner structure (square) include octahedron, cube, and Hexaciscoherdron. Example: Silver, Garnet, Gold, and Diamond.



IDEAL CRYSTAL:- A crystal in which there are no defects or impurities.

CRYSTAL IMPERFECTIONS

Crystal Imperfections Crystals are not perfect. An important characteristic which determines some important properties of crystalline materials is the presence of imperfections. Except some ideal crystals most of the crystals have some type of defects or imperfections? All crystals are not composed of identical atoms on identical sites throughout a regularly repeating 3D lattice. These imperfection or defects are used to describe any deviation from an orderly periodic array of atoms and influence the characteristics like mechanical strength, electrical properties and chemical reactions.

4.2 CLASSIFICATION OF CRYSTAL IMPERFECTIONS:-

Crystal imperfections can be divided into four basic types based on type of defect and its dimensionality. They are

1) point defects (0-dimensional),

2) line defects (1-dimensional),

3) surface defects (2-dimensional) and

4) volume defects (3-dimensional)

4.3 TYPES AND CAUSES OF POINT DEFECTS

POINT DEFECTS

In crystal lattice, point defect is completely local in its effect. When point defect gets introduced in crystal lattice, internal energy of the crystal increases.

TYPES

Vacancies, interstitialcies and impurities are example of point defctes.

CAUSES

A vacant lattice site is a point defect.

VACANCIES

The number of vacancies at equilibrium present in a crystal at a given temperature can be determined by the equation.

n0 = Ne- □E/KT

Where n0 = number of vacancies per mole

N = total number of atomic sites per mole.

□E = activation energy for formation of vacancy

K = Boltzman’s constant.

T = Temperature in absolute scale.

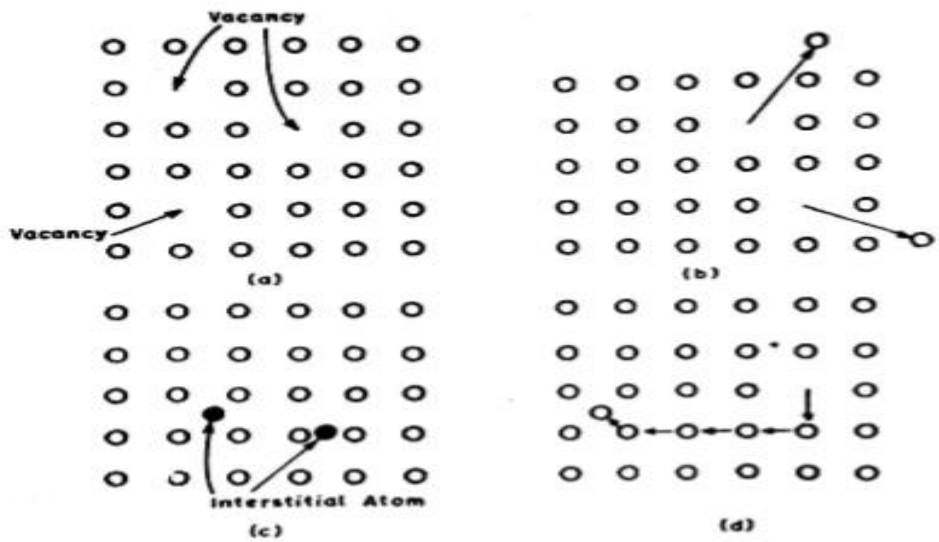
Vacancies are atomic sites from which the atoms are missing and exist in metal at all temperatures above absolute zero. It play a great role in diffusion of atoms in the crystal lattice. It arises from thermal vibrations and introduced during solidification.

INTERSTITIALCIES

When an atom is displaced from a regular site and occupies an interstitial site, an interstitialcy is formed. It also gives rise to lattice distortion because interstitial atom tends to push the surrounding atoms apart. The smaller the size of interstitial atoms smaller the defect.

IMPURITIES

Impurities are foreign atoms which are present in the crystal lattice. Impurity atoms may occupy either interstitial or substitutional position. It is a small atom occupies an interstitial void space between atoms at lattice points of the crystal.

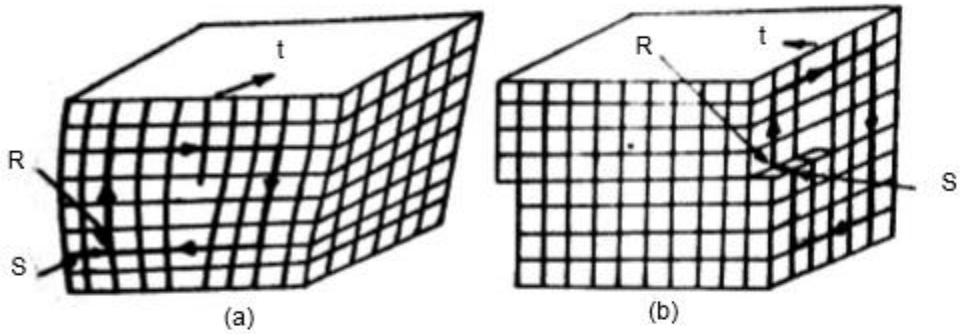


Various types of point defects. (a) Vacancy, (b) Schottky defect, (c) Interstitialcy, (d) Frankel

4.4 TYPES AND CAUSES OF LINE DEFECTS, EDGE DISLOCATION AND SCREW DISLOCATION.

LINE DEFECTS

Line defects are also known as dislocations. Dislocation is the region of localized lattice disturbance between slipped and unslipped regions of a crystal. Due to lattice disturbances, elastic strain fields and stresses are associated with dislocations.



TYPES

Dislocations are of two types : (1) Edge dislocation (2) Screw dislocation

EDGE DISLOCATION

In the figure of edge dislocation in which a burger's vector lies perpendicular to the dislocation line. A burger circuit is drawn around the dislocation line and the vector required to close the circuit RS is known as the burger vector of the dislocation. An edge dislocation moves in the direction of the burger vector. It has an extra row of atoms either above or below the slip plane in crystal.

When the extra row of atoms is above the slip plane it is called positive and is denoted by sign ⊥When the extra row of atoms is below the slip plane, it is called negative edge dislocation and is represented by sign T. Here the atoms above the edges are in compression and those below are in tension.

SCREW DISLOCATION

Here the burger vector is parallel to the dislocation line and distortion is of shear type. It follows a helical path and it may follow right hand or left hand screw rule. Positive and negative dislocations are shown by clockwise and anticlockwise signs, respectively. It shows cross slip, where it moves from one slip plane to another.

Either edge or screw of opposite signs if present in the same line, attract each other and can annihilate each other.

4.5 EFFECT OF IMPERFECTIONS ON MATERIAL PROPERTIES.

It affects or influences the characteristics like mechanical strength, electrical properties and chemical reactions. The role of imperfections in heat treatment is very important. Imperfections account for crystal growth, diffusion mechanism, annealing and precipitation, besides this, other metallurgical phenomena, such as oxidation, corrosion, yield strength, creep, fatigue and fractures' are governed by imperfections. Imperfections are not always harmful to metals. Sometimes they are generated to obtain the desired properties. For example, carbon is added to steel as interstitial impurity to improve the mechanical properties and these properties are further improved by heat treatment.

4.6 DEFORMATION BY SLIP AND TWINNING

SLIP -

Metals deform plastically by slip. Slipping is facilitated in the presence of dislocation.

Slip is defined as the process or mechanism by which a large displacement of one part of the crystal relative to another along particular crystallographic planes takes place.

There may be one or more slip planes and one or more slip directions in each crystal. Slip begins when the shearing stress acting along the slip planes in the direction of slip exceeds a certain value known as critical slip planes are planes of high atomic densities

TWINS AND TWINNING

Other than slip, twinning also gives rise to plastic deformation in crystals. It may be called as a special case of slip movement. In twinning, instead of whole blocks of atoms moving different distances along the slipping planes, each plane of atoms concerned moves a definite distance and the total movement at any point relative to the twinning plane is proportional to the distance from this plane. In bcc and hcp it occurs frequently.

4.7 EFFECT OF DEFORMATION ON MATERIAL PROPERTIES

The mechanical properties are greatly affected by deformation i.e plastic deformation. The deformation process like rolling, forging, extrusion, drawing. Strain hardening takes place, so hardness changes. Elasticity changes, cracking takes place, grain growth takes place. Residual stress is produce in cold working.

CHAPTER-5.0

HEAT TREATMENT

5.1- PURPOSE OF HEAT TREATMENT

DEFINITION- It may be defined as heating and cooling operations applied to metals and alloys in solid state so as to obtain the desired properties.

The object of this process is to make the metal better suited, structurally and physically, for some specific applications. Heat treatment may be undertaken for the following purposes.

(i) Improvement in ductility
(ii) Relieving internal stresses
(iii) Refinement of grain size
(iv) Increasing hardness or tensile strength and achieving changes in chemical composition of metal surface as in the case of case-hardening.

Also compress machinability, alteration in magnetic properties, modification of electrical conductivity, improvement in toughness and development of re-crystallized structure in cold-worked metal.

5.2. PROCESS OF HEAT TREATMENT

ANNEALING

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

(i) Relieve interval stresses developed during solidification, machining, forging, rolling or welding.
(ii) Improve or restore ductility and toughness.
(iii) Enhance machinability.
(iv) Eliminate chemical non-uniformity.
(v) Refine grain size.
(vi) Reduce the gaseous contents in steel.

NORMALIZING

Normalizing is a process of heating steel to about 40-500C above upper critical temperature, holding for proper time and then cooling in still air or slightly agitated air to room temperature. After normalizing the resultant microstructure should be pearlite. This is important for some alloy steels which are air hardening by nature. Better dispersion of ferrite and cementite in the final structure results in enhanced mechanical properties. The grain size is finer and refinement of grain size. Rolled and forged steels possessing coarse grains due to high temperatures involved are subjected to normalizing. Normalized steels are generally stronger and harder than fully annealed steels.

HARDENING

Hardening consists of heating to hardening temperature, holding at that temperature, followed by rapid cooling such as quenching in water oil or salt baths. High hardness developed by this process is due to phase transformation with rapid cooling. For plain carbon steels, it depends on carbon content. Hypo-eutectoid steels are heated to about 30 – 500C above the critical temperature where as eutectoid and hyper eutectoid steels are heated to about 30 – 500C above the lower critical temperature.

TEMPERING

The process which consists of heating hardened steel below the lower critical temperature, followed by cooling in air or at any other desired rate, is known as tempering. This treatment lowers hardness strength and wears resistance of the hardened steel marginally. The higher the tempering temp, the more is the restored ductility and toughens the steel. Proper tempering treatment results are optimum combination of mechanical properties. Elastic properties are affected by this. Hardening followed by tempering will improve elasticity.

5.3- SURFACE HARDENING

In order to process considerable strength to with stand forces acting on them and to withstand wear on their surface, the parts must be made of tough materials and provided with a hard surface by introducing carbon or nitrogen on its surface with core remaining soft. Surface hardening or case-hardening provides us a hand and wear resistant surfaces, close tolerance in machining parts and tough-core combined with a higher fatigue limit and high mechanical properties in core. It is carried out by following operations

(a) Carburizing

(b) Nit-riding

(c) Carbonitriding

(d) Cyaniding

(e) Induction hardening

f) Flame hardening.

CARBURIZING

It is the process of producing a hard surface on low carbon steel parts. There are three methods of carburizing such as (a) pack or solid carburizing (b) Gas carburizing (c) Liquid carburizing.

Liquid carburizing is performed in activated bath of calcium cyan amide, sodium or potassium cyanide and other controlling chemicals which govern the decomposition of the cylinders. The baths are operated at 815.50C to 898.850C produce a case of depth of 0.5mm in 90 minutes. The process extremely flexible and easily controlled. The reaction in the bath is 2Na2CO3 + SiC – Na2SiO3 + Na2O + 2CO + C.

NITRIDING

The introduction of nitrogen into the outer surface of steel parts in order to give an extremely hard, wear resisting surface is called nitriding. It is provided by placing the article in ammonia vapour a temperature between 4500C and 5500C for 10 hours. The core should be brought to its original toughness before nitriding by quenching in oil from about 9000C and tempering from about 6000C to 6500C. It is used for various automotives, airplane and diesel engine parts like cylinders, sleeves, liners etc.

5.5 HARDENABILITY OF STEEL

It is defined as property of a steel to be hardened by quenching and determined the depth and distribution of hardness throughout a section obtained by quenching. Factors are as follows The main factors affecting hardenability are:

(a) Alloying elements

(b) Carbon content

(c) Grain size of steel

(d) The homogeneity of starting steel

(e) Homogeneity obtained in the austenite before quenching by increasing carbon content, hardness can be increased.

CHAPTER-6

NON-FERROUS ALLOYS

6.1 ALUMINUM ALLOY:-

An aluminum alloy is a composition consisting mainly of aluminum to which other elements have been added. The alloy is made by mixing together the elements when aluminum is molten (liquid), which cools to form a homogeneous solid solution. The other elements may make up as much as 15 percent of the alloy by mass. Added elements include iron, copper, magnesium, silicon, and zinc. The addition of elements to the aluminum gives the alloy improved strength, workability, corrosion resistance, electrical conductivity, and/or density, compared with the pure metallic element. Aluminum alloys tend to be lightweight and corrosion resistant.

The aluminum may be easily alloyed with other elements like copper, magnesium, zinc, manganese, silicon and nickel to improve various properties. The addition of small quantities of alloying elements into other metals helps to converts the soft and weak metal into hard and strong metal, while still retaining its light weight.

LIST OF ALUMINUM ALLOYS

This is a list of some important aluminum or aluminium alloys.

- AA-8000: used for building wire per the National Electrical Code
- Alclad: aluminum sheet made by bonding high-purity aluminum to a high strength core material
- Al-Li (lithium, sometimes mercury)
- Alnico (aluminum, nickel, copper)
- Birmabright (aluminum, magnesium)
- Duralumin (copper, aluminum)
- Hindalium (aluminum, magnesium, manganese, silicon)
- Magnalium (5% magnesium)
- Magnox (magnesium oxide, aluminum)
- Nambe (aluminum plus seven other unspecified metals)
- Silumin (aluminum, silicon)
- Titanal (aluminum, zinc, magnesium, copper, zirconium)
- Zamak (zinc, aluminum, magnesium, copper)
- Aluminum forms other complex alloys with magnesium, manganese, and platinum

VARIOUS ALUMINUM ALLOYS ARE

1. Duralumin
2. Y-alloy
3. Magnalium
4. Hindalium

These alloys are discussed as below

1. **DURALUMIN**

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 %
Aluminum = 94 %

PROPERTIES:-

- ✓ Duralumin can be very easily forged,
- ✓ Casted and worked because it possesses low melting point.
- ✓ It has high tensile strength.
- ✓ Comparable with mild steel combined with the characteristics lightness of Al.
- ✓ It however possesses low corrosion resistance and high electrical conductivity.
- ✓ This alloy possesses higher strength after heat treatment and age hardening.
- ✓ After working, if this alloy is age hardened for 3 or 4 days.
- ✓ This phenomenon is known as age hardening.
- ✓ It hardens spontaneously when exposed to room temperature.
- ✓ This alloy is soft enough for a workable period after it has been quenched.
- ✓ It is light in weight as compared to its strength in comparison to other metals.
- ✓ It can be easily hot worked at a temperature of 500°C.
- ✓ However after forging and annealing, it can also be cold worked.

APPLICATIONS

- ✓ Duralumin is used in the wrought conditions for forging, stamping, bars, sheets, tubes, bolts, and rivets.
- ✓ Due to its higher strength and lighter weight, this alloy is widely used in automobile and aircraft components.
- ✓ To improve the strength of duralumin sheet, a thin film of Al is rolled along with this sheet.

- ✓ Such combined sheets are widely used in air-craft industries.
- ✓ It is also employed in surgical and orthopedic work, non-magnetic work and measuring instrument parts constructing work.

2. Y -ALLOY

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

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 aluminum 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.

3. MAGNALIUM:-

Magnalium is an alloy of aluminum, magnesium, copper, nickel and tin etc.

It contains

Al =85 to 95%

Cu= 0 to 25%

Mg=1 to 5%

Ni=0 to 1.2%

Sn=0 to 3%
Fe= 0 to 0.9%
Mn=0 to 0.03%
Si= 0.2 to 0.6%

It is made by melting the aluminum with 2-10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres.

PROPERTIES

Magnalium is light in weight and brittle. This alloy possesses poor castability and good machinability. It can be easily welded.

APPLICATIONS

Due to its light weight and good mechanical properties, it is mainly used for making aircraft and automobile components.

4. HINDALIUM:-

Hindalium is a common trade name of aluminium alloy. It is an alloy of aluminium, magnesium,manganese, chromium and silicon etc. In India, it is produced by Hindustan Aluminium Corporation Ltd., Renukoot (U.P.). Hindalium is commonly produced as a rolled product in 16 gauges. Utensils manufactured by this alloys are strong and hard, easily cleaned, low cost than stainless steels, having fine finish, having good scratch resistance, do not absorb much heat etc.

APPLICATIONS

Hindalium is mainly used for manufacturing anodized utensil. Utensils manufactured by this alloys are strong and hard, easily cleaned, low cost than stainless steels, having fine finish, having good scratch resistance, do not absorb much heat etc.

6.2 COPPER ALLOYS

Copper alloys are alloys based on copper, in which the main alloying elements are Zn, Sn, Si, Al, and Ni. Cu-based alloys constitute mostly substitutional solid solutions, for which solute or impurity atoms replace or substitute for the host atoms. Several features of the solute and solvent atoms determine the degree to which the former dissolves in the latter. These are expressed as the **Hume–Rothery rules**. There are as many as **400 different copper and copper alloy compositions** loosely grouped into the categories: copper, high copper alloy, brasses, bronzes, copper nickels, copper–nickel–zinc (nickel silver), leaded copper, and special alloys. In addition, a limited number of copper alloys can be strengthened by heat treatment.; consequently, cold working and/or solid-solution alloying must be used to improve these mechanical properties.

PROPERTIES OF COPPER

Copper is a soft, tough, ductile, and malleable material, and 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 thermal conductivity**. Copper has a 60% higher thermal conductivity rating than aluminium, so it is better to reduce thermal hot spots in electrical wiring systems. The electrical and thermal conductivities of metals **originate from** their **outer electrons being delocalized**.
- **Excellent electrical conductivity**. The conductivity of copper is 97% that of silver. Due to its much lower cost and greater abundance, copper has traditionally been the standard material for electricity transmission applications. However, aluminum is usually used in overhead high-voltage power lines because it has about half the weight and lowers the cost of a comparable resistance copper cable. At a given temperature, metals' **thermal and electrical conductivities** are **proportional**, but raising the temperature increases the thermal conductivity while decreasing the electrical conductivity. This behavior is quantified in the **Wiedemann–Franz law**.
- **Good corrosion resistance**. Copper does not react with water but slowly reacts with atmospheric oxygen to form a layer of brown-black copper oxide. Unlike the rust that forms on iron in moist air, it protects the underlying metal from further corrosion (passivation). Copper-nickel alloys, aluminium brass, and aluminium demonstrate superior resistance to saltwater corrosion.
- **Good biofouling resistance**
- **Good machinability**. Machining of copper is possible, although alloys are preferred for good machinability in creating intricate parts.
- Retention of mechanical and electrical properties at cryogenic temperatures
- Diamagnetic

TYPES OF COPPER ALLOYS

As was written, there are as many as 400 different copper and copper alloy compositions loosely grouped into the categories: copper, high copper alloy, brasses, bronzes, copper nickels, copper–nickel–zinc (nickel silver), leaded copper, and special alloys. In the following points, we summarize the key properties of selected copper-based materials.

(a) Copper-Aluminium alloys

Aluminum gets hardened and strengthened by the addition of copper. The most extensively used alloys for castings are those containing 4, 5, 7,10and12% of copper and with ultimate strength ranging from 1.12–4.185t/cm2. It is employed in industry for light casting requiring greater strength and hardness than ordinary aluminum.

It is used for automobile piston, crank-cases, cylinder heads and connecting rods.

(b) Copper-Tin

These bearing alloys containing greater proportion of tin with copper and antimony and known as whit metals. Another alloys of this type having composition of 86%tin, 10.5% antimony,3.5%copper has a tensile strength of 0.996t/cm2,elongation7.1% with brinell hardness of 33.3 and compressive yield point of 4.3. It is used in main bearings of motors and aero-engines.

(c) Babbit

It is a general white metal alloy with soft lead and tin base metals covering arrange of alloy having similar characteristics varying composition .Its actual composition is 82.3% tin,3.9% copper, 7.1%antimony.

A cheaper Babbitt metal used for bearings subjected to moderate pressure has composition as59.54%tin, 2.25 to 3.75%copper, 9.5to11.5%antimony,26%lead, 0.08%iron,0.08%bismuth.Edited with the trial version of They are use as liners in bronze or steel backing and are prepared for higher speed, excellent embed ability, conformability, ability to deform plastically used in IC engine bearing, general machinery purpose bearings.

(d) Phosphorous bronze

The phosphorous bronzes are the alloys of copper and tin with 0.1to1.5% phosphorous. Phosphorous is added both for deoxidizing the tin oxide and developing the structure and general properties of the metal. In the form of casting phosphorous bronze gives and ultimate strength of about 18 tonnes/cm2 with elongation of 4% brinell hardness number 80-100. Itis used for heavy compressive loads and issued for gear wheels and slide values. Phosphorous bronze in wrought

This alloy form containing 10%tin, 0.1–0.35% phosphorous has a tensile strength 3.72t/cm2,Bhn100–130. It has good corrosion resistance to sea water and is used for spring and turbine blades.

(e) Brass

These are the alloys of copper and zinc with varying percentage of two metals. If small amount of one or more metals are added they provide more specific properties like colour, strength, ductility, machinability.

-brasses-36% zinc and 64%cu.
–brasses–40 to 44%zn and 64 to55% cu.
– brasses possess good tensile strength ,good ductility, suitable for producing sheet, strips, tubes, wires etc.

–brasses are used for hot pressings, stampings.

(f) Copper-Nickel

Nickel forms with copper in varying properties a large number of alloys. The addition of even a small amount of nickel to copper has a marked effect upon its mechanical properties and increases its corrosion resistance.

Cupro-Nickel has a nickel content between 10 –30% has remarkable drawing properties with tensile strength of 6.2t/cm2 used for sheats or envelopes of rifle bullet.A70/30cupro nickel used for condenser tubes produced by extrusion process. 8t/cm2 elastic limit,5.9t/cm2 ultimate strength,Bhn140.

6.3 PREDOMINATING ELEMENTS OF LEAD ALLOYS, ZINC ALLOYS AND NICKEL ALLOYS.

LEAD ALLOYS:-

The tin is replaced by lead base alloys and contains 10–15% antimony, 15%Cu, 20% Tin and 60%Lead. These alloys are cheaper than tin base alloys, but not strong and do not possess the lead carrying capacity strength decreases with increasing in temperature. An alloy containing 80% lead, 15% antimony and 5% tin or 20% antimony generally used for long bearings with medium loads.

Binary copper-lead alloys-lead10–20%, 20–30% and above30%.

ZINC ALLOYS

These alloys used in the form of tooling plate and easy and speed of fabrication.

Brasses – Alloys of Cu and Zn.

NICKEL ALLOYS

Nickel is one of the most important metals which is used as a pure metal and alloyed with other elements.

Nickel copper, nickel copper silicon alloys.
Nickel copper tin, sometimes with lead.
Nickel chromium- with iron or cobalt.
Nickel molybdenum-also with chromium.
Nickel silicon.
Nickel manganese, nickel aluminum.

LOW ALLOY MATERIALS LIKE P-91, P-22 FOR POWER PLANTS AND OTHER HIGH TEMPERATURE SERVICES. HIGH ALLOY MATERIALS LIKE STAINLESS STEEL GRADES OF DUPLEX, STIPER DUPLEX MATERIALS

LOW ALLOY MATERIALS

Which possess slowly cooled micro structures, similar to those of plain carbon steel in the same condition namely pearlite, pearlite plus ferrite. These low alloy also known as pearlite alloy steel.

P91 is a chrome moly alloy metal that contains excellent strength and temperature resistance. It is designed for enhanced creep strength, making it a creep strength enhanced ferritic (CSEF).

This metal is made by normalizing at 1050 °C, air cooling to 200 °C, and then tempered through heating to 760 °C.

P22 Alloy Steel Seamless Pipes are Carbon steel pipes with addition of chromium, molybdenum, and sometimes vanadium. Chromium, or chrome, improves high-temperature strength, increases oxidation resistance and raises the tensile, yield and hardness at room temperatures.

HIGH ALLOY STEEL

Which possess slowly cooled micro structure, consisting either of martensite, austenite or ferrite plus carbide particle. It is more than 8% in the case of steels.

Duplex Stainless Steels

Duplex stainless steels are becoming more common. They are being offered by all the major stainless steel mills for a number of reasons:

- Higher strength leading to weight saving
- Greater corrosion resistance particularly to stress corrosion cracking
- Better price stability
- Lower price

There is a conference on the subject of duplex every 2-3 years where dozens of highly technical papers are presented. There is a lot of marketing activity surrounding these grades. New grades are being announced frequently.

Yet, even with all this interest, the best estimates for global market share for duplex are between 1 and 3%. The purpose of this article is to provide a straightforward guide to this steel type. The advantages and disadvantages will be described.

SUPER DUPLEX

Super duplex is a shorthand term for a family of high-performance stainless steels designed with around 25% chromium content in the alloy’s makeup. As the duplex name suggests, this family of alloys have a microstructure made up of both austenitic and ferritic grains of steel. This duplex nature provides Super Duplex’s unique combination of physical and mechanical properties.

CHAPTER-7

BEARING MATERIAL

BEARING MATERIAL

When a lubricant film cannot completely separate the moving parts of a bearing, friction and wear increase. The resulting frictional heat combined with high pressure promotes localized welding of the two rubbing surfaces.

These welded contact points break apart with relative motion and metal is pulled from one or both surfaces decreasing the life of the bearing.

Babbitt's offer an almost unsurpassed combination of compatibility, conformability, and embed-ability. They easily adapt their shapes to conform to the bearing shaft and will hold a lubricant film. Foreign matter not carried away by the lubrication is embedded below the surface and rendered harmless.

These characteristics are due to Babbitt's hard/soft composition. High-tin Babbitt's, for example, consist of a relatively soft, solid matrix of tin in which are distributed hard copper-tin needles and tin-antimony cuboids.

This provides for "good run-in" which means the bearing will absorb a lubricant on the surface and hold the lubricant film. Even under severe operating conditions, where high loads, fatigue problems, or high temperatures dictate the use of other stronger materials, Babbitt's are often employed as a thin surface coating to obtain the advantages of their good rubbing characteristics.

Classification of Bearing Material

1. Tin Based Babbitt

2. Lead based Babbitt

3. Cadmium Based Bearing Material

4. Copper based Bearing Material (Cantered Metal)

Composition & uses of different type of bearing material

1. Tin Based Babbitt

Compositions

85Sn-10Sb-5Cu

Applications

High speed bearing bushes in steam and gas turbine, electric motor, blower, pumps etc.

2. Lead Based Babbitt

Compositions:

80Pb-12Sb-8Sn

Applications:

Railway Wagon bearing.

3. Cadmium Based

Compositions:

95cd-5ag & small amount of iridium

Applications:

Medium loaded bearing subjected to high temperature

4. Copper Based

80Cu-10Pb-10Si

Applications

Heavy duty bearing.

Properties of Bearing Material

A bearing metal should possess the following important properties.

i) It should have enough compressive and fatigue strength to possess adequate load carrying capacity.

ii) It should have good plasticity for small variations in alignment & fittings.

iii) It should have good wear Resistance to maintain a specified fit.

iv) It should have low co-efficient of frictim to avoid excessive heating.

v) The material should resist vibration.

vi) It should have high Thermal conductivity so as to take away the heat produced due to friction between two moving parts.

vii) It should have the properties to from a continuous thin film of lubricant between the shaft & bearing to avoid direct contact between two rotating surface.

CHAPTER-8

SPRING MATERIALS

SPRING MATERIAL

Springs are fundamental mechanical components found in many mechanical systems. Developments in material, design procedures and manufacturing processes permit springs to be made with longer fatigue life, reduced complexity, and higher production rate. Most springs are linear which means the resisting force is linearly proportional to its displacement.

Linear springs obey the Hooke's Law,

$F = k \times Dx$

Where F is the resisting force, k is the spring constant and Dx is the displacement.

DEPENDING ON LOAD CHARACTERISTICS SPRING MAY BE CLASSIFIED AS

SPRING MATERIAL

Most springs are made with iron- based alloy(high-carbon spring steels, alloy spring steels, stainless spring steels), copper base spring alloys and nickel base spring alloys.

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. They are suitable to use in sub-zero temperatures.

i) Brasses (Cu67, Zn33): Switch control, electrical application.

ii) Nickel Silver (Cu56, Ni18, Zn18): Electrical relays.

iii) Lead Bronze (Cu92, Sn8, Pb 0.1): Bushes.

Iv) Beryllium Copper (Cu98, Be2.0): Relays and Bushes

ii) Nickel Base Spring Alloys

Nickel base alloys are corrosion resistant, and they can withstand a wide temperature fluctuation.

The material is suitable to use in precise instruments because of their non-magnetic characteristic, but they also poses a high electrical resistance and therefore should not be used as an electrical conductor.

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

CHAPTER-9

POLYMERS

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

Polymers are created by the process of polymerization, wherein their constituent elements, called monomers, are reacted together to form polymer chains, i.e., 3-dimensional networks forming the polymer bonds.

The type of polymerization mechanism used depends on the type of functional groups attached to the reactants. In the biological context, almost all macromolecules are either completely polymeric or are made up of large polymeric chains.

CLASSIFICATION OF POLYMERS BASED ON THE SOURCE OF AVAILABILITY

There are **three types of classification** under this category, namely, 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 human-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, etc.

CLASSIFICATION OF POLYMERS BASED ON THE STRUCTURE OF THE MONOMER CHAIN

This category has the following classifications:

LINEAR POLYMERS

The structure of polymers containing long and straight chains falls into this category. PVC, i.e., polyvinyl chloride, is largely used for making pipes, and an electric cable is an example of a linear polymer.

BRANCHED-CHAIN POLYMERS

When linear chains of a polymer form branches, then such polymers are categorised as branched chain polymers. For example, low-density polythene.

CROSS-LINKED POLYMERS

They are composed of bifunctional and trifunctional monomers. They have a stronger covalent bond in comparison to other linear polymers. Bakelite and melamine are examples of cross-linked polymers.

OTHER WAYS TO CLASSIFY POLYMERS

Classification Based on Polymerization

- **Addition Polymerization:** For example, poly ethane, Teflon, polyvinyl chloride (PVC), etc.
- **Condensation Polymerization:** Examples include nylon -6, 6, perylene, polyesters, etc.

CLASSIFICATION BASED ON MONOMERS

- **Homomer:** In this type, a single type of monomer unit is present. For example, polyethene.

- **Heteropolymer or co-polymer:** It consists of different types of monomer units. For example, nylon -6, 6.

CLASSIFICATION BASED ON MOLECULAR FORCES

- **Elastomers:** These are rubber-like solids, and weak interaction forces are present in them. 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:** These polymers greatly improve the material's mechanical properties. It provides enhanced chemical and heat resistance. For example, phenolics, epoxies and silicones.

STRUCTURE OF POLYMERS

Most of the polymers around us are made up of a **hydrocarbon backbone**. A hydrocarbon backbone is a long chain of linked carbon and hydrogen atoms, possibly due to the tetravalent nature of carbon.

A few examples of hydrocarbon backbone polymers are polypropylene, polybutylene and polystyrene. Also, there are polymers which, instead of carbon, have other elements in their backbone. For example, nylon contains nitrogen atoms in the repeated unit backbone.

TYPES OF POLYMERS

On the basis of the type of backbone chain, polymers can be divided into

- **Organic Polymers**: Carbon backbone
- **Inorganic Polymers**: Backbone constituted by elements other than carbon On the basis of their synthesis:

- Natural Polymers
- Synthetic Polymers

- **Biodegradable Polymers**

Polymers which are degraded and decayed by microorganisms, like bacteria, are known as **biodegradable polymers**. These types of polymers are used in surgical bandages, capsule coatings, etc. For example, poly hydroxybutyrate co vel [PHBV]

- **High-temperature Polymers**

These polymers are stable at high temperatures. Due to their high molecular weight, these are not destroyed even at very high temperatures. They are extensively used in the healthcare industries, for making sterilisation equipment and in the manufacturing of heat and shock-resistant objects.

A FEW OF THE IMPORTANT POLYMERS ARE

Polypropylene: It is a type of polymer that softens beyond a specific temperature allowing it to be moulded, and on cooling, it solidifies. Due to its ability to be easily moulded into various shapes, it has a lot of applications.

A few of which are in stationary equipment, automotive components, reusable container speakers and much more. Due to its relatively low energy surface, the polymer is fused with the welding process and not using glue.

Polyethene: It is the most common type of plastic found around us. Mostly used in packaging, from plastic bags to plastic bottles. There are different types of polyethene, but their common formula is $(C_2H_4)_n$.

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 Van der 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.

USES OF POLYMERS

Here, we will list some of the important uses of polymers in our everyday life.

- Polypropene finds usage in a broad range of industries, such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys, etc.
- Polystyrene is one of the most common plastic actively used in the packaging industry. Bottles, toys, containers, trays, disposable glasses and plates, TV cabinets and lids are some of the daily-used products made up of polystyrene. It is also used as an insulator.
- The most important use of polyvinyl chloride is the manufacture of sewage pipes. It is also used as an insulator in electric cables.
- Polyvinyl chloride is used in clothing and furniture and has recently become popular for the construction of doors and windows as well. It is also used in vinyl flooring.

- Urea-formaldehyde resins are used for making adhesives, moulds, laminated sheets, unbreakable containers, etc.
- Glyptal is used for making paints, coatings and lacquers.
- Bakelite is used for making electrical switches, kitchen products, toys, jewellery, firearms, insulators, computer discs, etc.

Commercial Uses of Polymers

Polymer	**Monomer**	**Uses of Polymer**
Rubber	Isoprene (1, 2-methyl 1 – 1, 3-butadiene)	Making tyres, elastic materials
BUNA – S	(a) 1, 3-butadiene (b) Styrene	Synthetic rubber
BUNA – N	(a) 1, 3-butadiene (b) Vinyl Cyanide	Synthetic rubber
Teflon	Tetra Fluoro Ethane	Non-stick cookware – plastics
Terylene	(a) Ethylene glycol (b) Terephthalic acid	Fabric
Glyptal	(a) Ethylene glycol (b) Phthalic acid	Fabric
Bakelite	(a) Phenol (b) Formaldehyde	Plastic switches, Mugs, buckets
PVC	Vinyl Cyanide	Tubes, Pipes
Melamine Formaldehyde Resin	(a) Melamine (b) Formaldehyde	Ceramic, plastic material
Nylon-6	Caprolactam	Fabric

THERMOSETTING POLYMER

A thermosetting polymer which is also known as a thermoset or thermosetting plastic is a polymer consisting of cross-linked structure or heavily branched molecules.

These polymers which are in the soft solid or viscous state on heating undergo extensive cross-linking in moulds and become irreversibly hard as well as insoluble products.

PROPERTIES OF THERMOSETTING POLYMERS

- One of the main properties of thermoset plastics or polymers is that they harden during the moulding process and after solidifying they cannot be softened.
- Typically, when the polymers are moulded and shaped they acquire a three-dimensional cross-linked structure along with strong covalent bonds that further help them retain their strength as well as a structure even if the temperatures are set high.
- However, thermoset plastics are brittle and tend to char and burn if heat is applied for a prolonged state. Normally, thermosets decompose before melting. Meanwhile, thermoset resins are insoluble in most of the inorganic solvents.

THERMOSETTING PROCESS

Processing thermoset polymers usually involve three stages.

- The first stage is commonly referred to as resole where during this stage the resin is an insoluble and fusible condition or state.
- In the second stage, the thermosets are only partly soluble, and they tend to display the characteristics of a thermoplastic where the changes are reversible.
- However, this is a temporary state as the molten form of thermoset lasts only for a short time because the increase in temperatures promotes cross-linking.
- The final stage is where the cross-linking reaction occurs and the final structure of thermosets is constructed. This mostly involves the moulding phase which is conducted under controlled temperature and some application of pressure.
- The final product will have a three-dimensional internal network structure consisting of highly cross-linked polymer chains. At this point, the product cannot be thermally deformed.

In addition, thermoset plastics can also be processed via a single-stage method called reaction injection moulding (RIM). While this process is similar to the method described above the only distinction here are that polymers are combined during the curing process to form a permanent chemical bond. The process basically uses polymerization in the mould instead of cooling to facilitate the formation of a solid polymer.

Some common methods of moulding thermosets include:

- Extrusion moulding which is used for making insulation for electrical cables, threads of fabric and pipes.
- Compression moulding is used to give shape to BMC and SMC thermosetting plastics.
- Spin casting which is a process mainly used for the production of figurines, fishing lures and jigs, emblems and even replacement parts.

EXAMPLES

- One of the most common examples of thermosets is bakelite which is relatively a bad conductor of electricity and heat.
- It is mainly used for making electrical switches, handles of various utensils, etc.
- Another example is Melamine which has a capacity to resist fire and heat much efficiently than other plastics.
- It is used in kitchenware and fabrics as well as floor tiles.
- Some other examples of thermoset plastic polymers include silicones, vulcanized rubber, epoxies, polyesters and phenolics.

THERMOSETTING PLASTIC ADVANTAGES AND DISADVANTAGES

1. Some **main advantages** of thermosetting plastics include – they are more resistant to high temperatures, they have high levels of dimensional stability, are cost-effective, and allow highly flexible design.
2. On the other hand, some thermosetting plastics **disadvantages** include, the products can not be recycled or reused and the products cannot be remoulded or reshaped.

THERMOPLASTIC POLYMERS

All the plastic materials which can be softened and melted by heating, but they set again when cool are called thermoplastics.
Thermoplastic polymers can be very broadly classified ***as amorphous or crystalline***. Most thermoplastics suitable for use as matrices for high performance composite exhibit some degree of crystallinity because this type of structure has better resistance to chemical attack by field, hydraulic oil and paint stripper.

With regard to behaviour at elevated temperatures, polymers are classified as either **thermoplastics or thermosetting.** Thermoplastic polymers have linear and branched structures they soften when heated and harden when cooled. In contrast, thermosetting polymers once they have hardened, will not soften upon heating; their structures are cross-linked and network.

THERMOPLASTIC POLYMERS PROPERTIES

Many thermoplastic polymers are reinforced with fibres. Reinforcement is used to improve physical properties – specifically heat deflection temperature. Glass fibres are the most commonly used reinforcing material. The wear resistance and abrasion resistance of thermoplastic polymers are improved by the use of aramid reinforcing. Although fibres can be used with any thermoplastic polymer, the following are the most important.

- Polyamide polymers use glass fibres to control brittleness. Tensile strengths are increased by a factor of three, and heat deflection temperature increases from 150 to 500ºF.
- Polycarbonate compounds using 10, 20, 30 and 40% glass fibre loading have their physical properties greatly improved.
- Other polymers benefiting from the addition of glass fibres include polyphenylene sulfide, polypropylene and polyethersulfone.

Polymers chosen for structural application are usually selected as a replacement for metal. Usually a like replacement of a polymer section for a metallic section will result in a weight saving. In addition polymers can be easily formed into shapes that are difficult to achieve with metals. By using a polymer, the engineer can design an attractive shape that favours plastic forming and achieve a saving in cost and weight and a cosmetic improvement.

An additional cost saving is realised since the polymer part does not require painting for corrosion protection as would the comparable metal part. Selection of the specific polymer will be based on mechanical requirements and the temperature and chemical end-use environment.

THERMOPLASTIC POLYMERS APPLICATIONS

Thermoset composites are used therefore for the most structurally demanding applications particularly if high temperatures are involved.

In choosing a resin system the suitability of the physical and chemical properties of the resin for the chosen processing route, matching to the reinforcements and also how the properties of the cured resin will suit the end use of the composites.

***Factors to consider are*:**

- **Resin viscosity –** sufficiently low to penetrate the reinforcement.
- **Size of moulding –** cure reactions are often exothermic, therefore if the moulding is thick, it may be that the rate of curve of the moulding must be reduced to prevent an uncontrolled rise in temperature during the curing process which may be sufficient to actually damage the moulding.
- **Speed of reaction –** has an important bearing on the rate of article production.
- **Compatibility with reinforcement –** the resin must wet and adhere to the reinforcement.

- **Moisture level –** some polymers are not as satisfactory as others in wet conditions, one of the reasons to use vinyl ester rather than polyester resins. Moisture ingress into a laminate can lead to severe loss of properties.

USES OF THERMOPLASTIC POLYMERS

Thermoset Type	**Common Uses**
Alkyl (polyester)	Automotive body panels and fender/wing walls, tool housings, brackets, industrial equipment housings, coatings.
Epoxy	Coatings, casting compounds, encapsulating for electrical components, laminates and adhesives.
Phenolic	Electrical switch housings, relays, laminates, adhesives (plywood, particle board), handles (cooking pots and pans), knobs and electrical motor components.
Polyurethane	Sealants, adhesives and coatings. Automotive body panels (Reaction Injection Moulding), foams.
Urea and Melamine Formaldehyde	Electrical breakers, receptacles, closures, knobs and handles, appliance components, adhesives, coatings and laminates.

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

Following are the properties of elastomers:

- **Temperature:** The specific working temperature of elastomers varies 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.

TYPES OF ELASTOMERS

Following are the two types of elastomers:

1. Saturated elastomers
2. Unsaturated elastomers

1. **Saturated Elastomers:** Sulphur vulcanization can not cure them. They showcase superior stability against oxygen, radiation, heat, and ozone. Comparably they are less reactive. Their reactivity is limited to certain circumstances and conditions. Polyacrylic rubber and silicone rubber are examples of saturated elastomers.
2. **Unsaturated Elastomers:** They can be cured with the Sulphur vulcanization process. Butyl rubber and natural polyisoprene are examples of unsaturated elastomers.

DIFFERENCE BETWEEN ELASTOMER AND POLYMER

Although elastomers are the specialized category of polynomials, They are often compared for their differences. Refer to the table below to get a clear idea about regular polymer and special elastic-polymer, i.e., elastomers.

Property	**Elastomers**	**Polymer**
Definition	It is a polymer with very weak intermolecular forces and Viscoelasticity. Thus, they are famously known as elastic polymers.	Is a macromolecule or large molecule made up of clusters of subunits.
Physical property	They inherit the unique property of elasticity.	They inherit diverse properties based on the category.
Morphology	They are amorphous structure	They vary from crystalline form to amorphous form.
Flexibility	They are elastic in nature. They are capable of configuring the right distribution of applied pressure to retain their original size and shape	They are mostly brittle/ hard/rigid in nature except for elastomers. Application of force can result in permanent deformation

ELASTOMERS APPLICATIONS

They play an essential and ubiquitous role in day to day life due to their elasticity, flexibility, insolubility, and lot many prominent features. Some of their applications are listed below-

- **Motor vehicles:** Some elastomers like thermosets don’t melt easily, making them efficient in building seals, tyres various components throughout the automobile design. Especially those components which will be exposed to heat during the functioning. The material of the type polybutadiene offers extraordinary wear resistance hence they are preferable in building tyres.
- **Consumer products:** This comprises the widest range of products starting from shoe soles to baby pacifiers and many more miscellaneous.
- **Constructions:** Adhesives and sealants materials enfolded under elastomers, which are an unavoidable part of any constructions. Especially for filling the gaps.
- **Industrial products:** Elastomers are hugely used in making industrial tools, appliances, belts, molds, lubricants, etc.

- **Wire and cable:** Material needed to build wires should have high resistance to heat, be easily reshaped(elongated), and provide insulation. Elastomers like neoprene are perfect for this.
- **Medical products:** Medical field needs a wide range of products like prosthetics, lubricants, and moulds with superior class of chemical and thermal resistance. Elastomer like silicon has widely used the material to build them and many other goods.

CHAPTER-10

COMPOSITES AND CERAMICS

COMPOSITE MATERIALS

A composite material is a combination of two materials with different physical and chemical properties. When combined they produce a material that is specific to a certain work, for instance, to become stronger, lighter, or resistant to electricity and also improve strength and stiffness.

The components maintain their identity within the composite, i.e. they do not dissolve or completely merge into one another, though they act in concert.
Here we will learn about composites material, types of composites material & much more.

INTRODUCTION TO COMPOSITES MATERIAL:

Composites material are probably the most extensively used materials due to their adaptability to varied situations.

It is easy to mixed with different materials and the efficiency of desirable properties to serve particular functions.

The composite materials has excessive strength and hardness with decrease density than bulk materials.

PROPERTIES OF COMPOSITE MATERIALS

- The tensile strength of composite materials is 4-6 times higher than conventional materials such as steel, aluminum, etc.
- They have better torsion and stiffness properties.
- It has a high fatigue endurance limit (ultimate tensile strength of up to 60%).
- They are 30–45% lighter than aluminum structures designed for the same functional requirements.
- Also has low embedded energy.
- Composites make less noise during operation and provide less vibration.
- Composite materials are additional versatile.

TYPES OF COMPOSITE MATERIALS

1.POLYMER MATRIX COMPOSITE(PMCs)

It consists of polymer resin within the type of a matrix, the variety and the greatest amount is being used.Glass fibre-reinforced polymer composites (GFRP) are the largest amount of produced carbon fibre-reinforced polymer composites (CFRP).

2. HIGH PERFORMANCE COMPOSITE

They are Aramid Fiber Reinforced Polymer Composites (AFRPs).

It has high strength, high modulus and high impact resistance composites.

3. METAL MATRIX COMPOSITES (MMCs)

It is also extra ductile compared to matrix reinforcement.

Reinforcement can improve strength, abrasion resistance, creep resistance, thermal conductivity and dimensional stability of composite composites.

Metal matrix composites are additional resistance to extreme working temperatures, non-flammability, and corrosion of organic fluids.

4.CERAMICS METAL COMPOSITES(CMCs)

For use in high temperature and severe stress applications, e.g. automobile and aircraft gas turbine engines.

It has high strength, very high service temperature & Low weight.

Classification of composite materials:

MICROSPHERES

They are considered to be some of the most useful filters.

This particular gravity, fixed particle amplitude, power and managed density is the most extreme property for switching products without compromising profitability or physical properties.

Stable micro-spheres have a relatively low density hence affecting the commercial value and weight of the finished product.

Studies shows that their specific strength is covered in the finished mould, in which they form a component.

Hollow microspheres are basically silicate-based constructed at managed specific gravity.

They are larger than the stationary glass spheres used in polymers and are commercially supplied in a wide range of particle sizes.

FILLED COMPOSITE

The filler may be a core component or addition in a composite.The particles of the filler may be irregular structures or may contain precise geometric shapes such as polyhedrons, small fibres, or spheres. Filled composer fillers may be a core component or an addition to a composite.

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FLAKES STRUCTURES

Flakes are often used in place of fibre because it can be stored in dense packs.

Metal flakes that has close contact with each other in polymer matrixs can conduct the electrical energy or heat while opposing both mica flakes and glass.

Flexes will not be expensive to produce and will generally have a lower price than fibre.

PARTICULATE REINFORCED COMPOSITE

Microstructures of metal and ceramic composites, which show particles of one phase scattered in another are called particle reinforced composites.

The square triangular and spherical shapes of reinforcement are recognized, however the dimensions of all their sides are considered roughly equal.

The size and volume concentration make it different from the dispersion hardened material.

LAMINAR COMPOSITES

Laminar composites are found as the number of materials in many combinations, they can be described as materials in which layers of material are bound together.

These may consist of several layers of two or more metal materials alternately or in a prescribed order, as many numbers are necessary for a specific purpose.

FIBRE REINFORCED COMPONENT

Fibers are essential for reinforcement, as they meet specified conditions and transfer strength to affect the matrix element and improve their properties as desired.

APPLICATION OF COMPOSITE MATERIALS

FRP IN TRAINS

Composite materials are progressively used in the railway industry, saving up to 50% for structural and 75% for non-structural applications at high speeds, low power consumption, low inertia & track wear and carrying more loads.

Now, increasingly components are made from GFRP, which additionally resists corrosion and has excellent performance.

ROAD BRIDGE:

The fibre-line bridge was designed by the Danish engineering firm, Ramboll utilizing prevailing profiles.

The 40-meter (131-ft) long, 3-meter (9.8-ft) wide crossings of pedestrians, bicycles and motorbikes that run on an already dangerous set of rail tracks.

FRP DOORS AND WINDOW FRAMES:

Doors made of FRP skins are sandwiched with core materials such as flexible polyurethane foam, expanded polystyrene, paper honeycomb.

Jute/coir felt and many others might have potential use in residential buildings, offices, schools, hospitals, laboratories and many others.

ADVANTAGES OF COMPOSITE MATERIALS

1. They are light in weight and have low density.
2. It has high creep resistance.
3. Strength-to-weight and stiffness-to-weight are greater than in steel or aluminum.
4. Fatigue properties are higher than normal engineering metals.
5. Composites cannot corrode like steel.
6. Ease of fabrication of large advanced structural shapes or modular-modular constructions.
7. The ability to include sensors into the fabric to monitor its performance-smart composites.
8. It has excessive resistance to impression damage.
9. Also, enhance corrosion resistance.

DISADVANTAGES OF COMPOSITE MATERIALS

1. It has an excessive price for raw materials and manufacture.
2. Composites are extra brittle than wrought metals, thus they get additionally damaged.

3. The transverse properties are also weak.
4. The matrix is weak, so there is very little toughness.
5. Reuse and disposal of composite material will be difficult.
6. It is difficult to attach.
7. Difficulty with analysis.
8. Costs may fluctuate.

CERAMICS

Ceramics, an ancient and versatile art form, have captivated human imagination and creativity for millennia. With roots dating back to prehistoric times, ceramics encompass a wide range of materials and techniques used in the creation of functional and decorative objects. From delicate porcelain to robust earthenware, ceramics offer a unique blend of durability, aesthetic beauty, and practicality. This art form has evolved across different cultures, leaving an indelible mark on human history and shaping the way we perceive and interact with the world around us.

The art of ceramics involves the manipulation and transformation of clay, a naturally occurring material abundant in the Earth’s crust. Clay possesses remarkable plasticity, allowing it to be shaped into various forms before undergoing a process of firing to achieve a durable, hardened state. The firing process involves subjecting the clay to high temperatures, which causes chemical and physical changes within the material, resulting in its characteristic strength and permanence. Additionally, ceramics can be embellished through techniques like glazing, which adds a decorative and protective layer to the surface, further enhancing the artistic and functional qualities of the finished piece. From pottery and tableware to sculpture and architectural elements, ceramics offer a diverse range of applications, making them an integral part of both artistic expression and everyday life.

TYPES OF CERAMICS

In the field of material science, ceramics can be broadly classified into several types based on their composition, structure, and properties. Here are some common **types of ceramics**:

OXIDE CERAMICS

Oxide ceramics are the most widely used type of ceramics and are composed of metallic and non-metallic elements. Examples include alumina (aluminum oxide), zirconia (zirconium dioxide), and magnesia (magnesium oxide). These ceramics exhibit excellent mechanical strength, high melting points, and good electrical and thermal insulation properties. They find applications in industries such as electronics, aerospace, and automotive.

CARBIDE CERAMICS

Carbide ceramics are composed of carbon and metallic elements, such as silicon carbide (SiC) and tungsten carbide (WC). They are known for their exceptional hardness, high melting points, and resistance to wear and corrosion. Carbide ceramics are widely used in cutting tools, abrasives, and industrial machinery components.

NITRIDE CERAMICS

Nitride ceramics, such as silicon nitride (Si_3N_4) and aluminum nitride (AlN), are composed of nitrogen and metallic elements. They possess excellent thermal conductivity, high strength, and resistance to chemical attack. Nitride ceramics find applications in heat sinks, electronic substrates, and components for high-temperature and high-stress environments.

SILICATE CERAMICS

Silicate ceramics are based on the silicate mineral structure and include materials like porcelain and earthenware. They are composed of silica (silicon dioxide) combined with other oxides such as alumina, magnesia, or calcium oxide. Silicate ceramics are known for their low cost, ease of processing, and good insulation properties. They are commonly used for tableware, tiles, and building materials.

GLASS CERAMICS

Glass ceramics, as the name suggests, exhibit properties of both glass and ceramics. They are formed by controlled crystallization of specific compositions of glass. Glass ceramics combine the transparency and amorphous nature of glass with the strength and thermal stability of ceramics. They are used in cookware, dental restorations, and aerospace applications.

APPLICATIONS OF CERAMICS

Ceramics have a wide range of applications across various industries due to their unique properties and versatility. Here are five common applications of ceramics:

1. **Electronics and Electrical Engineering:** Ceramics are extensively used in the electronics industry for their excellent electrical insulation properties. They are used in the production of capacitors, resistors, insulators, and substrates for electronic components. Ceramics such as alumina and zirconia are employed in circuit boards, spark plugs, and sensors due to their high thermal and electrical conductivity.
2. **Aerospace and Defense:** Ceramics play a crucial role in aerospace and defense applications where high strength, temperature resistance, and lightweight properties are essential. Ceramic composites, such as carbon-carbon and carbon-silicon carbide, are used in the manufacturing of aerospace components, including turbine blades, heat shields, and rocket nozzles, due to their ability to withstand extreme temperatures and provide superior performance.

3. **Biomedical and Dental:** Ceramics have found extensive use in the biomedical and dental fields due to their biocompatibility, inertness, and durability. Bioactive ceramics like hydroxyl-apatite are used as bone substitutes and coatings for dental implants. Dental crowns, bridges, and braces are often made from ceramic materials such as zirconia and porcelain due to their natural appearance and strength.
4. **Automotive Industry**: Ceramics have made significant advancements in the automotive industry. Ceramic materials are utilized in components like catalytic converters, brake systems, and engine parts due to their high-temperature resistance, low friction coefficient, and excellent wear resistance. Ceramic matrix composites (CMCs) are also being explored for lightweight and high-performance engine components.
5. **Architecture and Construction:** Ceramics have long been used in architectural applications due to their aesthetic appeal, durability, and resistance to environmental factors. Ceramic tiles are commonly used for flooring, walls, and roofs. Additionally, ceramic materials such as bricks and refractories find application in construction for their ability to withstand high temperatures, chemical corrosion, and mechanical stress.

ADVANTAGES OF CERAMICS

Ceramics offer a multitude of advantages that make them highly desirable materials, including exceptional strength, heat resistance, chemical resistance, electrical insulation, and aesthetic appeal, among others.

- **High Strength:** Ceramics exhibit exceptional strength, making them ideal for applications that require durability and resistance to wear and tear.
- **Hardness:** Ceramics are known for their hardness, which enables them to withstand harsh conditions and resist scratching and abrasion.
- **Heat Resistance:** Ceramics have excellent thermal stability and can withstand high temperatures without deforming or losing their structural integrity. This property makes them suitable for use in high-temperature environments such as furnaces and engines.
- **Chemical Resistance:** Ceramics are highly resistant to chemical corrosion, allowing them to be used in industries where exposure to harsh chemicals is common, such as the chemical processing and pharmaceutical industries.
- **Electrical Insulation:** Ceramics are excellent electrical insulators, meaning they do not conduct electricity. This property makes them ideal for applications in electrical and electronic components where insulation is crucial.
- **Low Thermal Expansion:** Ceramics have low coefficients of thermal expansion, meaning they expand and contract minimally with temperature changes. This property makes them resistant to thermal shock and allows for precise dimensional stability.

DISADVANTAGES OF CERAMICS

While ceramics offer numerous advantages, they also have some drawbacks, such as brittleness, difficulty in shaping complex designs, and a tendency to crack under sudden changes in temperature or stress.

- **Brittleness:** Ceramics are known for their high hardness, but this also makes them brittle. They are prone to cracking and breaking under stress or impact, which limits their use in applications that require durability and resistance to mechanical forces.
- **Limited ductility:** Unlike metals, ceramics have limited ductility, meaning they cannot be easily deformed or stretched without fracturing. This restricts their use in processes that require shaping or forming, making them less versatile in manufacturing applications.
- **High processing costs:** Ceramics often require specialized and energy-intensive processes for manufacturing, such as high-temperature firing or sintering. These processes can be costly, making ceramics less economically viable for certain applications compared to other materials.
- **Poor thermal shock resistance:** Ceramics have low thermal shock resistance, meaning they are prone to cracking or breaking when exposed to rapid temperature changes. This limits their use in applications that involve extreme temperature variations, such as aerospace components or cooking utensils.
- **Difficulty in machining**: Ceramics are extremely hard materials, which makes machining and shaping them a challenging task. Specialized tools and techniques are required, which can increase the cost and complexity of the manufacturing process.

THANK YOU