Engineering Material

3^{RD} SEM

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Chapter1

Engineering Materials and their properties

Classification of Metal:

The three main types of metals are ferrous, non-ferrous, and alloys. Ferrous metals contain iron, non-ferrous metals do not, and alloys are combinations of two or more metals.

Ferrous Metals:

These metals contain iron as a major component and are generally strong and magnetic. Examples include steel, cast iron, and wrought iron.

Non-Ferrous Metals:
These metals do not contain iron and are typically resistant to corrosion. Examples include aluminium, copper, and zinc.

Alloys:
These are combinations of two or more metals, or a metal and other elements. They are created to achieve specific properties not found in the individual constituent metals. Examples include stainless steel (an alloy of iron, chromium, and other elements) and brass (an alloy of copper and zinc

Properties of Material:
a) Mechanical Properties
b) Physical Properties
c) Chemical Properties

Mechanical Properties:

1. Strength

Definition: The ability of a material to withstand an applied force without failure or plastic deformation.

Types:

Tensile Strength: Resistance to being pulled apart.

Compressive Strength: Resistance to being pushed together.

Shear Strength: Resistance to sliding failure.

2. Elasticity

Definition: The ability of a material to return to its original shape after the removal of a deforming force.

Example: Rubber is highly elastic.

Measured By: Young’s Modulus (Modulus of Elasticity).

3. Plasticity

Definition: The ability of a material to undergo permanent deformation without rupture after the elastic limit is exceeded.

Application: Useful in metal forming processes like forging and rolling.

4. Ductility

Definition: The ability of a material to be drawn into a wire or stretched without breaking.

Measured By: Percentage elongation or reduction in area.

Example: Copper and aluminium are highly ductile.

5. Malleability

Definition: The ability of a material to deform under compressive stress, often into thin sheets.

Example: Gold and lead are highly malleable.

6. Brittleness

Definition: The tendency of a material to break or shatter without significant deformation.

Example: Glass and ceramics.

Opposite of: Ductility.

7. Stiffness

Definition: The resistance of a material to deformation under load.

Measured By: Young’s Modulus.

Note: A stiff material may not necessarily be strong (e.g., glass is stiff but brittle).

8. Hardness

Definition: The ability of a material to resist indentation, scratching, or wear.

Measured By: Mohs, Brinell, Rockwell, or Vickers scales.

Example: Diamond is the hardest known material.

9. Creep

Definition: The slow, time-dependent deformation of a material under constant stress, usually at high temperature.

Important In: Turbines, boilers, and engines.

10. Fatigue

Definition: The weakening or failure of a material due to repeated loading and unloading cycles.

Leads To: Cracks or sudden failure over time.

Common In: Rotating machinery, aircraft structures.

11. Resilience

Definition: The ability of a material to absorb energy when deformed elastically and release it upon unloading.

Measured By: Area under the stress-strain curve up to the elastic limit.

12. Toughness

Definition: The ability of a material to absorb energy and plastically deform without fracturing.

Measured By: Total area under the stress-strain curve.

Example: Steel is tough; glass is not.

13. Weldability

Definition: The ease with which a material can be welded without defects.

Depends On: Chemical composition, thermal properties, and mechanical properties.

Good Weldability: Low-carbon steel.

Poor Weldability: High-carbon steel and some aluminum alloys.

Physical Properties of Material:

Physical properties describe the observable and measurable characteristics of a material without changing its chemical composition. These properties determine how a material behaves under physical conditions.

1. Dimension: This refers to the size and shape of a material, including length, width, height, and thickness. It is important in manufacturing and fitting of components.

2. Appearance and Colour: These are visual characteristics. Appearance includes surface finish (shiny, dull, smooth), while colour helps in identifying and classifying materials, especially metals and polymers.

3. Density: Density is mass per unit volume ($\rho = m/V$). It influences the weight and strength-to-weight ratio of materials, crucial in construction and aerospace industries.

4. Melting Point: This is the temperature at which a material changes from solid to liquid. It indicates thermal stability and helps in material selection for high-temperature applications.

5. Porosity: It is the measure of void spaces within a material. High porosity can reduce strength and increase water absorption, while low porosity is preferred in structural applications.

6. Structure: Refers to the internal arrangement of atoms or grains. It can be crystalline (ordered) or amorphous (disordered), affecting mechanical properties like hardness and ductility.

Chemical Properties of Engineering Materials

Definition:

Chemical properties are the characteristics of a material that determine how it reacts with other substances. These properties influence the material's behaviour in various chemical environments.

Key Chemical Properties:

1. Corrosion Resistance:

Ability of a material to withstand degradation due to chemical or electrochemical reactions with its environment (e.g., stainless steel resists rust).

2. Oxidation Resistance:

Resistance to reaction with oxygen at elevated temperatures (e.g., nickel alloys used in high-temperature environments).

3. Acid and Alkali Resistance:

Ability to resist chemical attack from acids or bases (e.g., PTFE is highly resistant to most chemicals).

4. Toxicity:

Degree to which a material can release harmful substances under chemical reaction (important for biomedical and food-grade materials).

5. Flammability:

Tendency of a material to ignite and sustain combustion (e.g., polymers vary in flammability depending on their structure).

Performance Requirements:

Performance requirements can include factors like **load-bearing capacity, durability, corrosion resistance, and thermal stability**. These requirements help engineers select the right materials that will withstand the expected stresses and environmental conditions throughout the product's life.

These requirements include mechanical properties, thermal properties, chemical resistance, and processing characteristics, as well as considerations for cost, availability, and environmental impact.

Material Reliability:

Material reliability refers to a material's ability to consistently perform its intended function without failing or degrading over a specified period under given conditions.

Material Safety:

Material safety, on the other hand, focuses on preventing harm or damage to people or property due to the material's use, including factors like toxicity, flammability, and potential for hazardous reactions.

Chapter-2

Ferrous Materials and alloys

Characteristics of Ferrous Materials

1. High Strength: Ferrous metals, especially steels, have high tensile strength, making them suitable for load-bearing applications.

2. Magnetic Properties: Most ferrous metals are magnetic, particularly those with high iron content like pure iron and low-carbon steels**.**

3. Corrosion-Prone: They are generally more prone to rust and corrosion (especially plain carbon steel) unless alloyed or coated.

4. Ductility and Malleability: Some ferrous metals, like mild steel, are ductile and can be drawn into wires or hammered into thin sheets.

5. Conductivity: Ferrous materials have good electrical and thermal conductivity, though less than non-ferrous metals like copper or aluminium**.**

6. Density and Weight: Ferrous metals are relatively dense and heavy, which contributes to their strength but can be a disadvantage in weight-sensitive applications.

7. Hardness and Wear Resistance: Alloyed ferrous metals (like tool steels) can be extremely hard and wear-resistant, especially after heat treatment.

Application of Ferrous Materials:

1) Construction: Steel is a primary material for building structures, bridges, and infrastructure like pipelines.
2) Automotive: Ferrous metals are used in engine components, chassis, and other critical parts.
3) Manufacturing: They form the basis of various machinery, tools, and industrial equipment.
4) Everyday items: Ferrous materials are found in cutlery, cookware, and even furniture.
5) Electrical applications: The magnetic properties of iron make it suitable for motors, generators, and other electrical components

Low Carbon Steel: Also known as **mild steel**, low carbon steel has low strength relative to steel with higher carbon levels. Low carbon steel is the most ductile – or machinable – type of carbon steel as well.

Composition: Low-carbon steel, also known as mild steel, is primarily composed of iron and a relatively low percentage of carbon, typically ranging from 0.05% to 0.32% by weight.

Application of low carbon steel:

1. Construction: **Structural components:** Low-carbon steel is commonly used for beams, columns, and other load-bearing elements in buildings and bridges.
2. **Machinery and Equipment**: **Shafts and plungers:** Low-carbon steel is used in parts requiring wear resistance, like small shafts and plungers.

Medium Carbon Steel:

Medium carbon steels typically have a carbon content ranging from 0.30% to 0.60%. Common grades include AISI/SAE 1030-1055, as well as 4140. These steels are stronger than low-carbon steels and are often used in applications requiring a balance of strength, toughness, and wear resistance.

Application:

Thanks to their high strength, resistance to wear and overall toughness, medium carbon steels are typically used for **railway tracks, train wheels, crankshafts, and gears and machinery parts** where a combination of material properties is required.

High Carbon Steel:

High carbon steel is a type of steel characterized by a carbon content of 0.60% to 1.5%, offering high strength, hardness, and wear resistance. This makes it suitable for applications requiring these properties but also results in increased brittleness and reduced ductility compared to lower carbon steels.

Application:

Cutting Tools: Knives, chisels, saw blades, etc.
Springs: Because of its strength and ability to return to its original shape (memory), it's used for springs.
High-Strength Wires: Used in applications where high tensile strength is required.
Rails and Wheels: In railway tracks and wheels due to their hardness and wear resistance

1. Low Alloy Steel

Definition:

Low alloy steels contain a total alloy content of less than 5% to 8% (depending on the standard) of elements like chromium, nickel, molybdenum, vanadium, and others.

Characteristics:

Improved strength and hardness over carbon steel

Better toughness and wear resistance

Moderate corrosion resistance

Applications:

Pressure vessels, Pipelines, Construction machinery, automotive components

Examples of Alloying Elements:

Chromium (Cr), Molybdenum (Mo), Nickel (Ni), Vanadium (V)

2. High Alloy Steel

Definition: High alloy steels contain more than 8% total alloying elements, often significantly higher.

Characteristics:

Enhanced strength and hardness

High resistance to wear and corrosion

Good performance at high temperatures

Applications:

Aerospace and defence equipment

High-performance machine parts

Power plants and turbines

Example:
Stainless steel (often considered a high alloy steel due to its high chromium content)

3. Tool Steel

Definition:
Tool steels are highly alloyed steels designed for making tools, dies, and cutting instruments. They are known for hardness, wear resistance, and ability to retain shape at high temperatures.

Main Categories:

Water-hardening (W-type)

Cold-work (O, A, D types)

Hot-work (H-type)

High-speed (M and T types)

Key Properties:

Very hard and abrasion-resistant

Maintains sharpness

Good heat resistance (especially hot-work and high-speed tool steels)

Applications:

Cutting tools (drills, knives)

Dies and molds

Punching tools

4. Stainless Steel

Definition:
Stainless steels are iron-based alloys with at least 10.5% chromium by mass, which forms a protective chromium oxide layer that resists corrosion.

Main Types:

Austenitic (non-magnetic, high corrosion resistance)
e.g., 304, 316

Ferritic (magnetic, moderate corrosion resistance)
e.g., 430

Martensitic (magnetic, hardenable, lower corrosion resistance)
e.g., 410, 420

Duplex (mixed structure, high strength and corrosion resistance)
e.g., 2205

Applications:

Food processing equipment

Medical instruments

Chemical plants

Kitchenware

Construction and architecture

The effect of various alloying elements

1. Chromium (Cr)

Primary Effect: Increases corrosion and oxidation resistance.

Other Effects:

Improves hardenability and wear resistance.

Contributes to toughness.

Forms stable carbides (e.g., Cr_7C_3, $Cr_{23}C_6$), which increase hardness.

Applications: Essential in stainless steels (≥11% Cr), tool steels, and wear-resistant steels.

2. Manganese (Mn):

Primary Effect: Improves toughness and hardenability.

Other Effects:

Acts as a deoxidizer and desulfurizer during steelmaking.

Combines with sulphur to form MnS, which prevents hot-shortness.

Enhances tensile strength.

Applications: Structural steels, Hadfield steel (~12% Mn) for high impact resistance.

3. Nickel (Ni):

Primary Effect: Enhances toughness and impact strength, especially at low temperatures.

Other Effects:

Improves corrosion resistance.

Refines grain structure.

Increases strength without reducing ductility.

Applications: Austenitic stainless steels (e.g., 304, 316), cryogenic steels, marine applications.

4. Vanadium (V):

Primary Effect: Enhances strength and wear resistance.

Other Effects:

Refines grain size (leading to better mechanical properties).

Forms vanadium carbides/nitrides (VC, VN) which are stable and hard.

Increases resistance to tempering (secondary hardening).

Applications: High-speed tool steels, HSLA steels, spring steels.

5. Molybdenum (Mo) :

Primary Effect: Improves high-temperature strength and creep resistance.

Other Effects:

Enhances hardenability.

Increases resistance to pitting and crevice corrosion.

Improves toughness and wear resistance.

Applications: Creep-resistant steels, stainless steels (like 316), tool steels.

Chapter -3
Iron Carbon System

Concept of Phase Diagram and cooling curves

Phase Diagram: A phase diagram is a graphical representation showing the phases of a substance as a function of temperature and pressure (or composition, in alloys).

Key Features of a Phase Diagram (for a Pure Substance):

Triple Point: The point where solid, liquid, and gas phases coexist in equilibrium.

Critical Point: The end of the liquid-gas boundary; above this point, the substance is a supercritical fluid.

Phase Boundaries:

Solid-Liquid: Melting/freezing line

Liquid-Gas: Boiling/condensation line

Solid-Gas: Sublimation/deposition line

Example: Water Phase Diagram

```
Pressure ↑
  |
  |      /
  |     /  (Solid)
  |    /
  |----●--------- (Liquid)
  |   /        \
  |  /          \
  | /            \  (Gas)
  -------------------------→ Temperature
```

The solid line divides phases; crossing it means a phase change.

2. Cooling Curve

A cooling curve is a plot of temperature vs. time as a substance cools, showing how temperature changes during phase transitions.

Key Features of a Cooling Curve:

Sloped Lines: Represent cooling within a single phase (e.g., cooling a liquid).

Plateaus (Flat Regions): Indicate phase changes, where temperature remains constant despite heat loss.

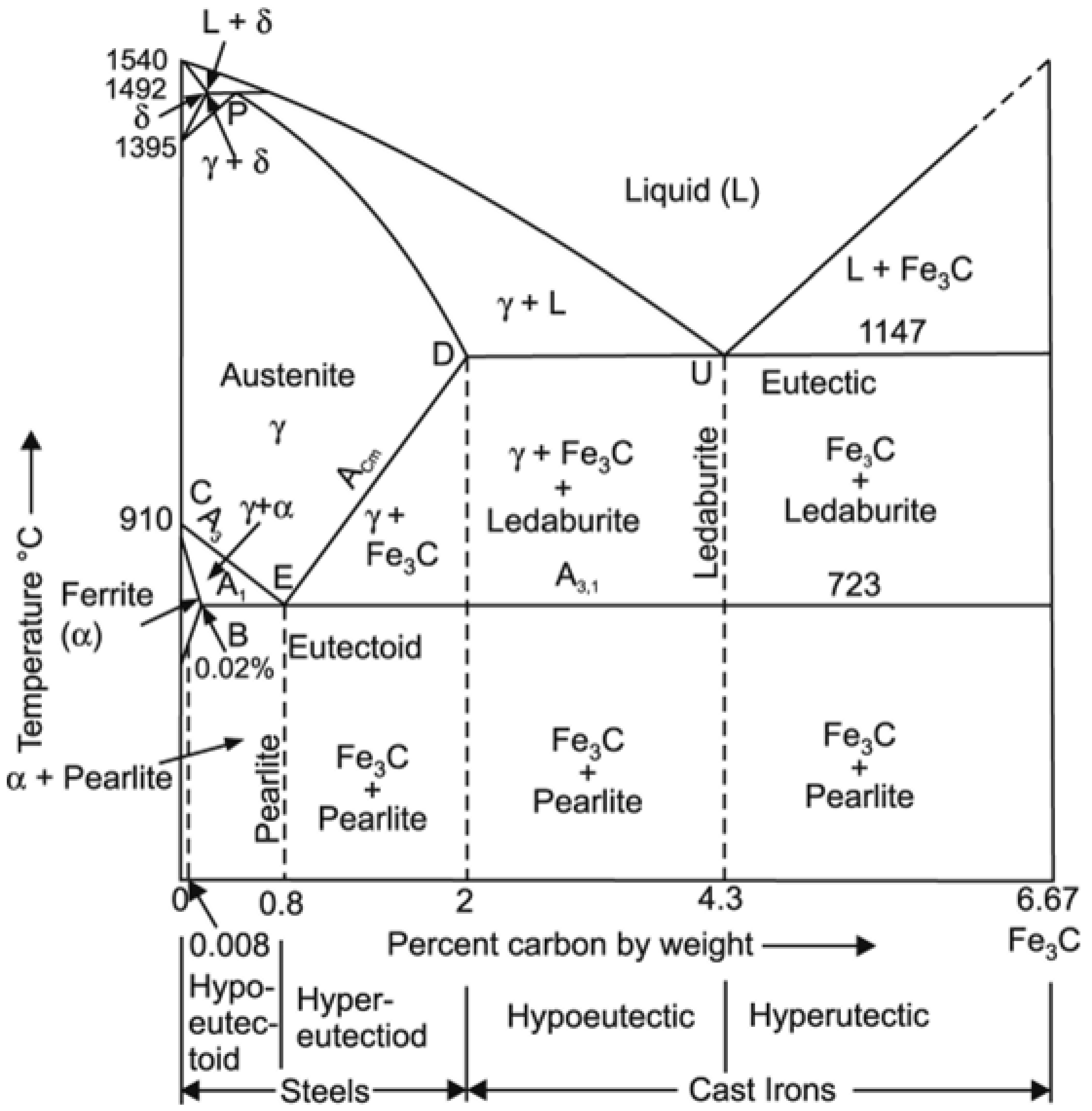
Example: During freezing, energy is used to change phase, not lower temperature.

Example: Cooling Curve for a Pure Substance

```
Temperature ↑
    |
    |      *
    |     * \
    |    *  \   (Liquid)
    |   *    \
    |  *      *___ (Freezing Plateau)
    | *            *
    |*              * (Solid)
    ---------------------------→ Time
```

Supercooling: Sometimes temperature dips below freezing point before solidification starts.

Iron- Carbon Diagram with salient Micro constituents of Iron and Steel



Iron-Carbon Phase Diagram (Detailed Explanation)

The Iron-Carbon Phase Diagram represents the equilibrium phases of mixtures of iron (Fe) and carbon (C) at various temperatures and carbon compositions, up to 6.67% carbon by weight (which corresponds to iron carbide, Fe_3C).

1. Critical Points and Lines:

Eutectoid Point (A_1): At 0.8% C and 723°C, austenite (γ) transforms into pearlite (a lamellar structure of ferrite + cementite).

Eutectic Point: At 4.3% C and 1147°C, liquid transforms directly into a mixture of austenite and cementite (called ledeburite).

Peritectic Point (P): At about 0.18% C and 1495°C, δ-ferrite and liquid transform into austenite (γ).

2. Phases Present:

Ferrite (α): Nearly pure iron with very little carbon; exists below 910°C.

Austenite (γ): A solid solution of carbon in γ-iron; stable between 910°C and 1395°C.

Cementite (Fe_3C): Iron carbide, a hard and brittle compound.

Pearlite: A lamellar mixture of ferrite and cementite formed at eutectoid composition.

Ledeburite: Mixture of austenite and cementite formed during eutectic solidification.

3. Regions Based on Composition:

Hypoeutectoid Steels (0.02% – 0.8% C): Below eutectoid, contain proeutectoid ferrite + pearlite.

Eutectoid Steel (0.8% C): Entirely pearlite at room temperature.

Hypereutectoid Steels (0.8% – 2.0% C): Contain proeutectoid cementite + pearlite.

Cast Irons (2.0% – 6.67% C): Contain austenite, cementite, and/or ledeburite depending on carbon content and temperature.

4. Transformations:

On cooling, different transformations occur (e.g., $\gamma \rightarrow \alpha + Fe_3C$).

Alloys with carbon > 2.1% are cast irons; < 2.1% are steels.

5. Uses:

This diagram helps engineers determine the microstructure, hardness, ductility, and heat treatment routes for steel and cast iron components.

Chapter -4

Crystal Imperfections

Crystal: A *crystal* or crystalline solid is a solid material whose constituents (such as atoms, molecules, or ions) are arranged in a highly ordered microscopic structure.

Classification of Crystal:

Crystal Systems:

Cubic (Isometric): Characterized by three equal axes at right angles to each other.

Tetragonal: Has one four-fold axis of symmetry and two equal axes at right angles to it.

Hexagonal: Features one six-fold axis of symmetry and two axes at 120 degrees to each other.
Trigonal: Has one three-fold axis of symmetry and two axes at 120 degrees to each other.
Orthorhombic: Has three unequal axes at right angles to each other.
Monoclinic: Has three unequal axes, with two at right angles and one at an oblique angle.
Triclinic: Has three unequal axes at oblique angles to each other

Ideal Crystal:

An ideal crystal is defined as a crystal that is perfect in structure and does not contain any defects or imperfections. In other words, it has a perfectly ordered arrangement of atoms, ions, or molecules throughout its entire structure.

Crystal Imperfection:

In engineering materials, crystal imperfections, or defects, are deviations from the perfect, repeating arrangement of atoms in a crystal structure. These imperfections significantly influence material properties like strength, ductility, and electrical conductivity. They are broadly classified into point, line, surface, and volume defects.

Point Defects:

- **Vacancies:** Missing atoms from their regular lattice sites.
- **Interstitial atoms:** Extra atoms occupying spaces between lattice sites.
- **Substitutional impurities:** Foreign atoms replacing host atoms.
- **Frenkel defects:** A cation vacancy paired with an interstitial cation.
- **Schottky defects:** Pairs of cation and anion vacancies.

Line Defects:

Dislocations: One-dimensional defects where atoms are misaligned along a line. They are crucial for plastic deformation (e.g., ductility) in metals.

Edge dislocations: Involve an incomplete extra plane of atoms.

Screw dislocations: Involve a shear distortion of the lattice.

Surface Defects:

- **Grain boundaries:** Interfaces between crystals with different orientations.
- **Twin boundaries:** Mirror-image relationships between crystal regions.
- **External surfaces:** The outer boundary of a crystal.

Volume Defects:

- **Cracks:** Openings or fractures within the material.
- **Voids:** Empty spaces or pores within the material.

Types and Causes of Point defect:

1. Vacancies

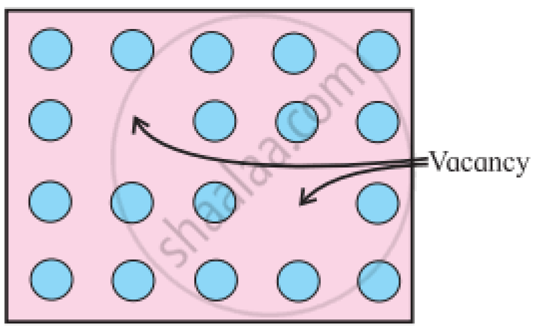
Definition: A vacancy occurs when an atom is missing from one of the lattice sites where it would normally be found.

Causes:

Thermal excitation: At high temperatures, atoms gain enough energy to leave their lattice sites.

Irradiation: High-energy particles (like neutrons or ions) can knock atoms out of place.

Quenching: Rapid cooling from high temperatures can "freeze in" vacancies before they are eliminated.



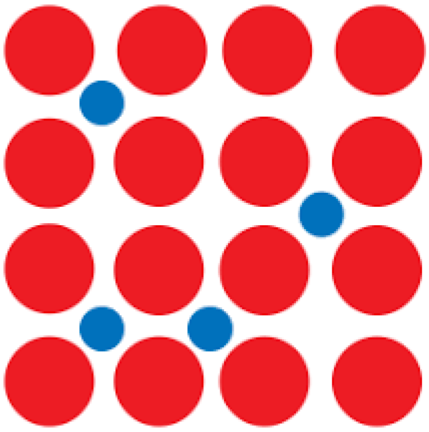
2. Interstitial Defects

Definition: An interstitial defect occurs when an extra atom occupies a space between the regular lattice sites (interstitial site).

Causes: Atomic size difference: Smaller atoms (like hydrogen, carbon, nitrogen) can fit into the interstitial spaces of a metal lattice.

Irradiation: Can force atoms into interstitial positions.

High concentrations of atoms: When the number of atoms exceeds available lattice sites, some occupy interstitial positions.



3. Impurity Defects

These are caused by the presence of foreign atoms in the crystal lattice.

Types:

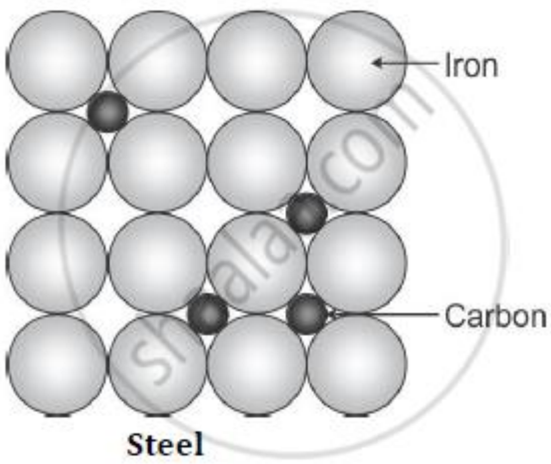
Substitutional impurity: A foreign atom replaces a host atom at a lattice site.

Interstitial impurity: A foreign atom occupies an interstitial position.

Causes: Doping (intentional): In semiconductors, small amounts of impurities are deliberately added to alter electrical properties.

Contamination (unintentional): During processing, foreign atoms can be introduced.

Solid solution formation: Alloys form when atoms of different elements mix and occupy lattice or interstitial sites.



Types and Causes of Line defect:

There are two main types of line defects:

1. Edge Dislocation

Description:

An edge dislocation occurs when an extra half-plane of atoms is inserted into a crystal structure. The dislocation line runs along the edge of this half-plane.

Characteristics:

The Burgers vector (a vector that represents the magnitude and direction of lattice distortion) is perpendicular to the dislocation line.

Causes distortion in the lattice near the extra half-plane.

Causes: Plastic deformation (slip during shearing)

Crystal growth errors

Internal stresses during solidification or phase transformation

2. Screw Dislocation

Description: A screw dislocation results from a shear distortion, where part of the crystal is shifted relative to another part along a helical path around the dislocation line.

Characteristics: The Burgers vector is parallel to the dislocation line.

Atoms spiral around the dislocation line, like threads on a screw.

Visualization:

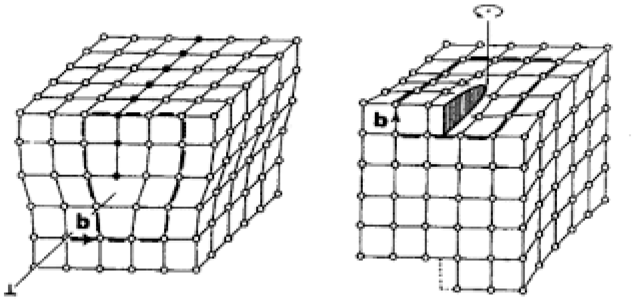
Imagine cutting a crystal along a plane, shearing it by one atomic spacing, and reattaching it.

Causes:

Shear stress during deformation

Growth imperfections

Mechanical loading during processing



Effects of Imperfections on Material Properties

1. Mechanical Strength & Hardness

Dislocations (line defects) hinder other dislocations from moving—this "dislocation hardening" increases yield and tensile strength, but reduces ductility.

Grain boundaries (planar defects) act as barriers to slip too—refining grains boosts strength (Hall–Petch effect), though excessive grain boundaries may reduce ductility.

2. Ductility & Toughness

High concentrations of vacancies or interstitials (point defects) can create stress concentrators or voids, lowering toughness and promoting brittle fracture.

On the positive side, controlled micro-imperfections in architected structures can enhance fracture resistance by deflecting cracks.

3. Electrical & Thermal Properties

Impurity atoms disrupt electron flow and scatter phonons, reducing conductivity—used intentionally in doping semiconductors.

Vacancies and dislocations serve as scattering centres, increasing electrical resistivity.

4. Diffusion and Creep Behaviour

Vacancies, interstitials, grain boundaries enhance atomic mobility: higher diffusion rates at elevated temperatures, accelerating creep or sintering processes.

5. Chemical Reactivity & Corrosion

Grain boundaries and surface defects are highly reactive, often becoming sites for corrosion or precipitate formation.

Segregation of impurities at boundaries can weaken interfaces, leading to intergranular corrosion or embrittlement.

Deformation by Slip and Twinning:

1. Deformation by Slip

Slip is the most common mechanism of plastic deformation in crystalline materials.

What is Slip?

Slip occurs when dislocations (line defects in the crystal lattice) move along specific crystallographic planes and directions, known as slip systems.

Characteristics:

Crystallographic in nature: occurs on planes of highest atomic density (e.g., {111} in FCC metals).

Involves shear deformation.

Produces permanent shape change without breaking the crystal structure.

Example:

In face-centred cubic (FCC) metals like copper and aluminium, slip is easy due to multiple slip systems, making them highly ductile.

2. Deformation by Twinning

Twinning is a less common mode of plastic deformation, typically observed in materials where slip is limited.

What is twinning?

Twinning occurs when a portion of the crystal takes up an orientation that is a mirror image of the original structure across a specific plane called the twin plane.

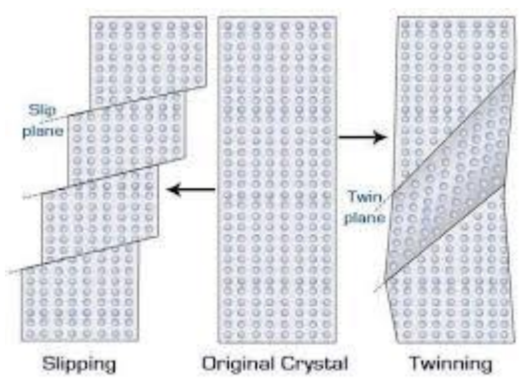
Characteristics:

Produces a reoriented region within the crystal.

Less shear than slip but still leads to deformation.

Often occurs in hexagonal close-packed (HCP) metals or at low temperatures or high strain rates.

Example: In magnesium (an HCP metal), twinning is a dominant deformation mode due to the limited number of slip systems.



Effect of Deformation on material Properties:

1. Mechanical Properties

a. Strength

Yield Strength Increases (Strain Hardening): Plastic deformation, especially in metals, increases dislocation density, which hinders further movement of dislocations. This phenomenon is known as work hardening or strain hardening.

Ultimate Tensile Strength may also increase initially but can decrease after excessive deformation due to damage accumulation.

b. Ductility

Decreases with plastic deformation. As dislocations accumulate and material becomes harder, it loses the ability to deform further without breaking.

c. Toughness

Generally decreases with deformation, especially if the material becomes brittle after strain hardening or experiences micro cracking.

d. Hardness

Increases due to strain hardening; the resistance to indentation or penetration improves after plastic deformation.

2. Thermal Properties

Thermal Conductivity may decrease due to increased defect density (e.g., dislocations, voids), which scatter phonons.

Specific Heat is typically less affected, but localized phase changes due to deformation (e.g., martensitic transformation) may alter it.

Thermal Expansion can change in anisotropic materials due to texture development during deformation.

3. Electrical Properties

In metals, deformation increases resistivity due to more dislocation scattering of conduction electrons.

In semiconductors or piezoelectric materials, deformation can cause significant changes due to band structure distortion (piezoelectric/piezo resistive effects).

4. Magnetic Properties

In ferromagnetic materials, deformation can alter domain wall movement, thus changing coercivity and magnetic permeability.

Magnetostriction may occur (change in shape due to magnetization and vice versa).

5. Microstructural Changes

Grain Refinement: Severe plastic deformation can lead to finer grains, improving strength (Hall-Petch relationship).

Texture Development: Preferred grain orientations develop, leading to anisotropic behaviour.

Phase Transformation: In some alloys (e.g., steels), deformation can induce phase transformations (e.g., austenite to martensite).

6. Fatigue and Fracture Behaviour

Fatigue Resistance: Can decrease due to micro crack initiation sites formed during deformation.

Fracture Toughness: May decrease as the material becomes more brittle due to work hardening or phase changes.

Chapter- 5

Heat Treatment

Purpose of Heat Treatment

1. Increase Hardness:
Heat treatment can significantly increase the hardness of a metal, making it more resistant to scratching, wear, and indentation.
2. Improve Strength:
By altering the internal structure, heat treatment can enhance the tensile strength, yield strength, and overall load-bearing capacity of a metal.
3. Enhance Ductility:
Certain heat treatment processes, like annealing, can increase a metal's ductility, making it more pliable and less prone to cracking or breaking under stress.
4. Increase Toughness:
Heat treatment can also improve a metal's toughness, which is its ability to absorb energy and resist fracture, particularly under impact or shock loading.
Relieve Internal Stresses:
Internal stresses can develop in metals due to manufacturing processes like casting, welding, or machining. Heat treatment can help relieve these stresses, preventing future cracking or distortion.
6. Refine Grain Size:
Heat treatment can control the size and shape of the grains within a metal's microstructure. Smaller, more uniform grains generally lead to improved mechanical properties.
7. Improve Machinability:
By softening the metal, heat treatment can make it easier to machine, cut, or shape, improving manufacturing efficiency.
8. Enhance Wear Resistance:
Heat treatment can make metals more resistant to wear and abrasion, particularly in applications where surfaces are subjected to friction or rubbing.
9. Improve Corrosion Resistance:
In some cases, heat treatment can be used to improve a metal's resistance to corrosion, especially when combined with other treatments like surface coatings.

Process of Heat Treatment:

1. Annealing

Purpose:

To soften the metal

Improve ductility

Refine grain structure

Relieve internal stresses

Process:

Heating the metal to a specific temperature (usually below the melting point)

Holding it at that temperature for a certain time

Slow cooling, usually in a furnace

Application:

Cold-worked metals (like copper, steel)

Improves machinability and electrical conductivity

2. Normalizing

Purpose:

To make the structure uniform

Refine grain size

Increase strength and toughness

Reduce residual stresses

Process:

Heating the metal above its critical temperature

Holding it for a specific time

Air cooling (faster than annealing)

Application:

Carbon steels, castings, and forgings

Prepares steel for further hardening or machining

3. Hardening

Purpose:

To increase hardness and strength

Improve wear resistance

Process:

Heating the metal (especially steel) above critical temperature

Rapid cooling (quenching) in water, oil, or air

Result:

Formation of hard microstructures like martensite

Application:

Cutting tools, dies, machine parts

4. Tempering

Purpose:

Reduce brittleness after hardening

Increase toughness

Adjust hardness level

Process:

Reheating the hardened metal to a lower temperature (below critical)

Holding for a time

Cooling (often in air)

Application:

Follows the hardening process

Used for tools, springs, and structural parts

5. Stress Relieving

Purpose:

To reduce residual internal stresses caused by machining, welding, or cold working

Improve dimensional stability

Process:

Heating the metal to a moderate temperature (below transformation range)

Holding and then slow cooling

Application:

Welded structures, castings, and large machined parts

Prevents warping and cracking

Surface Hardening

1. Carburizing

Definition:
Carburizing is a heat treatment process in which carbon is diffused into the surface layer of low-carbon steel at high temperatures (usually between 900°C and 950°C) to increase surface hardness.

Process:

The steel part is heated in a carbon-rich atmosphere (gas, liquid, or solid).

Carbon atoms diffuse into the surface.

After carburizing, the part is typically quenched to form a hard martensitic layer on the surface.

Result:

Hard, wear-resistant surface with a tough, ductile core.

Depth of hardness depends on time and temperature.

Applications:

Gears, Crankshafts, Camshafts, Bearing surfaces

2. Nitriding

Definition:

Nitriding is a surface hardening process in which nitrogen is diffused into the surface of steel at lower temperatures (typically 500–550°C) to form hard nitrides.

Process:

The steel part is exposed to a nitrogen-rich atmosphere (ammonia gas or plasma).

Nitrogen reacts with alloying elements (like Al, Cr, Mo) to form nitrides.

No quenching is needed, minimizing distortion.

Result:

Very hard, wear- and corrosion-resistant surface.

Excellent fatigue resistance.

Case depth is shallower than carburizing but with better precision.

Applications:

Dies and moulds, Valves, Engine components, Aerospace parts

Effect of Heat Treatment on Properties of Steel

Heat treatment significantly alters the mechanical and structural properties of steel. The major effects include:

1. Increased Hardness: Processes like quenching increase hardness by forming martensite, a hard microstructure.

2. Improved Toughness: Tempering after hardening reduces brittleness and increases toughness.

3. Enhanced Ductility: Annealing softens steel, improving ductility and machinability.

4. Refined Grain Structure: Normalizing produces a uniform grain structure, enhancing mechanical strength.

5. Stress Relief: Heat treatment relieves internal stresses caused by welding or machining, preventing deformation and cracking.

Hardenability of Steel:

Definition: Hardenability is not the same as hardness. Hardness is a measure of how hard the steel is after treatment.
Hardenability tells how deep the hardness extends from the surface toward the core after quenching.

2. Importance:

Determines the ability to form martensite throughout the section.

Crucial for selecting steel for components with different sizes and shapes—e.g., shafts, gears, and large forgings.

Helps avoid soft cores or undesired microstructures in thicker parts.

3. Factors Affecting Hardenability:

Chemical Composition:

Carbon increases maximum hardness.

Alloying Elements (Cr, Mn, Mo, Ni, etc.) improve hardenability by slowing down pearlite/bainite formation.

Grain Size:
Larger austenite grains increase hardenability (reduce nucleation sites for pearlite).

Austenitizing Temperature and Time:

Must be optimized to dissolve carbides and form uniform austenite.

4. Measurement of Hardenability:

A. Jominy End-Quench Test:

A standard-size steel sample is heated and quenched at one end with water.

Hardness is measured at specific intervals from the quenched end.

A Jominy curve is plotted: hardness vs. distance from quenched end.

Chapter-6
Non Ferrous Alloys

Aluminium alloys:

Aluminium alloys are broadly classified into:

1. Wrought Alloys – worked into shapes by rolling, extrusion, forging.

2. Cast Alloys – shaped by pouring into molds.

They are usually alloyed with elements like copper, magnesium, manganese, silicon, and zinc to improve strength, corrosion resistance, and machinability.

1. Duralumin

Composition (Typical % by weight)

Aluminium (Al): ~90–95%

Copper (Cu): ~3.5–5%

Magnesium (Mg): ~0.4–1%

Manganese (Mn): ~0.4–1%

Properties

High strength-to-weight ratio

Good machinability

Moderate corrosion resistance (improves with coating)

Age hardenable (strength increases over time after heat treatment)

Uses

Aerospace structures (aircraft frames, fuselage, wings)

Automotive components

Structural parts in engineering

Rivets and fasteners

2. Y-Alloy (Also known as Nickel-Aluminium Alloy)

Composition (Typical % by weight)

Aluminium (Al): ~92%

Copper (Cu): ~4%

Nickel (Ni): ~2%

Magnesium (Mg): ~1.5%

Properties

High strength at elevated temperatures

Good thermal stability

Better creep resistance than Duralumin

Corrosion resistance slightly better than Duralumin

Retains strength up to ~150–200°C

Uses

Aircraft engine components (pistons, cylinder heads)

Automotive engine parts

Turbochargers

Marine applications where strength and temperature resistance are critical

Copper Alloys

1. Copper-Aluminium (Aluminium Bronze)

Composition:

Copper: 85–90%

Aluminium: 5–12%

May contain iron, nickel, manganese, or silicon in small amounts

Properties:

High strength and corrosion resistance

Good wear and fatigue resistance

Non-sparking and non-magnetic

Excellent resistance to marine and chemical environments

Uses:

Marine hardware (propellers, pumps, valves)

Aircraft components

Bushings and bearings

Tools used in explosive environments

2. Copper-Tin (Tin Bronze)

Composition:

Copper: 80–95%

Tin: 5–20%

May include small amounts of phosphorus or zinc

Properties:

High strength and hardness

Good corrosion resistance, especially in seawater

Excellent wear resistance

Good machinability

Uses:

Bearings and bushings, Gears and worm drives, Marine fittings, Sculpture and coins

3. Babbitt Metal (White Metal)

Composition:

Typically tin-based or lead-based with additions of antimony and copper

Tin: 80–90%

Antimony: 5–10%

Copper: 3–5%

Properties:

Excellent anti-friction properties

Good conformability and embeddability

Low wear and high fatigue resistance

Uses:

Bearing linings (especially in internal combustion engines)

High-speed machinery bearings

Applications where lubrication is difficult

4. Phosphor Bronze (Copper-Tin-Phosphorus)

Composition:

Copper: 88–95%

Tin: 4–10%

Phosphorus: 0.01–0.5%

Properties:

Increased strength and wear resistance compared to plain tin bronze

High fatigue resistance

Excellent spring qualities

Good corrosion resistance

Uses:

Springs and fasteners

Electrical connectors and terminals

Bearings and bushings

Musical instruments

5. Brass (Copper-Zinc)

Composition:

Copper: 60–70%

Zinc: 30–40%

May contain small amounts of lead, tin, or iron

Properties:

Good corrosion resistance

Excellent machinability (especially leaded brass)

Attractive golden appearance

Good thermal and electrical conductivity

Uses:

Plumbing fittings and valves, Musical instruments, Decorative items and jewelry, Radiators and heat exchangers

6. Copper-Nickel (Cupronickel)

Composition:

Copper: 60–90%

Nickel: 10–40%

May contain iron and manganese for added strength

Properties:

Excellent corrosion resistance, especially in seawater

High thermal stability

Antibacterial and biofouling resistance

Good strength and ductility

Uses:

Marine components (hull cladding, heat exchangers, and condensers)

Coinage (e.g., modern coins)

Desalination plants

Offshore oil and gas equipment

Predominating elements of Lead Alloys, Zinc Alloys, and Nickel Alloys

1. Lead Alloys (Pb Alloys)

Lead alloys are primarily made of lead (Pb) with other elements added to improve mechanical properties, corrosion resistance, or machinability.

Common Predominating Elements:

Antimony (Sb) – Improves hardness and strength (e.g., in battery grids).

Tin (Sn) – Increases corrosion resistance and castability (used in solder alloys).

Calcium (Ca) – Used with tin or lead in batteries to improve mechanical strength and reduce gassing.

Silver (Ag) – Enhances corrosion resistance in some high-performance lead-based solders.

Copper (Cu) – Sometimes added to improve strength and wear resistance.

2. Zinc Alloys (Zn Alloys)

Zinc alloys are widely used in die casting and galvanizing. Zinc is the base, with several elements added to enhance strength and performance.

Common Predominating Elements:

Aluminium (Al) – Most common alloying element; improves strength and hardness.

Copper (Cu) – Increases strength, hardness, and wear resistance.

Magnesium (Mg) – Improves corrosion resistance and reduces grain growth.

Tin (Sn) – Occasionally used for improved corrosion resistance.

Lead (Pb) – In some older or low-cost alloys, for improving machinability (though largely phased out due to toxicity concerns).

3. Nickel Alloys (Ni Alloys)

Nickel alloys are known for their excellent corrosion, heat, and wear resistance. Nickel is the base element, with alloying elements depending on the specific use.

Common Predominating Elements:

Chromium (Cr) – Enhances corrosion and oxidation resistance.

Iron (Fe) – Present in many structural nickel alloys (e.g.Ni-Fe alloys).

Molybdenum (Mo) – Improves strength and corrosion resistance in reducing environments.

Copper (Cu) – Increases resistance to certain types of chemical corrosion (e.g., Monel).

Titanium (Ti) and Aluminium (Al) – Improve strength, especially in super alloys (e.g., Inconel).

Cobalt (Co) – Sometimes used for high-temperature strength.

Chapter -7

Bearing Material

Introduction:

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. This friction and welding is most common when like metals, such as steel or cast iron, are used as bearings – they easily weld together. Compatibility of bearing materials, therefore, and absorption of lubricant upon the bearing surface, is necessary to reduce metallic contact and extend bearing life.

Babbitt: White metal was originally a term used to describe any of several tin, lead, and antimony alloys used for babbitt bearings. Now frequently used to refer to any cast aluminum, zinc, and magnesium alloys.

babbitt metal, any of several tin- or lead-based alloys used as bearing material for axles and crankshafts

Classification of Bearing Material

1. Tin Based Babbitt
2. Lead based Babbitt
3. Cadmium Based Bearing Material
4. Copper based Bearing Material

Composition & uses of different type of bearing material.

1. Copper-Based Bearing Materials

Composition:

Copper (Cu): 70–90%

Tin (Sn): 2–10% (as bronze)

Lead (Pb): 2–15% (for lubricity)

Zinc (Zn): Small amounts (up to 5%)

Nickel or Iron: Occasionally added for strength

Usage:

High-load, high-speed applications

Automotive engines, gearboxes

Industrial pumps and compressors

2. Tin-Based Bearing Materials (Babbitt Alloys)

Composition:

Tin (Sn): 80–90%

Antimony (Sb): 4–12%

Copper (Cu): 3–7%

Lead (Pb): ≤ 10% (optional)

Usage:

Light-to-medium duty applications

Steam turbines, electric motors, railways

Journal bearings, marine engines

3. Lead-Based Bearing Materials

Composition:

Lead (Pb): 60–90%

Antimony (Sb): 10–15%

Tin (Sn): 5–10%

Copper (Cu): Trace amounts

Usage:

Low-speed, low-load applications

Compressors, industrial machinery, older automotive engines

4. Cadmium-Based Bearing Materials

Composition:

Cadmium (Cd): 80–90%

Silver (Ag): 5–15%

Copper (Cu): Trace amounts

Usage:

Aircraft engines (historical use)

High-speed, high-load applications (before environmental restrictions)

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 friction 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.

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Chapter-8

Spring Materials

Engineering springs are mechanical devices that exhibit elastic properties, allowing them to deform under applied force and return to their original shape when the force is removed.

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.

a) 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.

b) 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)Nickle Silver(Cu56,Ni18,Zn18):Electrical relays.
iii)Pb Bronze (Cu92,Sn8,Pb 0.1):Bushes.
Iv) Beryllium Copper (Cu98,Be2.0):Relays and Bushes

c) 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.
i)Monels(Ni68,Cu27 &remaining Fe and Mn
ii)Inconels(Ni76,Cr16&Fe8)
iii)Chromels(Ni80,Cr20)
iv)Nichrome (Ni60,Cr16 &Fe24)
v)Elinver (Ni36,Cr12 &restFe)
vi)Inver (Ni35,Fe65)

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 any of a class of natural or synthetic substances composed of very large molecules, called macromolecules, which are multiples of simpler chemical units called monomers. Polymers make up many of the materials in living organisms and are the basis of many minerals and man-made materials.

There are 3 principal classes of polymers – **thermoplastics, thermosets, and elastomers**.

Thermosetting polymer: This means that thermosets will not melt even when exposed to extremely high temperatures. Common examples of thermoset plastics and polymers include **epoxy, silicone, polyurethane and phenolic**. In addition, some materials such as polyester can occur in both thermoplastic and thermoset versions.

Thermoplastics Polymers: Thermoplastics are linear or slightly chain polymers. Thermoplastics have the capability to soften on heating and hard on cooling. Examples for Thermoplastics are **Polythene, Polypropylene, Polystyrene, Polyvinyl chloride (PVC)**, etc.

Properties

The thermo setting plastics are soluble in alcohol and certain organic solvents when they are in thermo-plastic stage.

This property is utilised for making paints and varnishes from these plastics. These plastics are durable, strong and hard.

They are available in a variety of beautiful colours. They are mainly used in engineering application of plastics.

Properties of plastics

1. Appearance: Transparent
2. Chemical resistance: The plastics offer great resistance to moisture, chemicals and Solvents, excellent corrosion resistance.
3. Dimensional stability.
4. Ductility: The plastic lacks ductility. Hence its members may fail without warning.
5. Durability: The plastics are quite durable, if they possess sufficient surface hardness.
6. Electric insulation: They are far superior to ordinary electric insulators.
7. Finishing: Any surface treatment may be given to the plastics.
8. Fire resistance: All plastics are combustible.
9. Fixing: Can be easily fixed in position.
10. Humidity: PVC plastics offer great resistance to the moisture.
11. Maintenance: It is easy to maintain plastic surfaces. They do not require any protective Coat of paints.

Applications:

The typical use of plastics in building are as follows:

1. Bath and sink units.
2. Cistern ball floats.
3. Corrugated and plain sheets.
4. Decorative laminates and mouldings.
5. Electrical conduits.
6. Electrical insulators.
7. Floor tiles.
8. Foams for thermal insulation.
9. Joint less flooring.
10. Lighting fixtures.

Properties of Elastomers

These plastics are soft and elastic materials with a low modulus of elasticity. They deform Considerably under load at room temperature and return to their original shape, when the load is released. The extensions can range up to ten times their original dimensions.

Chapter-10
Compositions and Ceramics

Classification: The composite materials are shortened as composites. They are formed by combining two or more different materials to make better use of their virtues and by minimizing their deficiencies. Each material retains its physical or chemical properties separate and distinct within the finished product.

Composition: The composites are made from two main constituent materials. 1. Strong load carrying material known as reinforcement or reinforcing fibres. 2. Weaker material known as matrix.

Reinforcing fibres:
Following are the functions of reinforcing fibres:
(i)It provides strength and rigidity.
(ii) It helps to support structural load. There are three most common types of reinforcing fibres. (i) Glass fibres (ii) Carbon fibres
(iii) Aramid fibres Glass fibres are the heaviest having greatest flexibility and the lowest cost. Aramid has moderate stiffness and cost. Carbon is moderate to high in cost, slightly heavier than aramid but lighter than glass fibres. Carbon is the strongest.

2. Matrix:
Following are the functions of matrix.
i) It works as a binder
(ii) It maintains the position and orientation of the reinforcement.
(iii) It balances the loads between the reinforcement.
(iv) It protects the reinforcement degradation.
(v) It provides shape and form to the structure. The most common type of matrix is thermosetting resins. Epoxy resins are the most widely used thermo setting resins in advanced composites. Others resins used as matrix are polyester, vinyl ester, phenolic, bismaleimade, epoxy no volar.

Examples:
Composites natural Wood - Cellulose fibres plus polysaccharide.
Bones, teeth and mollusc shells = Hard ceramic + organic polymer
Manmade composites
1. Mud + straw
2. Bricks made up straw + mud
3. Plywood
4. Concrete, plastic, MMC, CMC

Classification and Uses of Ceramics
The term ceramics is used to indicate the potter’s art or articles made by the potter.
The ceramics are divided into the following three categories.

1. Clay products 2. Refractories 3. Glass

1) Clay products
The clay products which are used are tiles, terra-cotta, porcelain, bricks, stoneware’s & earth wares.
Tiles are of two types (1) Common tile (2) Encaustic tiles

Types of common tiles:

(i) Drain tiles (ii) Floor or paving tiles (iii) Roof tiles Types of roof tiles Allahabad tiles, Corrugated tiles, Flat tiles, Flemish tiles, Guna tiles, Mangalore tiles, pan tiles.

Refractories:
The term refractories is used to indicate substances that are able to resist high temperatures.
Classification
(i) According to chemical properties. (ii) According to resistance to temperature.

According to chemical properties
(a) Acidic (b) neutral and (c) Basic

(a) Acidic
Fire clay: It is used for the manufactured of fire bricks, crucibles, hollow tiles.
Quarizite- For making the silica bricks.
Silica- Coke over and lining for glass furnaces

(b) Neutral refractory materials

Bauxite- For tire bricks
Carbon- Lining material for furnaces
Chromite- Powerful neutral refractory material.
Forsterite- Used in furnaces for melting copper.

(c) Basic Refractory materials
Dolomite- For making refractory bricks.
Magnesia- Magnesia bricks.
According to resistance to temperature
(a) Low quality (b) High quality

High quality - Used in modern aeroplanes, rockets, jets etc. Molyblendum, tungsten, zirconium and their alloys are used as the refractory materials
Cement - Refractory material containing a combination of clay and metal.

Surface Preparation and Industrial Painting

Reasons of corrosion and surface wear.
The term corrosion is defined as an act or process of gradual wearing away of a metal due to chemical or electro-chemical reaction by its surroundings such that the metal is converted into an oxide.

The corrosion indicates the deterioration and loss of material due to chemical attack.

Following are the factors responsible for corrosion.

(i) Congested reinforcement in small concrete sections.
(ii) Excessive water-cement ratio.
(iii) Improper construction methods.
(iv) Inadequate design procedure
(v) Incompetent supervising staff or contractor.
(vi) Initially rusted reinforcement before placing concrete.
(vii) Insufficient cover to steel from the exposed concrete surfaces.
(viii) Presence of moisture in concrete.

(ix) Presence of salt.
(x) Unequal O_2 distribution over the steel surfaces

Factors influencing corrosion

(i) Blow holes, inclusions trapped gases. (ii) Chemical nature of the metals. (iii) Eddy electric currents. (iv) Presence of dust, dirt

Purpose of painting and methods of industrial pointing:

Purposes

(i) To protect the surface from weathering effects of the atmosphere and actions by other liquids, fames and gases.
(ii) To prevent decay of wood and corrosion in metal.
(iii) To give good appearance to the surface. The decorative effects may be created by painting and the surface becomes hygienically good, clear, colourful and attractive.
(iv) To provide a smooth surface for easy cleaning.

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