SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Mechanical Engineering

Material Science

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Material Science

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CHAPTER 01

Introduction

1.1 Classification of Engineering Materials

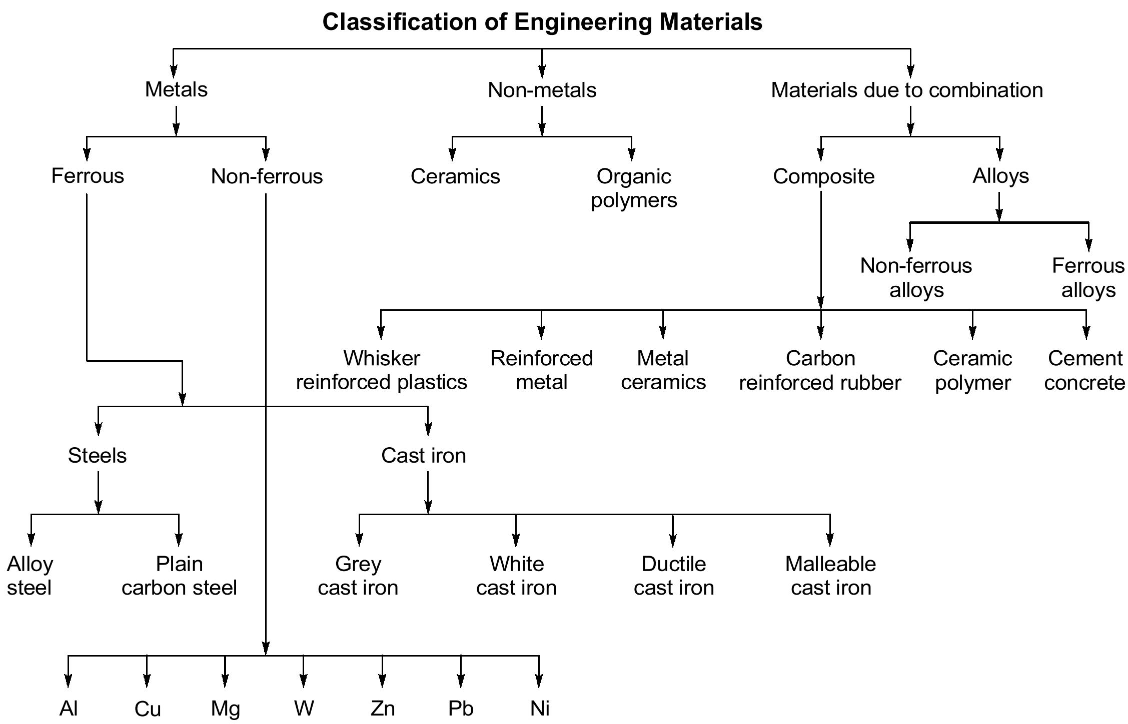


Figure 1.1

1.1.1 Materials Science

- It can be defined as science dealing with the relationships that exist between the structures and properties of materials, which are useful in practice of engineer's profession.

1.1.2 Properties of Materials

- All solid engineering materials are characterized for their properties.
- Engineering use of a material is reflection of its properties under conditions of use.
- All important properties can be grouped into six categories: Mechanical, Electrical, Thermal, Magnetic, Optical, and Decorative.

- Each material possess a structure, relevant properties, which dependent on processing and determines the performance.
- Normally material possessing strength have limited ductility. In such cases a reasonable compromise between two or more properties are important.
- A second selection consideration is any deterioration of material properties during service operations.
- Finally the overriding consideration is economics.

1.1.3 Classification of Materials

Three basic groups of solid engineering materials based on atomic bonds and structures are:

(i) Metals

(ii) Ceramics

(iii) Polymers (Organic Materials)

- Classification can also be done based on either properties (mechanical, electrical, optical), areas of applications (structures, machines, devices). Further we can subdivide these groups. According to the present engineering needs.
- Composites
- Semiconductors
- Biomaterials

(i) Metals

- Characteristics are owed to non-localized electrons (metallic bond between atoms) i.e. electrons are not bound to a particular atom.
- They are characterized by their high thermal and electrical conductivities.
- They are opaque, can be polished to high lustre. The opacity and reflectivity of a metal arise from the response of the unbound electrons to electromagnetic vibrations at light frequencies.
- Relatively heavier, strong, yet deformable.

Example —

▪ Steel ▪ Aluminium ▪ Brass ▪ Bronze ▪ Lead ▪ Titanium, etc.

(ii) Ceramics

- They contain both metallic and nonmetallic elements.
- Characterized by their higher resistance to high temperatures and harsh environments than metals and polymers.
- Typically good insulators to passage of both heat and electricity.
- Less dense than most metals and alloys.
- They are harder and stiffer, but brittle in nature.
- They are mostly oxides, nitrides, and carbides of metals.
- Wide range: traditional (clay, silicate glass, cement) to advanced (carbides, pure oxides, non-silicate glasses).

Example —

▪ Glass ▪ Porcelain ▪ Minerals, etc.

(iii) Polymers

- Commercially called plastics; noted for their low density, flexibility and use as insulators.
- Mostly are of organic compounds i.e. based on carbon, oxygen and other nonmetallic elements.
- Consists of large molecular structures bonded by covalent and van der Waals forces.
- They decompose at relatively moderate temperatures (100 - 400°C).

- Application : packaging, textiles, biomedical devices, optical devices, household items, toys, etc.

  Example —
  - Nylon
  - Teflon
  - Rubber
  - Polyester, etc.

1.1.4 Composites

- Consist of more than one kind of material. They are made so as to benefit from combination of best characteristics of each constituent.
- Available over a very wide range: natural (wood) to synthetic (fiberglass).
- Many are composed of two phases; one is matrix . which is continuous and surrounds the other dispersed phase.
- Classified into many groups: (1) depending on orientation of phases; such as particle reinforced, fiber reinforced, etc. (2) depending on matrix; metal matrix, polymer matrix, ceramic matrix.

  Example —
  - Cement concrete
  - Fiberglass
  - Special purpose refractory bricks, plywood, etc.

1.1.5 Semiconductors

- Their electrical properties are intermediate when compared with electrical conductors and electrical insulators.
- These electrical characteristics are extremely sensitive to the presence of minute amounts of foreign atoms.
- Have found many applications in electronic devices over decades through integrated circuits. In can be said that semiconductors revolutionized the electronic industry for last few decades.

1.1.6 Biomaterials

- Those used for replacement of damaged or diseased body parts.
- Primary requirements: must be biocompatible with body tissues, must not produce toxic substances.
- Important materials factors: ability to support the forces, low friction, wear, density, reproducibility and cost.
- All the above materials can be used depending on the application.
- A classic example: hip joint.

  Example —
  - Stainless steel
  - Co-28Cr-6Mo
  - Ti-6Al-4V
  - Ultra high molecular weight polyethelene
  - High purity dense Al-oxide, etc.

1.1.7 Advanced materials

- Can be defined as materials used in high-tech devices i.e. which operates based on relatively intricate and sophisticated principles (e.g. computers, air/space-crafts, electronic gadgets, etc.).
- These are either traditional materials with enhanced properties or newly developed materials with high performance capabilities. Thus, these are relatively expensive.
- Typical applications: integrated circuits, lasers, LCDs, fiber optics, thermal protection for space shuttle, etc.

  Example —
  - Metallic foams
  - Inter-metallic compounds

- Multicomponent alloys magnetic alloys
- Special ceramics and high temperature materials, etc.

1.18 Future materials

- Group of new and state-of-the-art materials now being developed, and expected to have significant influence on present-day technologies, especially in the fields of medicine, manufacturing and defense.
- Smart/Intelligent material system consists some type of sensor (detects an input) and an actuator (performs responsive and adaptive function).
- Actuators may be called upon to change shape, position, natural frequency, mechanical characteristics in response to changes in temperature, electric/magnetic fields, moisture, pH, etc.
- Four types of materials used as actuators:
  - Shape memory alloys
  - Piezoelectric ceramics
  - Magnetostrictive materials
  - Electro-/Magneto-rheological fluids
- Materials / Devices used as sensors:
  - Optical fibers
  - Piezoelectric materials
  - Micro-electro-mechanical systems (MEMS) etc.
- Typical applications:
  - By incorporating sensors, actuators and chip processors into system, researchers are able to stimulate biological humanlike behavior.
  - Fibers for bridges, buildings, and wood utility poles.
  - They also help in fast moving and accurate robot parts, high speed helicopter rotor blades.
  - Actuators that control chatter in precision machine tools.
  - Small microelectronic circuits in machines ranging from computers to photolithography prints.
  - Health monitoring detecting the success or failure of a product.

1.2 Non Metals

- The materials in the eight portion of the periodic table are called non metals.
- These materials are usually brittle and poor conductor of electricity (except graphite).
- They goes not form alloys but combine chemically to forms compounds.

STUDENT'S ASSIGNMENTS

Q.1 Consider the following statements:

1. Material science deals with the strength and stiffness behaviour of components (buildings/machines/vehicle facilities) based on their response to imposed stresses (forces, moments, torque etc.).
2. Material properties are dependent on their micro-structure and response to force fields and surface interaction.

Which of the above statements is/are correct?

(a) 1 only (b) 2 only
(c) Both 1 and 2 (d) Neither 1 nor 2

ANSWER KEY // STUDENT'S ASSIGNMENTS

1. (c)

HINTS & SOLUTIONS // STUDENT'S ASSIGNMENTS

1. (c)

Material science is the branch of engineering which deals with the study of structure, properties and applications of materials. Properties of materials are greatly influenced by the structure of materials.

■■■■

Chapter 02

Crystal Geometry

2.1 Introduction

- Properties exhibited by any material is dependent upon the arrangement of atoms in the lattice i.e., the regularity with which the atoms are arranged with respect to one another, the type of bond between the atoms, crystal structure and so on.

2.2 Crystal Structures

- All solid materials are made of atoms/molecules, which are arranged in specific order in some materials, called crystalline solids. Otherwise non-crystalline or amorphous solids.
- Groups of atoms/molecules specifically arranged in a particular manner is called crystal.
- Lattice is used to represent a three-dimensional periodic array of points coinciding with atom positions.
- Unit cell is smallest repeatable entity that can be used to completely represent a crystal structure. It is the building block of crystal structure.

2.2.1 Classification of Materials on the Basis of structure

- Crystalline material

  In this type of materials, atoms are arranged in orderly manner. ex. Metals.

- Non-crystalline or Amorphous material

  In these materials, atoms are not in regular or periodic manner. ex. Ceramic.

  - Space lattice

    A space lattice is defined as an infinite array of points in three dimensional space in which each point is identically spaced and located with respect to the other.

  - Unit cell

    A unit cell is defined as the basic structural part in the composition of materials.

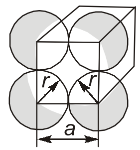
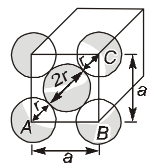
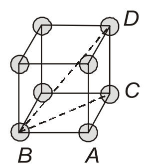
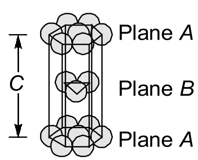
2.2.2 Various Properties of Unit Cell

- Co-ordination number

  The co-ordination number is defined as the number of nearest and equidistant atoms with respect to any other atom in a unit cell.

- Atomic Packing Fraction (APF)

  The atomic packing fraction is defined as the ratio of total volume of atoms per unit cell to the total volume of unit cell.

Space Lattice	Structure	Example	Co-ordination Number	Relation between a & r*	Effective no. of atoms (Ne)	Atomic Packing Factor (APF)
Simple Cubic (SC)	 Simple cubic	Po	6	$r = \frac{a}{2}$	1	0.523
Body Centered Cubic (BCC)	 Face Centered Cubic	Li, Na, V, Cr, Mo, W, Fe	8	$r = \frac{a\sqrt{3}}{4}$	2	0.68
Face Centered Cubic (FCC)	 Body Cenetred Cubic	Ni, Pt, Cu, Ag, Au, Al, Pb	12	$r = \frac{a}{2\sqrt{2}}$	4	0.74
Hexagonal Closed Packed (HCP)		Zn, Mg, Co	12	$C = 1.633a$ (ideal)	6	0.74

a* : Lattice Constant, r: atomic radius

$$APF = \frac{\text{Volume of atoms per unit cell}}{\text{Total volume of unit cell}}$$

- Density of the unit cell (ρ)

$$\rho = \frac{\text{Mass of the unit cell (M)}}{\text{Volume of the unit cell (V)}}$$

M = mass of one atom (m) x effective no. of atoms in a unit cell

$$m = \frac{\text{Atomic weight } (A_w)}{\text{Avogadro's number } (N_A)}$$

$$N_A = 6.023 \times 10^{23}$$

2.2.3 Miller Indices

- A system of notation is required to identify particular direction(s) or plane(s) to characterize the arrangement of atoms in a unit cell.
- Formulas involving Miller indices are very similar to related formulas from analytical geometry . simple to use.
- Use of reciprocals avoids the complication of infinite intercepts.
- Specifying dimensions in unit cell terms means that the same label can be applied to any plane with a similar stacking pattern, regardless of the crystal class of the crystal. Plane (111) always steps the same way regardless of crystal system.

Example 2.1 Given the atomic packing factor for the following crystal structures.

Simple Cubic, BCC, FCC, HCP

***Solution*:**

Simple Cubic → 52% Atomic packing factor
BCC → 68%
FCC → 74%
HCP → 74%

Example 2.2 Give the crystal structure for the following materials.

Fluorspar, Alpha-iron, Silver, Zinc, Manganese

***Solution*:**

Fluorspar → Simple cubic
Alpha-iron → BCC
Silver → FCC
Zinc → HCP
Manganese → Simple Cubic

Example 2.4 Which one of the following crystal systems is valid for gold?

(a) Orthogonal
(b) Cubic
(c) Hexagonal
(d) Triclinic

Solution :(b)

STUDENT'S ASSIGNMENTS

Q.1 The material property which depends only on the basic crystal structure is
(a) Fatigue strength (b) Work hardening
(c) Fracture strength (d) Elastic constant
[GATE-2010]

Q.3 Which one of the following pairs is not correctly matched?

Space Lattice	Relation between Atomic radius *r* & Edge element *a*
(a) Simple cubic structure	: $a^2 = 4r^2$
(b) Body-centred cubic structure	: $3a^2 = 16r^2$
(c) Triclinic	: $2a^2 = 3r^2$
(d) Face-centred cubic structure	: $a^2 = 8r^2$

[IES-2006]

Q.4 Match **List-I** (Crystal Structure) with **List-II** (Example) and select the correct answer using the codes given below the Lists:

List-I
A. Simple Cubic
B. Body-centered Cubic
C. Face-centered Cubic
D. Hexagonal Close Packed

List-II
1. Simple cubic
2. Copper
3. Alpha iron at room temperature
4. Manganese

Codes:

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

[IES-2003]

Q.5 Match **List-I** (Element) with **List-II** (Crystal Structure) and select the correct answer using the code given below the Lists :

List-I	List-II
A. Alpha Iron	1. Hexagonal closed packed
B. Copper	2. Body-centred cubic
C. Zinc	3. Amorphous
D. Glass	4. Face-centred cubic

Codes:

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

Q.6 In Zinc Blende structure, each atom is surrounded by four atoms of the opposite kind which are located at the comers of which one of the following?
(a) Tetrahedron (b) Hexahedron
(c) Cube (d) Orthorhombic
[IES-2006]

Q.7 In the atomic hard-sphere model of the crystal structure of Copper, what is the edge length of unit cell?
(a) 2 x Atomic radius
(b) $(4/\sqrt{3})$ x Atomic radius
(c) $(2\sqrt{2})$ x Atomic radius
(d) J2 x Atomic radius
[IES-2008]

Q.8 The coordination number for FCC crystal structure is
(a) 4 (b) 8
(c) 12 (d) 16
[IES-2003]