

Manufacturing
&
Material Science

For

Mechanical Engineering

By



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Syllabus for Manufacturing & Material Science

Engineering Materials: Structure and Properties of Engineering Materials, Heat Treatment, Stress-Strain Diagrams for Engineering Materials. **Metal Casting:** Design of Patterns, Moulds and Cores; Solidification and Cooling; Riser and Gating Design, Design Considerations. **Forming:** Plastic Deformation and Yield Criteria; Fundamentals of Hot and Cold Working Processes; Load Estimation for Bulk (forging, Rolling, Extrusion, Drawing) and Sheet (Shearing, Deep Drawing, Bending) Metal forming Processes; Principles of Powder Metallurgy. **Joining:** Physics of Welding, Brazing and Soldering; Adhesive Bonding; Design Considerations in Welding. **Machining and Machine Tool Operations:** Mechanics of Machining, Single and Multi-Point Cutting Tools, Tool Geometry and Materials, Tool Life and Wear; Economics of Machining; Principles of Non-Traditional Machining Processes; Principles of Work Holding, Principles of Design of Jigs and Fixtures **Metrology and Inspection:** Limits, Fits and Tolerances; Linear and Angular Measurements; Comparators; Gauge Design; Interferometry; Form and Finish Measurement; Alignment and Testing Methods; Tolerance Analysis In Manufacturing and Assembly. **Computer Integrated Manufacturing:** Basic Concepts of CAD/CAM and Their Integration Tools.

Previous Year GATE Papers and Analysis

GATE Papers with answer key

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Subject wise Weightage Analysis

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Engineering Materials

“Be a student as long as you still have something to learn, and this will mean all your life.”

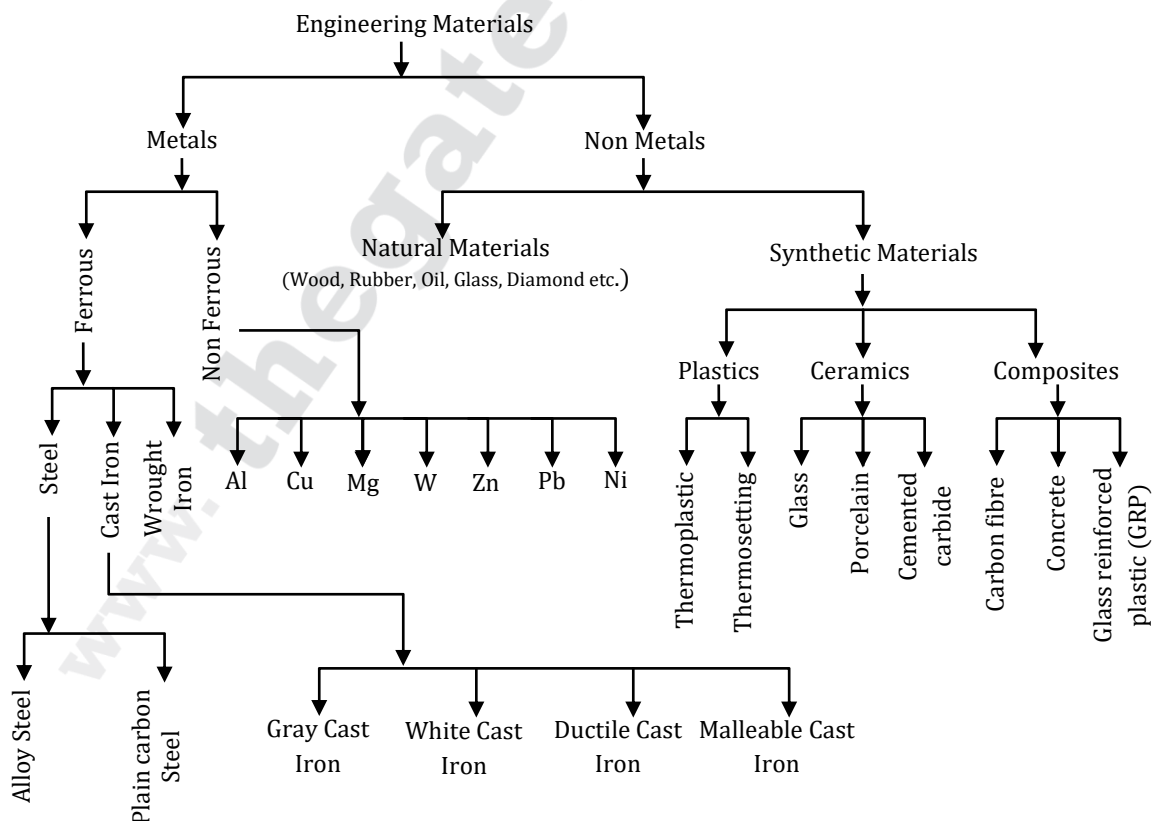
... Henry L. Doherty

Learning Objectives

After reading this chapter, you will know:

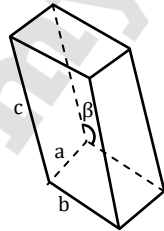
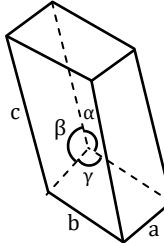
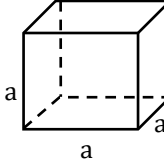
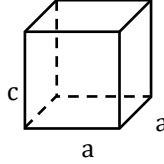
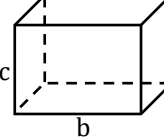
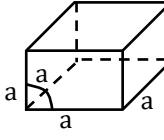
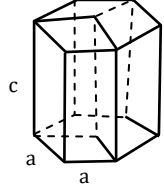
1. Classification of Engineering Materials
2. Unit Cell Geometry and Miller Indices
3. Inter-Planar Spacing
4. Atomic Packing Fraction (APF)
5. Crystal Imperfections and Cooling Curves
6. Iron Carbon Equilibrium Diagram
7. Heat Treatment
8. Physical and Mechanical Properties of Materials
9. Tensile Test and Brinell Hardness Test

Classification of Engineering Materials



Unit Cell Geometry

The properties of a material are intimately connected to its basic molecular structure. Some knowledge of this structure is therefore essential for understanding the various macroscopic properties exhibited by material. The “lattice parameter” is the length between two points on the corners of a unit cell. Each of the various lattice parameters are designated by the letters a, b, and c. If two sides are equal, such as in a tetragonal lattice, then the lengths of the two lattice parameters are designated a and c, with b omitted. The angles are designated by the Greek letters α , β , and γ , such that an angle with a specific Greek letter is not subtended by the axis with its Roman equivalent. For example, α is the included angle between the b and c axis.

System	Axial Lengths and Angles	Unit Cell Geometry
Monoclinic	$a \neq b \neq c, \alpha = \gamma = 90^\circ \neq \beta$	
Triclinic	$a \neq b \neq c, \alpha \neq \beta \neq \gamma \neq 90^\circ$	
Cubic	$a = b = c, \alpha = \beta = \gamma = 90^\circ$	
Tetragonal	$a = b \neq c, \alpha = \beta = \gamma = 90^\circ$	
Orthorhombic (Trigonal)	$a \neq b \neq c, \alpha = \beta = \gamma = 90^\circ$	
Rhombohedral	$a = b = c, \alpha = \beta = \gamma \neq 90^\circ$	
Hexagonal	$a = b \neq c, \alpha = \beta = 90^\circ, \gamma = 120^\circ$	

The cubic lattice is the most symmetrical of the systems. All the angles are equal to 90° and all the sides are of the same length ($a = b = c$). Only the length of one of the sides (a) is required to describe this system completely. In addition to simple cubic, the cubic lattice also includes body-centered cubic and face-centered cubic. Body-centered cubic results from the presence of an atom (or ion) in the center of a cube, in addition to the atoms (ions) positioned at the vertices of the cube. In a similar manner, a face-centered cubic requires, in addition to the atoms (ions) positioned at the vertices of the cube, the presence of atoms (ions) in the center of each of the cubes face. The tetragonal lattice has all of its angles equal to 90° , and has two out of the three sides of equal length ($a = b$). The system also includes body-centered tetragonal.

Miller Indices

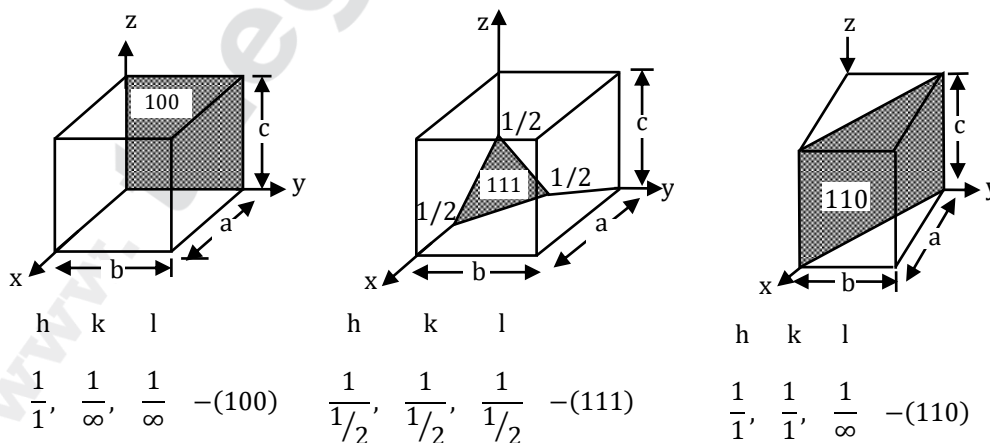
The designation of the individual vectors within any given crystal lattice is accomplished by the use of whole number multipliers of the lattice parameter of the point at which the vector exits the unit cell. The vector is indicated by the notation $[hkl]$, where h , k , and l are reciprocals of the point at which the vector exits the unit cell. The origination of all vectors is assumed and defined as $[000]$. Miller indices are the designation of the planes and direction in the unit cells. Miller indices of a given plane is the reciprocals of its intercepts on the x , y and z axis.

Properties of Miller Indices

- Miller indices of equally spaced parallel plane are the same.
- Miller indices of a plane passing through the origin is shown by Miller indices of a plane parallel to it.
- If two planes having Miller indices as $(h_1 k_1 l_1)$ and $(h_2 k_2 l_2)$ are perpendicular to each other then $h_1 h_2 + k_1 k_2 + l_1 l_2 = 0$
- Distance between the parallel planes having low index numbers are greater than those having high index numbers.
- All members of family of planes or directions are not necessarily parallel to one another.

Inter-Planar Spacing

The perpendicular distance between a plane and another parallel plane passing through the origin is called interplanar spacing.



For example, the direction along the a-axis is x, y or z according to this scheme would be [100] because this has a component only in the a-direction and no component along either the y or z axial direction. A vector diagonally along the face defined by the x and y axis would be [110], while going from one corner of the unit cell to the opposite corner would be in the [111] direction.

Crystal planes are the planes in a crystal and can be specified using a notation called Miller indices. The Miller index is indicated by the notation [hkl] where h, k, and l are reciprocals of the plane with the x, y, and z axis. To obtain the Miller indices of a given plane requires the following steps:

Step 1: The plane in question is placed on a unit cell.

Step 2: Intercepts with each of the crystal axis are then found.

Step 3: The reciprocal of the intercepts are taken.

Step 4: These are multiplied by a scalar to ensure that is in the simple ratio of whole numbers.

For example, the face of a lattice that does not intersect the y or z axis would be (100), while a plane along the body diagonal would be the (111) plane. An illustration of this along with the (111) and (110) planes is given in above figure.

These atoms, ions, or molecules are called **Lattice Points** and are typically visualized as round spheres. A **Unit Cell** is the smallest collection of lattice points that can be repeated to create the crystalline solid. The solid can be envisioned as the result of the stacking a great number of unit cells together. The unit cell of a solid is determined by the type of layer (square or close packed), the way each successive layer is placed on the layer below, and the **Co-ordination Number** for each lattice point (the number of "spheres" touching the "sphere" of interest).

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.

The **Packing Efficiency** (PE) is the fraction of the crystal (or unit cell) actually occupied by the atoms. It must always be less than 100% because it is impossible to pack spheres (atoms are usually spherical) without having some empty space between them.

$$P.E. = (\text{area of circles within the unit cell}) / (\text{area of unit cell})$$

1. Simple Cubic

The simple cubic system consists of one lattice point on each corner of the cube. Each atom at a lattice point is then shared equally between eight adjacent cubes and the unit cell therefore contains in total one atom.

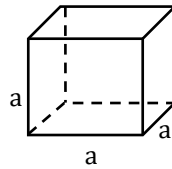
Placing a second square array layer directly over a first square array layer forms a "simple cubic" structure. Again not close packed - primitive or simple cubic cell with atoms only at the corners.

Co-ordination number = 6

Packing density (52%)

The atoms are in contact along the cell edge. Therefore $a = 2r$.

A very rare packing arrangement for metals, one example is a form of Polonium (Po)



Simple Cubic

2. Body Centered Cubic (BCC)

The body-centered cubic system has one lattice point in the center of the unit cell in addition to the eight corner points. It has a net total of 2 lattice points per unit cell.

A more efficiently packed cubic structure is the "Body-Centered Cubic" (BCC). The first layer of a square array is expanded slightly in all directions. Then, the second layer is shifted so its spheres nestle in the spaces of the first layer.

Co-ordination number = 8

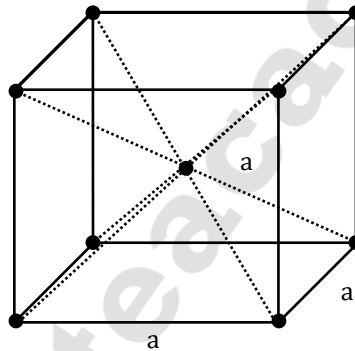
Packing density (68%)

The atoms are only in contact along the body diagonal.

For a unit cell edge length a , length body diagonal = $a(3)^{1/2} = 4r$.

Therefore $4r = a(3)^{1/2}$

Examples of BCC structures include one form of Fe, V, Cr, Mo, W, Li, Na



Body Centered Cubic

3. Face Centered Cubic (FCC)

The Face-Centered Cubic system has lattice points on the faces of the cube, that each gives exactly one half contribution, in addition to the corner lattice points, giving a total of 4 lattice points per unit cell. A Cubic Closest Packed (CCP) structure is created by layering close packed arrays. The spheres of the second layer nestle in half of the spaces of the first layer. The spheres of the third layer directly overlay the other half of the first layer spaces while nestling in half the spaces of the second layer.

Because the FCC structure is still close packed it is as efficient in its packing as the hcp structure (74%), and the coordination number of the atoms is still 12.

8 at the corners ($8 \times 1/8 = 1$), 6 in the faces ($6 \times 1/2 = 3$), giving a total of 4 per unit cell.

In the FCC cell the atoms touch along the face diagonals, but not along the cell edge.