METALLURGY

Teaching scheme: Examination scheme:

Lectures: 2 Hrs. / Week; Mid Exam.

Practical (Metallurgy Laboratory): 2 Hrs. / Week

Final Exam. : 60 Marks

Course Objective

Study of structures, composition, properties, applications, heat treatment and selection of various ferrous and non-ferrous materials

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Recommended books

1. Materials Science and Engineering, An Introduction (William D. Callister, Jr.)

2. Introduction to MATERIALS SCIENCE FOR ENGINEERS (James F.Shackelford)

3. Engineering Metallurgy by E. C. Rollason, (ELBS)

4. Introduction To Engineering Materials, B.K.Agrawal (TMH)

5. Engineering Metallurgy by Lakhtin, (MIR Publishers)

6. Materials Science And Metallurgy,Dr. Kodgire (Everest , Pune)

7. Heat treatment principles and technique, Rajan Sharma & Sharma

Introduction

Why do we study materials?

Many of applied scientists or engineers, whether mechanical, civil, chemical, or electrical, will at one time or another be exposed to a design problem relating to the selection of materials.

There are, it is said, more than 50,000 materials available to the engineers. In designing a structure or device, how is the engineer to choose from this vast menu the best material which suits the purpose? *Mistakes can cause disasters*.

During World War II, one class of welded merchant ship suffered heavy losses, not by enemy attack, but by breaking in half at sea; why? the *fracture toughness* of the steel - and, particularly, of the welds was too low.

More recently, three Comet aircraft were lost before it was realised that the designed fatigue strength of the window frames was greater than that possessed by the used material.

You yourself will be familiar with the poorly-designed appliances made of plastic: their excessive 'give' is because the designer did not allow for the low *modulus* of the polymer.

Material selection

The selection of the right material from many thousands available types depends on different factors:

- **Design/Geometry requirements:** Stresses, movements, dimensions ….
- **Material Properties:** The expected level of performance from the material.
- **Material Cost and Availability:** Material must be priced appropriately.
- **Production process:** how to make the part, for example: Casting Machining Welding.
- **Environment:** The effect of the service environment.
- **Safety considerations:** Flammability, explosion, fracture style, toxicity…

Properties of materials

The properties of the materials can be defined as the way that the material responds to the environment and/or external forces. The properties that the designer must consider when choosing a material are:

- **Mechanical properties:** Response to mechanical forces (Strength, Toughness, Hardness, Ductility, Elasticity, fatigue and creep).
- **Physical properties:** Properties that define the behavior of materials in response to physical forces other than mechanical (density, specific heat, melting and boiling point, thermal expansion and conductivity, electrical conductivity, optical properties and magnetic properties).
- **Chemical properties:** (Oxidation, corrosion, flammability, toxicity).

Classification of materials

There are different ways of classifying materials. One way is to describe five groups as illustrated in (**Figure 2**). Materials in each of these groups possess different structures and properties.

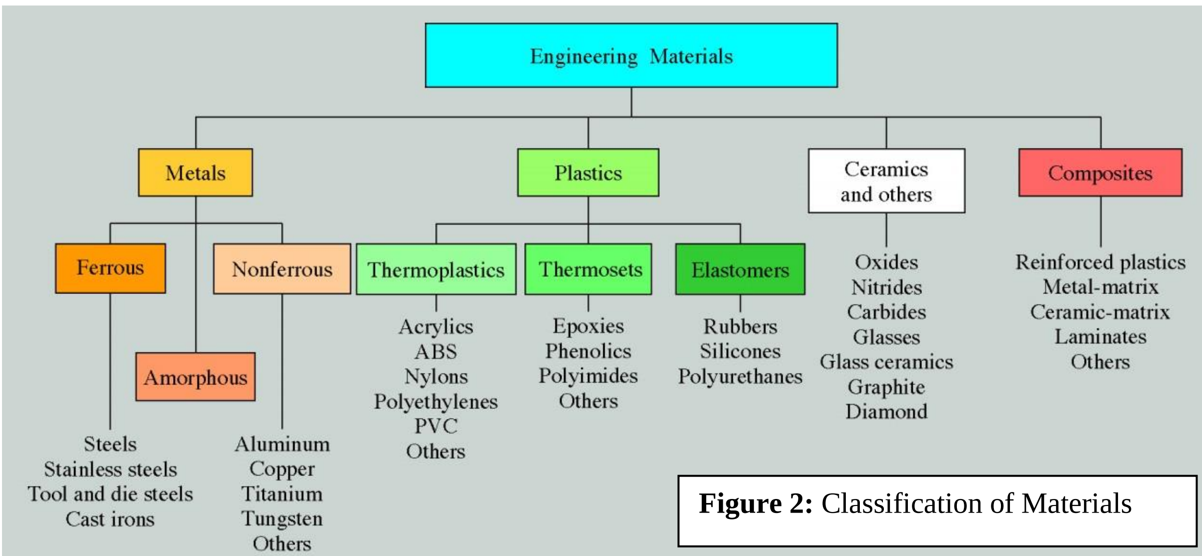
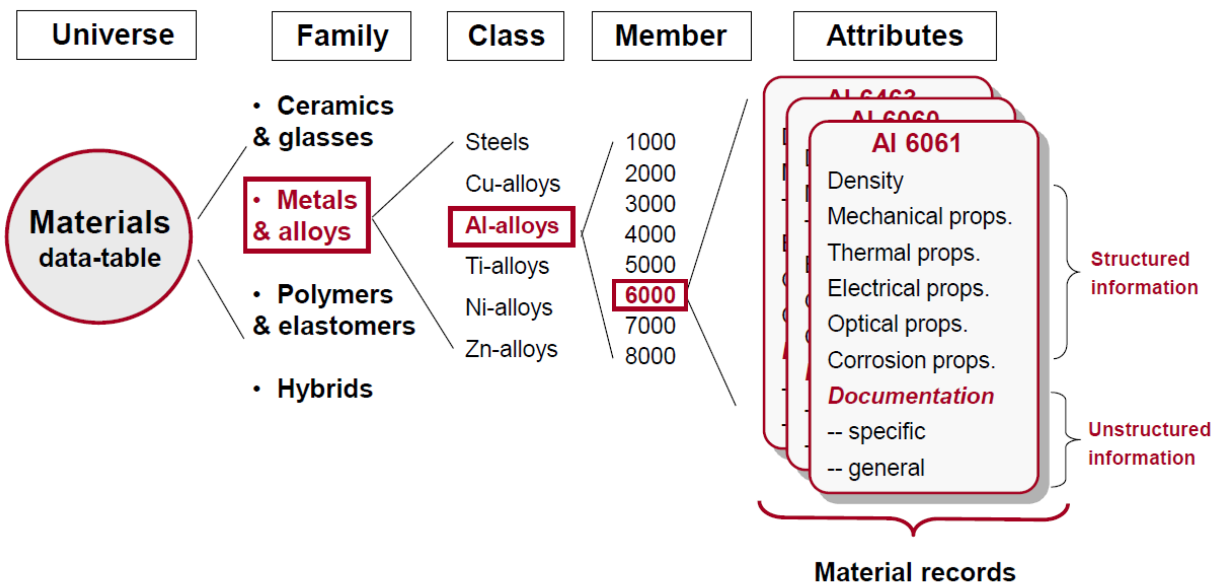


Figure 2: Classification of Materials

Materials Characteristics

Organising information: The materials tree



Materials Science and Engineering

Material science is the investigation of the relationship between ***processing, structure, properties, and performance of materials***.

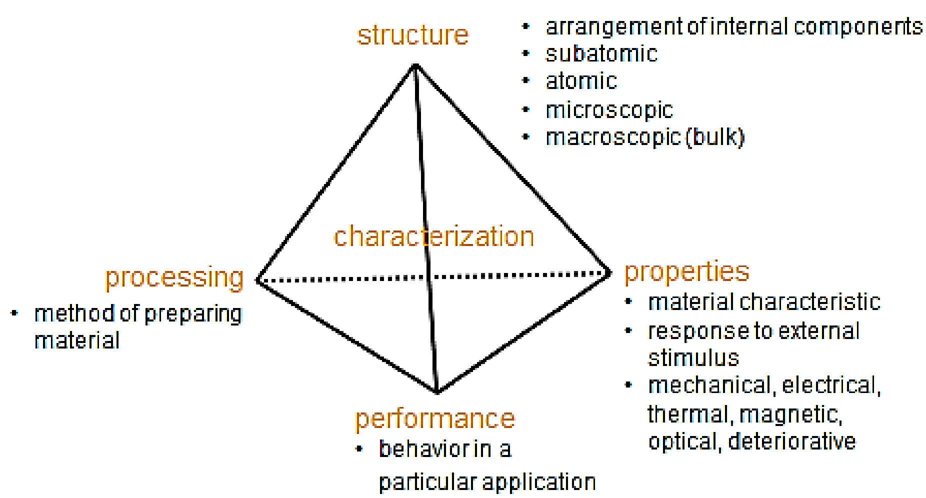
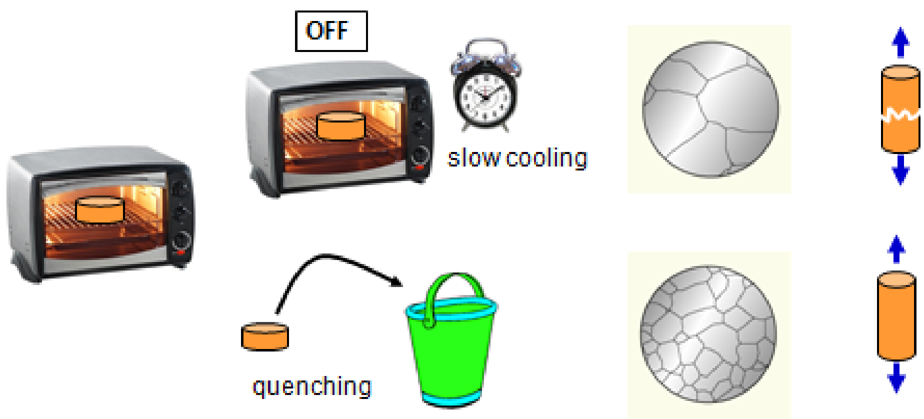


Figure : Material science scheme

Processing → Structure → Properties → Performance

Performance Goal: increased strength from a metallic material

In actuality, crystals are NOT perfect. There are **defects**!
In metals, **strength** is determined by how easily defects can move!



Length-scales

the human scale:	1 meter
the milliscale:	1×10^{-3} meter
the microscale:	1×10^{-6} meter
the nanoscale:	1×10^{-9} meter
the atomic scale:	1×10^{-10} meter.

- **Micro-structure** µm-scale –use optical microscopy imaging and scanning electron microscopy (SEM imaging).
- N**ano-structure** nm-scale –use transmission electron microscopy (TEM) and high resolution transmission electron microscopy (HRTEM imaging).
- A**tomic structure** Å-scale –use X-ray diffraction.

Atomic Structure

In order to understand bonding between atoms, we must specify the structure within the individual atoms. For this purpose, it is sufficient to use a relatively simple planetary model of atomic structure that is, **electrons** (the planets) orbit about a **nucleus** (the sun). The nucleus consists of number of **protons** and **neutrons** as the basis of the chemical identification of a given atom. Figure 2 is a planetary model of a carbon atom.

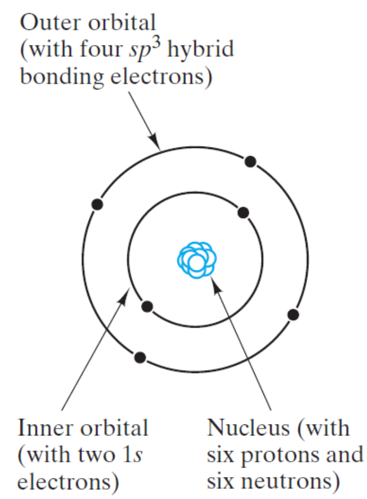
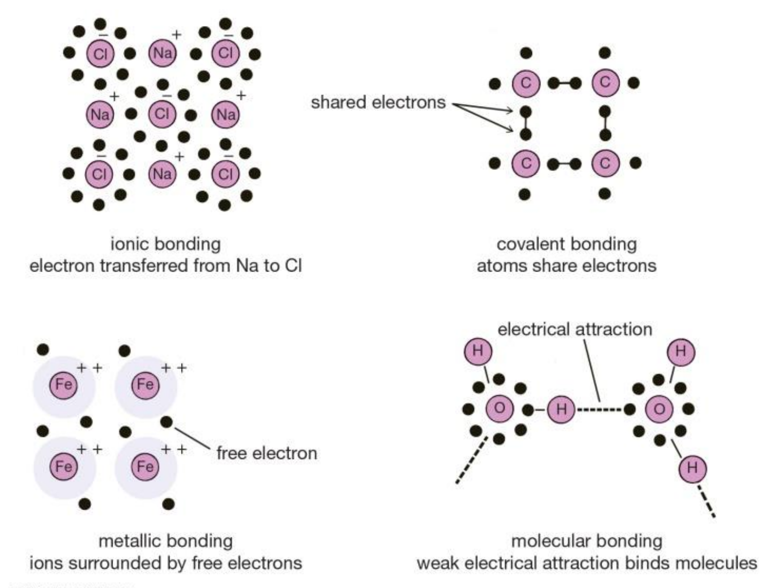


Figure 2 Schematic of the planetary model of a carbon atom

Atomic Bounding

There are four important mechanisms by which atoms are bonded in engineered materials, these are

1. Metallic bonds.
2. Covalent bonds.
3. Ionic bonds.
4. Van der Waals bonds.



The first three types of bonds are relatively strong and are known as **primary bonds** (relatively strong bonds between adjacent atoms resulting from the transfer or sharing of outer orbital electrons). The van der Waals bonds are secondary bonds and originate from a different mechanism and are relatively weaker

a) **Ionic bonding** (found in Ceramics and Glass) this type is always found in compounds that are composed of both metallic and nonmetallic elements. Atoms of a metallic element easily give up their valence electrons to the nonmetallic atoms.

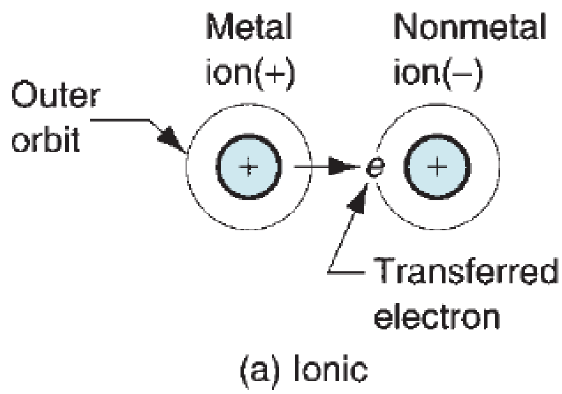


Figure 3 Schematic representation of ionic bonding

b) **Covalent bonding** (found in Polymers) in this type electrons are shared between adjacent atoms, each atoms contribute at least one electron to the bond, and the shared electrons may be considered to belong to both atoms.

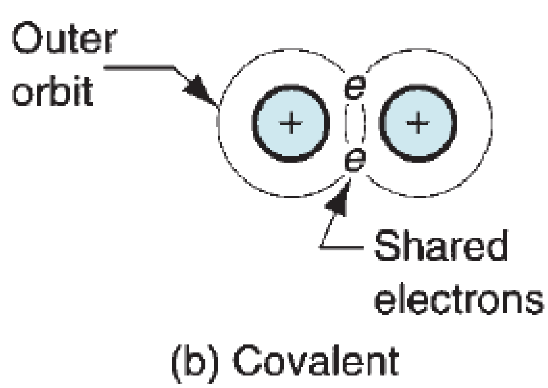


Figure 4 Schematic representation of covalent bonding

c) **Metallic Bond** (found in metals and their alloys) metallic materials have one, two, or at most, three valence electrons, these valence electrons are free to drift throughout the entire metal forming an electron cloud. The remaining non-valence electrons and atomic nuclei form what are called ***ion cores***, which possess a net positive charge equal in magnitude to the total valence electron charge per atom.

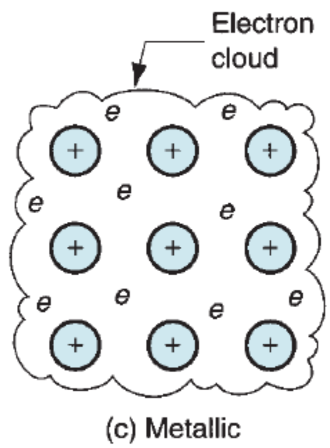
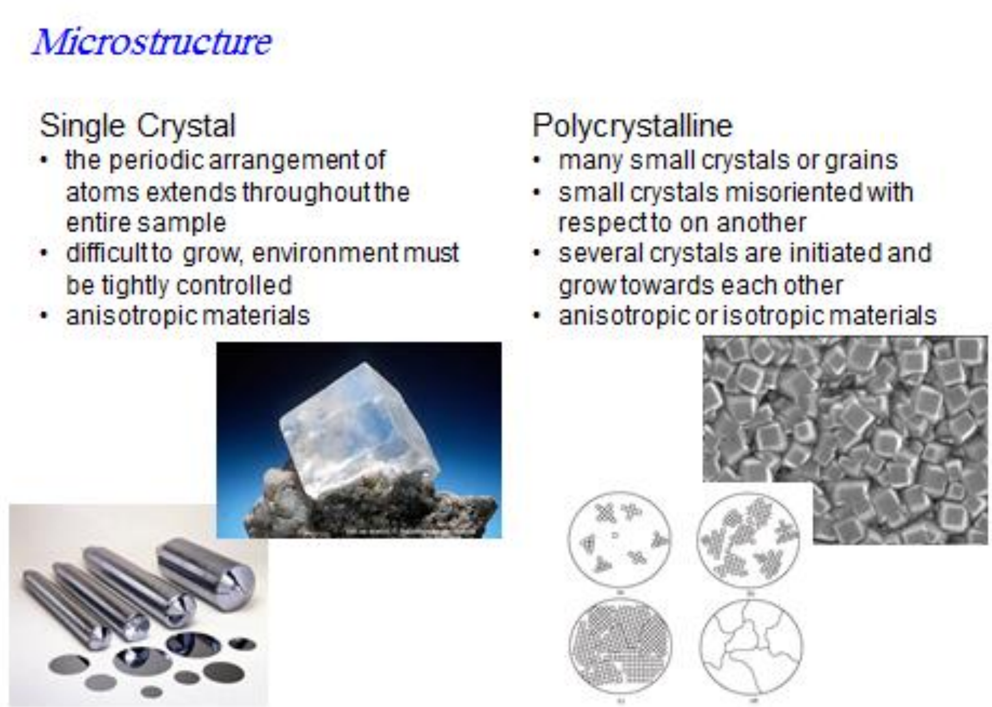


Figure 5 Schematic illustration of metallic bonding

Metallic crystal structures:

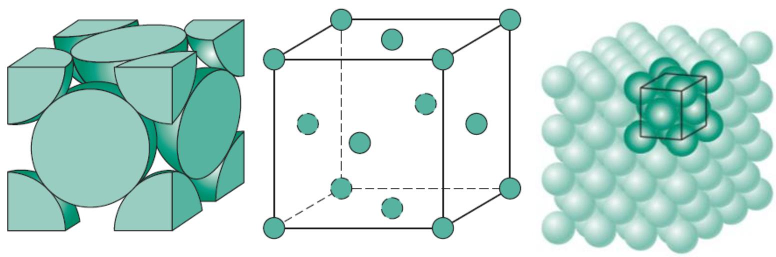


2nd Lec

Types of crystal structures

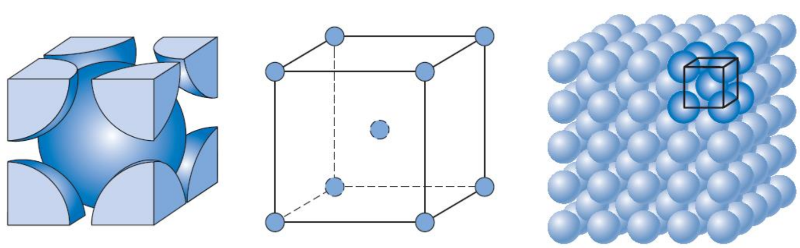
There are three main types of crystal structures of metals as follows:

1- The face-centered cubic crystal structure (FCC): some of the familiar metals having this crystal structure are copper, aluminum, silver, and gold.



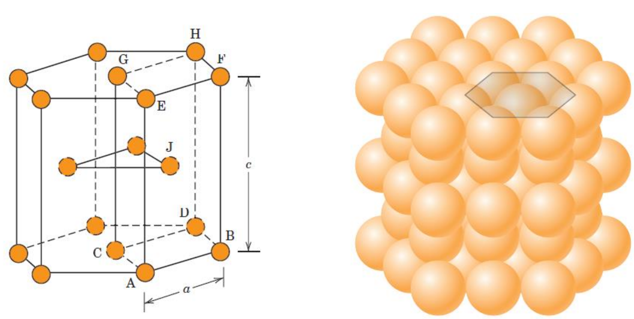
(a) (b) (c)

2- The Body-Centered Cubic Crystal Structure (BCC): Chromium, iron, tungsten exhibits a BCC structure.



(a) (b) (c)

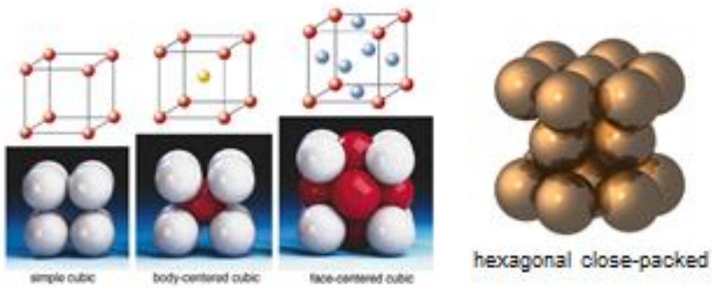
3- The Hexagonal Close-Packed Crystal Structure (HCP):



(a) (b)

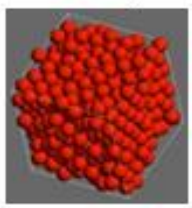
Atomic Arrangement: Ordered vs. Disordered

Crystalline:
atoms are arranged in a 3D, periodic array giving the material "*long range order*"



- stacking can effect properties (i.e. ductility)
- anisotropic materials

Non-crystalline or amorphous:
atoms only have short-range, *nearest neighbor order*



- viscous materials (generally complex formulas) or rapid cooling
- isotropic materials