Module-1

Introduction

Contents

Historic perspective

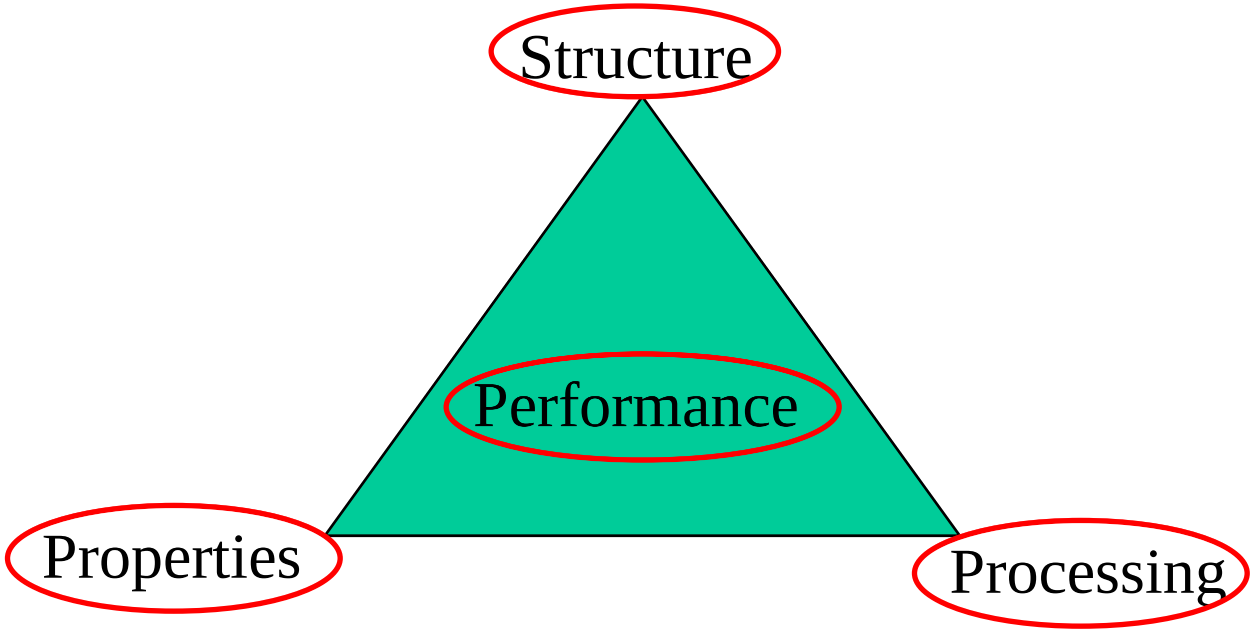
- Materials are very important in development of human civilization. In respect, their names are associated in history, e.g. stone age, Bronze age, Iron age, etc.

- With time humans discovered new materials and also techniques to produce known materials. This is an ongoing process for coming centuries, i.e. no end in sight!

Materials Science

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

- Basic components and their interrelationship:



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 Deteriorative.

- Each material possess a structure, relevant properties, which dependent on processing and determines the performance.

Why Study Properties of Materials?

- Since there are thousands of materials available it is almost impossible to select a material for a specific task unless otherwise its properties are known.

- There are several criteria on which the final decision is based on.

- There are less chances of material possessing optimal or idle combination of properties.

- A need to trade off between number of factors!

- The classic example involves strength and ductility:

  - Normally material possessing strength have limited ductility.In such cases a reasonable comprise 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.

Classification of Materials

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

Metals

Ceramics

Polymers

- 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, Biomatrials

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 luster. 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.

E.g.: Steel, Aluminium, Brass, Bronze, Lead, Titanium, etc.

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*).

E.g.: Glass, Porcelain, Minerals, etc.

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 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, ceramics household items, toys, etc.

E.g.: Nylon, Teflon, Rubber, Polyester, etc.

Composites

- Consist more than one kind of material; tailor made 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.

E.g.: Cement concrete, Fiberglass, special purpose refractory bricks, plywood, etc.

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.
- Found very many applications in electronic devices over decades through integrated circuits. In can be said that semiconductors revolutionized the electronic industry for last few decades.

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 and wear, density, reproducibility and cost.
- All the above materials can be used depending on the application.
- A classic example: hip joint.

E.g.: Stainless steel, Co-28Cr-6Mo, Ti-6Al-4V, ultra high molecular weight polyethelene, high purity dense Al-oxide, etc.

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.

E.g.: Metallic foams, inter-metallic compounds, multi-component alloys, magnetic alloys, special ceramics and high temperature materials, etc.

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.

Future materials (contd…)

- 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.

Future materials (contd…)

- Typical applications:

  - By incorporating sensors, actuators and chip processors into system, researchers are able to stimulate biological human-like 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.

Modern materials' needs

- Engine efficiency increases at high temperatures; requires high temperature structural materials.
- Use of nuclear energy requires solving problems with residue, *or* advance in nuclear waste processing.
- Hypersonic flight requires materials that are light, strong and resist high temperatures.
- Optical communications require optical fibers that absorb light negligibly.
- Civil construction – materials for unbreakable windows.
- Structures: materials that are strong like metals and resist corrosion like plastics.