Introduction to Material Science

Materials are very important in the development of human civilization. Historians have identified civilization by the name of most used material. Thus, we have: Stone Age, Bronze Age etc.

From early human civilization, people used only natural materials ,like stone, clay, skin, and wood for different purposes like weapons, instruments, shelter, etc. Thus the sites of deposits for better quality stones became early colonies of human civilization. However, need for better quality tools brought forth exploration that led to Bronze Age followed by Iron Age, when people found copper and how to make it harder by alloying. The use of iron and steel, a stronger material that gave advantage in

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wars started after the bronze age. Iron was abundant and thus availability was not limited to the affluent. This commonness of the material affected every person in many aspects, gaining the name DEMOCRATIC material. The next major step in human civilization was the making of steel through a relatively cheap process. This enabled the railroads and the building of modern infrastructure of the industrial world. One of the most significant features of the democratic material is that number of users exploded. We are presently in Space Age marked by many technological developments towards development of materials resulting in stronger and light materials like composites, electronic materials like semiconductors, materials for space voyage like high temperature ceramics, biomaterials, etc.

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In summary, materials constitute foundation of technology. Civilization evolved from the Stone Age to the Bronze Age, the Iron Age, the Steel Age, and to the Space Age. Each age is marked by the advent of certain materials. The Iron Age brought tools and utensils. The Steel Age brought railroads, instruments, and the Industrial Revolution. The Space Age brought the materials for stronger and light structures (e.g., composite materials). The Electronic Age brought semiconductors, and thus many varieties of electronic gadgets.

Materials Science: Engineering materials constitute foundation of technology. Thus an understanding of their properties become important. The combination of physics, chemistry, and the focus on the relationship between the properties of a material and its microstructure is the domain of Materials Science. Important components of the subject Materials Science are structure, properties, processing, and performance

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Importance of materials science and engineering:

All engineers need to know about materials. Innovation in engineering often means the clever use of a new material for a specific application. For example: plastic containers in place of age-old metallic containers. It is on record that engineering disasters are frequently caused by the misuse of materials. So it is vital that the professional engineer should know how to select materials which best fit the demands of the design - economic and aesthetic demands, as well as demands of strength and durability. Hence engineer should be able : To select a material for a given use based on considerations of cost and performance.; To understand the limits of materials and the change of their properties with use; To create a new material that will have some desirable properties; To use the material for different application.

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Classification of Materials : materials can be classified based on many criteria, for example crystal structure (arrangement of atoms and bonds between them), or properties, or use. Metals, Ceramics, Polymers, Composites, Semiconductors, and Biomaterials constitute the main classes of present engineering materials. Metals: These materials are characterized by high thermal and electrical conductivity; strong yet deformable under applied mechanical loads; opaque to light (shiny if polished). These characteristics are due to valence electrons that are detached from atoms and spread in an electron sea that glues the ions together, i.e. atoms are bound together by metallic bonds and weaker van der Waals forces. Pure metals are not good enough for many applications, especially structural applications. Thus metals are used in alloy form i.e. a metal mixed with another metal to improve the desired qualities. E.g.: steel, brass, gold.

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Ceramics: are inorganic compounds, made up either of oxides, carbides, nitrides, or silicates of metals. They are partly crystalline and partly amorphous. Atoms (ions often) in ceramic materials behave mostly like either positive or negative ions, and are bound by very strong Coulomb forces between them. They are characterized by very high strength under compression, low ductility. They are usually insulators to heat and electricity. Typical examples are: glass, porcelain, many minerals. Polymers: are in the form of thermo-plastics (nylon, polyethylene, polyvinyl chloride, rubber, etc.) consist of molecules that have covalent bonding within each molecule and van der Waals forces between them. Polymers in the form of thermo-sets (e.g., epoxy, phenolics, etc.) consist of a network of covalent bonds.

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They are based on H, C and other non-metallic elements. Polymers are amorphous, except for a minority of thermoplastics. Due to the kind of bonding, polymers are typically electrical and thermal insulators. However, conducting polymers can be obtained by doping, and conducting polymer-matrix composites can be obtained by the use of conducting fillers. They decompose at moderate temperatures (100 – 400 C), and are lightweight.

Composite materials: are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain. An example is a lightweight brake disc obtained by embedding SiC particles in Al-alloy matrix. Another example is reinforced cement concrete, a structural composite obtained by combining cement (the matrix, i.e., the binder, sand (fine aggregate), gravel (coarse aggregate), and, thick steel. However, we have natural ones like wood. In general, composites are classified according to their matrix materials. The main classes of composites are metal-matrix, polymer-matrix, and ceramic-matrix.

Semiconductors: are covalent in nature. Their electrical properties depend extremely strongly on minute proportions of contaminants. They are usually doped in order to enhance electrical conductivity. They are used in the form of single crystals without dislocations because grain boundaries and dislocations would degrade electrical behaviour. They are opaque to visible light but transparent to the infrared. Examples: silicon (Si), germanium (Ge), and gallium arsenide (GaAs, a compound semiconductor).

Biomaterials: These are types of material that can be used for replacement of damaged or diseased human body parts. They must be biocompatible with body tissues, and must not produce toxic substances.

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Other important factors are: ability to support forces; low friction, wear, density, and cost; reproducibility. Applications include heart valves, hip joints, dental implants, intraocular lenses. Examples: Stainless steel, Co-28Cr-6Mo, Ti-6Al-4V, ultra high molecular weight poly-ethylene, high purity dense Al-oxide, etc.

Advanced Materials : are used in High-Tech devices such as in computers, air/space-crafts, electronic gadgets, etc. They operate on relatively intricate and sophisticated principles. These materials are either traditional materials with enhanced properties or newly developed materials with high-performance capabilities. Hence these are relatively expensive. Applications include integrated circuits, lasers, LCDs, fibre optics, thermal protection for space shuttle, etc. Examples: Metallic foams, inter-metallic compounds, multi-component alloys, magnetic alloys, special ceramics and high temperature materials, etc.

Future Materials : are a 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 defence. 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.

Modern Materials needs: Although progress have been made in the field of materials science and engineering, innovation of new technologies, and need for better performances of existing technologies demands much more from the materials field. It is evident that new materials/technologies are needed to be environmental friendly. Some typical needs, thus, of modern materials are : Engine efficiency increases at high temperatures, which requires high temperature structural materials.

Quiz:

1. First material known to be used by man: (a) Cotton (b) Bronze (c) Iron (d) Rock
2. First metal known to be used by man: (a) Iron (b) Bronze (c) Silver (d) Aluminium
3. Which one of the following is not basic component of Materials Science?

(a) Cost (b) Properties (c) Structure (d) Performance

4. Figure out the odd statement about ceramics in the following : (a) Good insulators of heat and electricity (b) Usually less desire than metals (c) Ductile in nature (d) Contains both metallic and non-metallic elements.

5. Pick the composite from the list : (a) Wood (b) Steel (c) Nylon (d) Mica
6. Not an example for actuator: (a) Optical fiber (b) Shape memory alloys (c) Magneto-strictive materials (d) Electro-/Magneto-rheological fluids
7. Strong and ductile materials: (a) Polymers (b) Ceramics (c) Metals (d) Semiconductors
8. Presently most used metal in the world: (a) Aluminium (b) Gold (c) Steel (d) Silver
9. Detrimental property of a material for shock load applications: (a) High density (b) Low toughness

(c) High strength (d) Low hardness

10. Democratic material (a) Diamond (b) Titanium (c) Iron (d) Gold