Lecture 8, 9, 10:

Properties of Engg. Materials, Stress, Strain, Elasticity, Plasticity etc.

State of Matter:

Matter, we conventionally think, as solid, liquid or gas.

Main two classes of matter are fluids (gas or liquid) – which flow when a force is applied, and solids – which resist the applied force.

Fluids:

- Gases: have low density, expand to fill the container, are easily compressed, have low viscosity, diffuse readily into each other and exert a uniform pressure on the walls of the container. i.e. the gas particles are not in direct contact with each other and are in constant motion in random directions at high speeds
- Liquids: exhibit most of the above properties, most diffuse into each other readily, viscosity higher than gases, incompressible, evaporate to for a vapour when heated and return to the liquid state when cooled, small force causes irreversible flow and the viscosity is dependent on temperature

Solids:

Solids seem resist an applied force and do not flow under load normally, but under appropriate conditions all material flow.

Atomic Structure:

Everything is built up of atoms. Each atom has at its centre a nucleus consisting of a group of protons and neutrons whilst 'in orbit' around the nucleus are electrons. Since protons and neutrons in the nucleus are some 1836 times heavier than the electron, the mass of an atom tends to be concentrated in its nucleus. The number of protons in the nucleus of a stable atom is equal to the number of electrons in the various shells around the nucleus and so a stable atom is electrically neutral. The number of protons in the nucleus of an atom is called the Atomic Number (Z) of the element.

In a gas forces of attraction between atoms are negligible at high temperature. As the temperature decreases, the force of attraction becomes significant and the gas condenses to form a liquid. At a lower temperature still the force of attraction predominates to the extent that atoms fall into a fixed pattern and so form a solid.

About three quarters of the elements (92 ~ 110) are metals, about one eighth are non metals, whilst the remainder, the metalloids, have properties which are intermediate between metals and non-metals. The non-metals are highly electronegative, by being poor conductors of heat and electricity and by having low meting and boiling points. Metals have high melting and boiling points and are good conductors of heat and electricity.

Engineering Materials:

Any material which has got application in engineering construction is termed engineering material. Understanding of the fundamental nature of engineering materials is important in all branches of engineering. The subject engineering materials deals with the study of materials in respect of the following:

- Sources, composition and properties
- Manufacturing methods and testing
- Utility in the various fields of engineering and technology
- Modern techniques for handling and using materials to materialize economic and safer design

The engineering materials may be broadly classified as follows:

Group A:
- Civil engineering materials: stones, bricks, cement, concrete, timber, etc.
- Electrical engineering materials: copper, aluminium, silicon, asbestos, iron, cobalt etc.
- Mechanical engineering materials: cast iron, steel, lubricating materials etc.

Group B:
- Metals: iron aluminum, copper, zinc etc.
  - Ferrous metals : cast iron, wrought iron, etc
  - Non-ferrous metals: copper, zinc etc.
- Non metals: stones, cement, concrete etc.

Group C :
- Metals and alloys: steel, copper, brass, bronze etc.
- Ceramics: silica, soda lime, glass, concrete, ferrites, etc.
- Organic materials : plastics, PVC, synthetic rubber etc,

Properties of Materials: some of the important properties of engineering materials are,

- Physical properties
- Mechanical properties
- Chemical properties
- Thermal properties
- Magnetic properties
- Electrical properties

Physical properties: required to evaluate the condition of the material without any external force acting on it. These are,

- Shape, size
- Density, porosity
- Water absorption, permeability
- Fire resistance
- Frost resistance
- Weathering resistance
- Hygroscopicity
- Durability
- **Sound transmission properties**

Sound Transmission Properties:

The transmission of sound, which is a form of energy, can be studied by measuring the energy levels at different locations.

- The decibel: one tenth of a bell, used to define sound intensities and varies according to logarithmic scale.

- Sound absorption: property generally of porous materials whereby sound reflected by their surface is appreciably reduced

- Sound insulation: a characteristic of various forms of construction, for instance walls, whereby the transmission of sound through them is reduced. Transmission loss is the loss in intensity of sound expressed in decibels.

Chemical properties:

It is the tendency of the material to combine with other substances, its reactivity, solubility etc. These are,

- Chemical composition
- Acidity
- Alkalinity
- Corrosion resistance

Electrical properties: required to evaluate the ability of the materials to permit or resist the flow of electricity. These are,

- Resistivity
- Conductivity
- Temperature coefficient of resistance
- Dielectric strength
- Thermoelectricity
- Other electrical properties

Thermal properties: in order to know the response of the material to the thermal changes and are,

- Specific heat
- Thermal expansion
- Conductivity
- Melting point
- Boiling point

Magnetic properties: required when they are used for electric purposes. These are,

- Permeability
- Hysteresis
- Coercive force

Mechanical Properties: behaviour of material when external forces are applied

Strength, Stress, Strain:

Strength is the property of material that represents its ability to withstand various forces to which it is subjected during a test or in service. It is usually defined as tensile, compressive, shear, flexure, torsional strength.

Strength of a material is due to sum of forces of attraction between negatively charged electrons and positively charged protons within the material. The covalent bonds join large numbers of atoms to produce giant molecules and renders strength. The metallic bond which is a multiple covalent bond ensures high strength of most metals.

Stress: 'a measurement of density of forces' defined as force per unit of cross section. It is expressed by the expression, $\sigma = P/A$. The SI unit of stress is Pascal (Pa) which is equivalent to a force of one Newton acting on an area of one square metre i.e. N/m^2 or $N.m^{-2}$. For most civil engineering materials, it is $MPa = MN/m^2 = N/mm^2$. Like strength, stresses are of different types.

Strain: refers to the proportional deformation produced in a material under the influence of stress. It is measured as the number of metres of deformation suffered per metre of original length and is a numerical ratio. Strain is either elastic or plastic. Elastic strain is reversible and disappears when the stress is removed. Atoms are displaced from their initial positions by the application of stress but when the stress is removed they return to their initial positions relative to their neighbours provided that the strain has been of an elastic nature.

Young's Modulus of Elasticity: is the ratio between the stress applied and the elastic strain it produces. That is, it is the stress required to produce a unit quantity of elastic strain, related to rigidity of the material and is of supreme importance to the constructional engineer. The modulus of elasticity is expressed in terms of either tensile or compressive stresses and its units are the same as those for stress.

- E = stress/strain = $\{ N/m^2 \}/ \{m/m\} = N/m^2$ = Pa, commonly expressed as GPa[GN/m^2]

E for, mild steel = 210 GN/m^2, cast iron = 98 GN/m^2, wrought iron = 197 GN/m^2.
aluminum = 72 GN/m^2, tungsten = 430 GN/m^2, copper = 120 GN/m^2, zinc =100 GN/m^2

Modulus of Rigidity: Within the elastic range, shearing stress is proportional to shearing strain. Hence the ratio of shearing stress to shearing strain is expressed by G, the modulus of rigidity. $G = \tau / \gamma$

Bulk Modulus: The relationship between direct stresses with the resulting volumetric strain is called bulk modulus and is denoted by 'K'.

Poisson's Ratio: When a body is subjected to a stress in one direction, the body will undergo a change in dimensions at right angles to the direction of stressing. The ratio of the contraction or expansion to the applied strain is known as Poisson's ratio and for isotropic bodies is given by μ = lateral strain/longitudinal strain.

Plasticity: It is opposite to elasticity. Plasticity is the property that enables the formation of permanent deformation in a material. A plastic material will retain exactly the shape it takes under load, even after the load is removed. Gold and lead are highly plastic material.

Ductility: It is the ability of a material to deform in the plastic range without breaking. Due to this property wires are made by drawing out through a hole. Gold, silver, platinum, iron, nickel, copper, aluminum, zinc, lead are in order of ductility.

Malleability: This is the property by virtue of which a material may be hammered or rolled into thin sheets without rupture. This property increases with the increase of temperature. Gold, silver, copper, aluminum, tin, platinum, lead, zinc are in order of malleability

Brittleness: Lack of ductility and/or malleability is brittleness. When a body breaks easily under shocks or impact, it is said to be brittle. Cast iron is a brittle material.

Stiffness: Stiffness designates the resistance of a material to deformation in the elastic range. Young's modulus of elasticity (E) in the indicative of the property stiffness; small values of E indicate flexible materials and large value of E reflect stiffness and rigidity.

Toughness: Toughness (or tenacity) is the strength with which a material will have a rupture. It is due to the attraction between molecules giving them power opposes to resist tearing apart. The area under the stress – strain curve indicates the toughness (energy absorbed by the material up to the point of rupture). Toughness is expressed as energy absorbed (Nm) per unit volume of material participating in absorption (m^3) or $N.m/m^3$.

Fatigue: Fatigue is the phenomenon that leads to fracture under repeated or fluctuating stresses. Fatigue fracture is progressive, beginning as minute cracks and grows under the action of repeating or fluctuating load.

Hardness: Hardness is usually defined as resistance of materials to penetration and is primarily associated with the surface.

Resilience: It is the ability of a material to absorb energy in the elastic range and is measured by the energy per unit volume required to stress a material in tension from zero stress to the proportional limit.

Creep: It is the slow plastic deformation of materials under constant stress or under prolonged loading. It depends on material type, service temperature to be encountered, the time of stress and the amount of stress involved.

Selection of Engineering Materials: depends on,

- Properties of the materials
- Types of the element of the structure
- Engineers knowledge of materials
- Economy and availability