RGU IIIT NUZVID

CE2102: Construction Materials & Introduction To Design

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PROPERTIES OF MATERIALS & THEIR ROLE, SELECTION

2.1 GENERAL

In previous module various aspects of structural design and functional design of buildings & structures were discussed. In this module we are going to learn about role of materials in accommodating the design aspects, either structural or functional. For better understanding of the role of materials, one should be aware of the various properties of materials.

We conventionally think of a material as being either a solid or a fluid. These states of matter are conveniently based on the response of the material to an applied force. A solid will maintain its shape under its own weight, and resist applied forces with little deformation. An unconfined fluid will flow under its own weight or applied force. Fluids can be divided into liquids and gases; liquids are essentially incompressible and maintain a fixed volume when placed in a container, whereas gases are greatly compressible and will also expand to fill the volume available. Although these divisions of materials are often convenient, we must recognise that they are not distinct, and some materials display mixed behaviour, such as gels, which can vary from near solids to near liquids.

In construction we are for the most part concerned with solids, since we use these to carry the applied or self-weight loads, but we do need to understand some aspects of fluid behaviour, for example when dealing with fresh concrete or the flow of water or gas into and through a material. Intermediate viscoelastic behaviour is also important.

2.2 Levels of information – The Engineering Level

The structure of materials can be described on dimensional scales varying from the smallest, atomic or molecular, through materials structural to the largest, engineering. *Figure 2.1* shows that there is considerable overlap between these for the different materials that we consider.

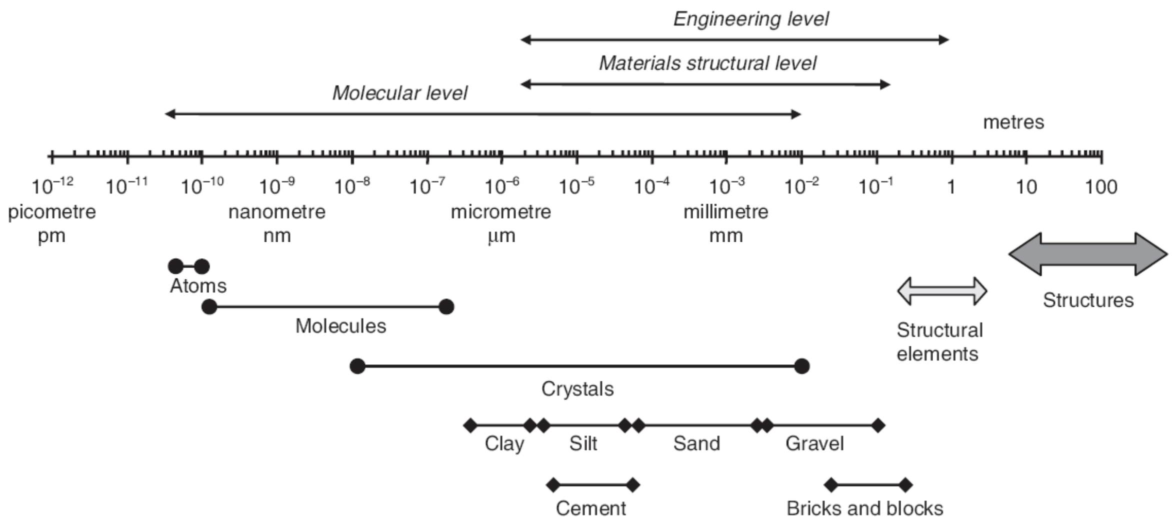

Fig 2.1 Sizes of constituents and components of structural materials and the levels

At ***the engineering level*** the total material is considered; it is normally taken as continuous and homogeneous and average properties are assumed throughout the whole volume of the material body. The materials at this level are those traditionally recognised by construction practitioners. Most of the technical information on materials used in practice comes from tests on specimens of the total material, which are prepared to represent the condition of the material in the engineering structure.

Units:

In common with all international publications, and with national practice in many countries, the SI system of units has been used throughout this text. Practice does however vary between different parts of the engineering profession and between individuals over whether to express quantities which have the dimensions of [force]/[length]^2 in the units of its constituent parts, e.g. N/m^2 , or with the internationally recognised combined unit of the Pascal (Pa). You may find the following relationships useful whilst reading:

$$1 \text{ Pa} = 1 \text{ N/m}^2 \text{ (by definition)}$$

$$1 \text{ kPa} = 10^3 \text{ Pa} = 10^3 \text{ N/m}^2 = 1 \text{ kN/m}^2$$

$$1 \text{ MPa} = 10^6 \text{ Pa} = 10^6 \text{ N/m}^2 = 1 \text{ N/mm}^2$$

$$1 \text{ GPa} = 10^9 \text{ Pa} = 10^9 \text{ N/m}^2 = 1 \text{ kN/mm}^2$$

The magnitude of the unit for a particular property is normally chosen such that convenient numbers are obtained e.g. MPa (or N/mm^2) strength and GPa (or kN/mm^2) for the modulus of elasticity of structural materials.

2.3 Building Materials – Classification

Building material is any material which is used for constructing structure for the building. Many naturally occurring substances, such as, clay, sand, gravel, wood logs, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many manmade synthetic and composite products are also being extensively used, such as concrete and steel.

Building materials may be categorized in two ways (see Fig 2.2). The first classification is bases on the source of availability of the material namely, natural and manufactured. The other classification is traditional and modern building materials.

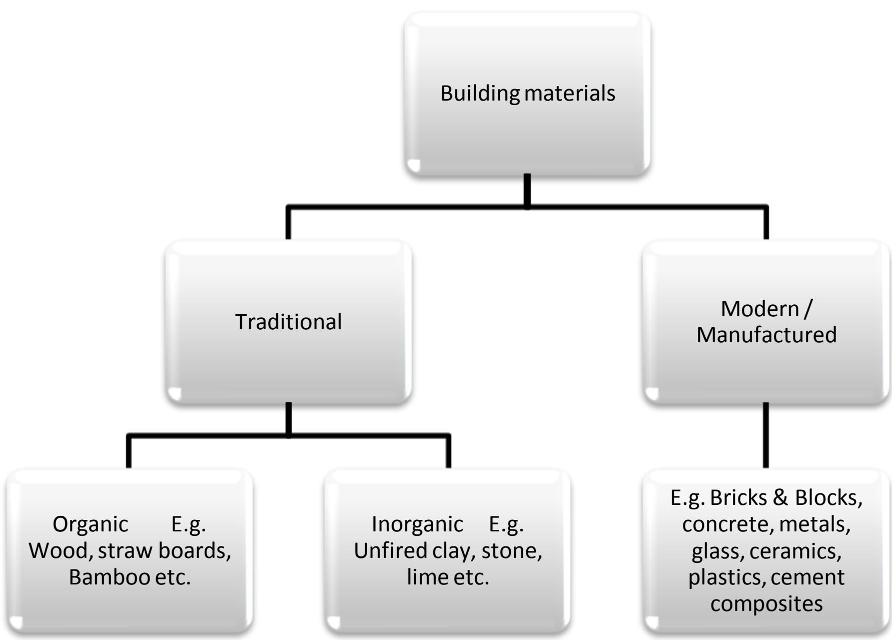

Fig 2.2 Classification of building materials

The traditional building materials are generally naturally occurring substances, whereas modern building materials mainly synthetic materials are made in industrial settings after laboratory formulation, such as plastics and petroleum based paints. The application of both the materials is extensive.

2.4 Building Products

In general, the term building products refers to the readymade elements or sections, made from various materials, which are fitted in architectural hardware and decorative hardware parts of a building. The list of building products excludes the building materials, which are used to construct the building and supporting fixtures like windows, doors, cabinets etc. It also refers to items used to put such hardware together such as glues, painting etc bought for the purpose of constructing a building. Building products can be divided into four categories;

1. *Paints, varnishes, lacquers; preservatives against rust or deterioration of wood; colourants and raw natural resins:* Although the use of paint goes far back into pre-history, nowadays the application of paint receives far more attention than in the past, whether the aim is to protect the exterior of th building or to decorate its interior.
2. *Rubber, gum, asbestos and mica:* Articles made from these materials are not included in the building materials; plastics in extruded form for use in buildings; insulating materials; flexible pipes.
3. *Products of metals and their alloys:* Transportable metal buildings; ironmongery; small items if metal hardware; pipes and tubes of metal.
4. *Non metallic products:* Rigid pipes for buildings; asphalt, pitch and bitumen.

2.5 Fundamental properties of Materials

Properties of materials are generally divided into chemical, physical. Chemistry gives a picture of material's elemental composition, while physics deals with its form, density and size etc. Chemistry is not influenced by the shape of the material; similarly physical properties such as strength, insulation values etc. are considered independent of chemical composition. However, there are many classification of these materials which are summarized in table 2.1.

Table 2.1 Groping of fundamental properties of building materials

Property Group	Properties
Physical	Shape, Size, Density, Porosity, Specific Gravity etc.
Mechanical	Strength, Elasticity, Plasticity, Hardness, Toughness, Ductility, Brittleness, Creep, Stiffness, Fatigue strength or endurance limit, Impact strength etc.
Thermal	Thermal conductivity, Thermal resistivity, Thermal capacity etc.
Chemical	Corrosion resistance, Chemical composition, , Acidity, Alkalinity etc.
Optical	Colour, Light reflectivity, Light Transmissibility etc.
Acoustical	Sound - Absorption, Transmission, Reverberation, Attenuation etc.
Physiochemical	Hygroscopicity, Shrinkage & Swelling due to moisture changes etc.
Metallurgical	Metals – Fusibility, Weldability, Hardening, Tempering etc

Among the properties given in the table no. 2.1, some important properties and hence the role of the materials is discussed below.

2.5.1 Physical Properties:

Density (ρ) is the mass of a unit volume of homogeneous material denoted by

$$\boldsymbol{\rho} = \frac{M}{V} \qquad \text{g/cm}^3$$

Where, M = mass (g), V = volume (cm^3),

Density of some building materials is as follows:

Table 2.2 Densities & Bulk densities of common building materials.

Material	*Density (kg/m3)*	*Bulk density* (kg/m^3)
Brick	2500–2800	1500 – 1800
Granite	2600 – 2900	2500 – 2700
Wood	1500 – 1600	500 – 600 (pine)
Steel	7800–7900	7850

Higher density indicates tighter packing of particles inside the substance. Density is a physical constant at a given temperature; density can help in identifying a substance.

Bulk density (ρ_b) is the mass of a unit volume of material in its natural state (with pores and voids) calculated as

$$\rho_b = \frac{M}{V} \qquad \text{kg/m}^3$$

where

M = mass of specimen (kg), V = volume of specimen in its natural state (m^3)

For most materials, bulk density is less than density but for liquids and materials like glass and dense stone materials, these parameters are practically the same. Properties like strength and heat conductivity are greatly affected by their bulk density. Bulk density and density may be also expressed in gm/cm^3, bur this presents some inconvenience, and this is why it is generally expresses as kg/m^3. For, example the bulk density of reinforced cement concrete is preferably expressed as 2500 kg/m^3 rather than 2.5 g/cm^3.

Density index (ρ_o) is the ratio of bulk density of the material to its density and is expressed as:

$$\rho_o = \textbf{Bulk density/ Density} = \frac{\rho_b}{\rho}$$

It indicates the degree to which the volume of a material is filled with solid matter. For almost all building materials ρ_o is less than 1.0 because there are no absolutely dense bodies in nature.

***Specific weight* (γ) (**also known as the unit weight) is the weight per unit volume of material,

$$\gamma = \rho \cdot g$$

Where, γ = specific weight (kN/m^3)

ρ = density of the material (kg/m^3)

g = gravity (m/s^2)

Specific weight can be used in civil engineering to determine the weight of a structure designed to carry certain loads while remaining intact and remaining within limits regarding deformation. It is also used in fluid dynamics as a property of the fluid (e.g., the specific weight of water on Earth is 9.80 kN/m^3 at 4°C). The terms *specific gravity*, and less often *specific weight*, are also used for relative density.

Specific Gravity (Gs) of solid particles of a material is the ratio of weight/mass of a given volume of solids to the weight/mass of an equal volume of water at 4°C.

$$Gs = \frac{\gamma_s}{\gamma_w} = \frac{\rho_s}{\rho_w}$$

At 4° C, γ_w = 1 g/cc or 9.8 kN/m^3.

True or Absolute specific gravity (G_a) If both the permeable and impermeable voids are excluded to determine the true volume of solids, the specific gravity is called true or absolute specific gravity.

$$G_a = \frac{(\rho_s)a}{\rho_w}$$

The absolute specific gravity is not much of practical use.

Apparent or Mass specific gravity (G_m)If both the permeable and impermeable voids are included to determine the true volume of solids, the specific gravity is called apparent specific gravity. It is the ratio of mass density of fine grained material to the mass density of water.

$$G_a = \frac{\rho}{\rho_w}$$

Porosity (n) is the degree to which volume of the material is interspersed with pores. It is expressed as a ratio of the volume of pores to that of the specimen.

$$n = V_s / V$$

Porosity is indicative of other major properties of material, such as bulk density, heat conductivity, durability, etc. Dense materials, which have low porosity, are used for constructions requiring high mechanical strength on other hand; walls of buildings are commonly built of materials, featuring considerable porosity. The air bubbles in the rocks during their formation lead to minute holes or cavities known as pores. The porosity of rocks is generally less than 20%. The porosity reduces resistance to freezing, thawing and to abrasion. The porous material absorbs more moisture; if used in concrete making, it results in loss of workability of concrete at a much faster rate. Porosity also influences the other major properties of materials such as bulk density, heat conductivity, durability etc. Fallowing interrelationship exists between void ratio and porosity.

$$n = \frac{e}{1+e}$$

Void ratio (e) is defined as the ratio of volume of voids (V_v) to the volume of solids (V_s).

$$e = \frac{V_v}{V_s}$$

If an aggregate is poured into a container of any sort it will be observed that not all of the space within the container is filled. To the vacant spaces between the particles of aggregate the name voids is applied. Necessarily, the percentage of voids like the specific weight is affected by the compactness of the aggregate and the amount of moisture which it contains. Generally void determinations are made on material measured loose.

2.5.2 Mechanical Properties:

The important mechanical properties considered for building materials are: strength,

compressive, tensile, bending, impact, hardness, plasticity, elasticity and abrasion resistance.

Strength is the ability of the material to resist failure under the action of stresses caused by loads, the most common being compression, tension, bending and impact. The importance of studying the various strengths will be highlighted from the fact that materials such as stones and concrete have high compressive strength but a low (1/5 to 1/50) tensile, bending and impact strengths.

Compressive Strength is found from tests on standard cylinders, prisms and cubes—smaller for homogeneous materials and larger for less homogeneous ones. Prisms and cylinders have lower resistance than cubes of the same cross-sectional area, on the other hand prisms with heights smaller than their sides have greater strength than cubes. This is due to the fact that when a specimen is compressed the platens of the compression testing machine within which the specimen is placed, press tight the bases of the specimen and the resultant friction forces prevent the expansion of the adjoining faces, while the central lateral parts of the specimen undergoes transversal expansion. The only force to counteract this expansion is the adhesive force between the particles of the material. That is why a section away from the press plates fails early.

The test specimens of metals for tensile strength are round bars or strips. Bending Strength tests are performed on small bars (beams) supported at their ends and subjected to one or two concentrated loads which are gradually increased until failure takes place.

Hardness is the ability of a material to resist penetration by a harder body. Mohs scale is used to find the hardness of materials. It is a list of ten minerals arranged in the order of increasing hardness. Hardness of metals and plastics is found by indentation of a steel ball.

Elasticity is the ability of a material to restore its initial form and dimensions after the load is removed. Within the limits of elasticity of solid bodies, the deformation is proportional to the stress. Ratio of unit stress to unit deformation is termed as *modulus of elasticity*. A large value of it represents a material with very small deformation.

Plasticity is the ability of a material to change its shape under load without cracking and to retain this shape after the load is removed. Some of the examples of plastic materials are steel, copper and hot bitumen. E.g. steel and hot bitumen.

Ductility is the property of being permanently elongated under tensile stress to an appreciable extent before necking begins. The change of form remains after the force is removed. It is therefore the converse of elasticity. E.g. Wrought iron and copper.

Brittleness is the tendency of the material to break sudden under stress. Brittle materials have very small deformation capability, either elastic or plastic. E.g. Bricks, Concrete, stone etc.

Creep property enables the material under constant load to deform slowly, but progressively over a certain period. It depends on temperature and this deformation is permanent. E.g. Rail sleepers.

Fatigue refers to the effect of cyclical repeated stress. A material has a tendency to fail at lesser stress level, when subjected to repeated loading. This is measured in terms of endurance limit using plot between stress level vs. no. of cycles of load.

Stiffness or ***Rigidity*** is the property of a material which enables it to resist deformation. Stiff materials have a high modulus of elasticity; thus permit small deformation for a given load.

Flexibility (also called as pliability) is the tendency of a body to change its form under different stresses. Flexible materials have low elastic modulus and can bend considerably without fracture.

Resilience is the term used to express the quantity of work done in deforming a piece of material up to elastic limit.

Toughness enables the material to be twisted, bent or stretched under high stress before rupture. Toughness depends upon strength and flexibility. Tough materials can withstand heavy shocks.

Durability is the ability of a material to resist the combined effects of atmospheric and other factors.

2.5.2 Thermal Properties:

Heat conductivity is the ability of a material to conduct heat. It is influenced by nature of material, its structure, porosity, character of pores and mean temperature at which heat exchange takes place. Materials with large size pores have high heat conductivity because the air inside the pores enhances heat transfer. Moist materials have a higher heat conductivity than drier ones. This property is of major concern for materials used in the walls of heated buildings since it will affect dwelling houses.

Thermal capacity is the property of a material to absorb heat described by its specific heat. Thermal capacity is of concern in the calculation of thermal stability of walls of heated buildings and heating of a material, e.g. for concrete laying in winter.

Fire resistance is the ability of a material to resist the action of high temperature without any appreciable deformation and substantial loss of strength. Fire resistive materials are those which char, smoulder, and ignite with difficulty when subjected to fire or high temperatures for long period but continue to burn or smoulder only in the presence of flame, e.g. wood impregnated with fire proofing chemicals. Some of the materials neither crack nor lose shape such as clay bricks, whereas some others like steel suffer considerable deformation under the action of high temperature.

Refractoriness denotes the ability of a material to withstand prolonged action of high temperature without melting or losing shape. Materials resisting prolonged temperatures of 1580°C or more are known as refractory. High-melting materials can withstand temperature from 1350–1580°C, whereas low-melting materials withstand temperature below 1350°C.

2.5.3 Physiochemical Properties:

Hygroscopicity is physiochemical property of a material which describes volume change (Shrinkage & Swelling) of a material due to moisture changes. The building materials may absorb water vapour from the air. Water absorption is influenced by air- temperature and relative humidity.

Water absorption describes the ability of the material to absorb and retain water. It is expressed as percentage in weight or volume of the dry material.

$$W_w = \frac{(M_1 - M)}{M} * 100$$

$$W_v = \frac{(M_1 - M)}{V} * 100$$

Where, M_1: Mass of saturated material (g)

M: Mass of dry material (g)

V: Volume of the material including the pores (mm^3)

Water absorption by volume is always less than 100%; whereas that by weight of porous material may exceed 100%.

Table 2.3 Typical properties of common construction materials.

Material	*Density* (kg/m^3)	*Tensile Strength* (MPa)	*Elastic Modulus* (GPa)	*Coefficient of Thermal Expansion* (10^{-6}/°C)	*Thermal Conductivity* (W/m·K)
Aluminum					
Pure	2800	100	70	23	220
Alloy	2800	300	70	23	125
Steel					
Mild	7800	400	210	12	50
High strength	7800	1900	210	12	50
Glass	2500	60	65	6	3
Wood					
Soft	350	50	5.5	—	0.2–0.6
Hard	700	100	10	—	0.2–0.6
Plastic (polystyrene)	1000	~50	~3	72	0.1
Rock (granite)	2600	~20(~25^b)	~50	7–9	3
Concrete	2300	3(35^b)	~25	10	3

2.6 Role of Materials

The role of materials in a construction activity can only be understood by better understanding of its properties. The materials selection should be based on no. of basic issues which including symbolism; appropriateness; physical & mechanical properties. These issues are discussed below.

2.6.1 Symbolism

Building materials generally carry specific tags with in cultures and regions. Terms such as natural or artificial, structural, climatic or surface materials describes a few such associations or groups. Each particular group of materials creates its own form of working. A few considerations are briefly discussed below.

1) The **weight** of the material determines a significant part of structural loading that the building will be required to support. For some structures, such as Gravity dams the weight contributes for robustness for the structure to resist against loads per se.

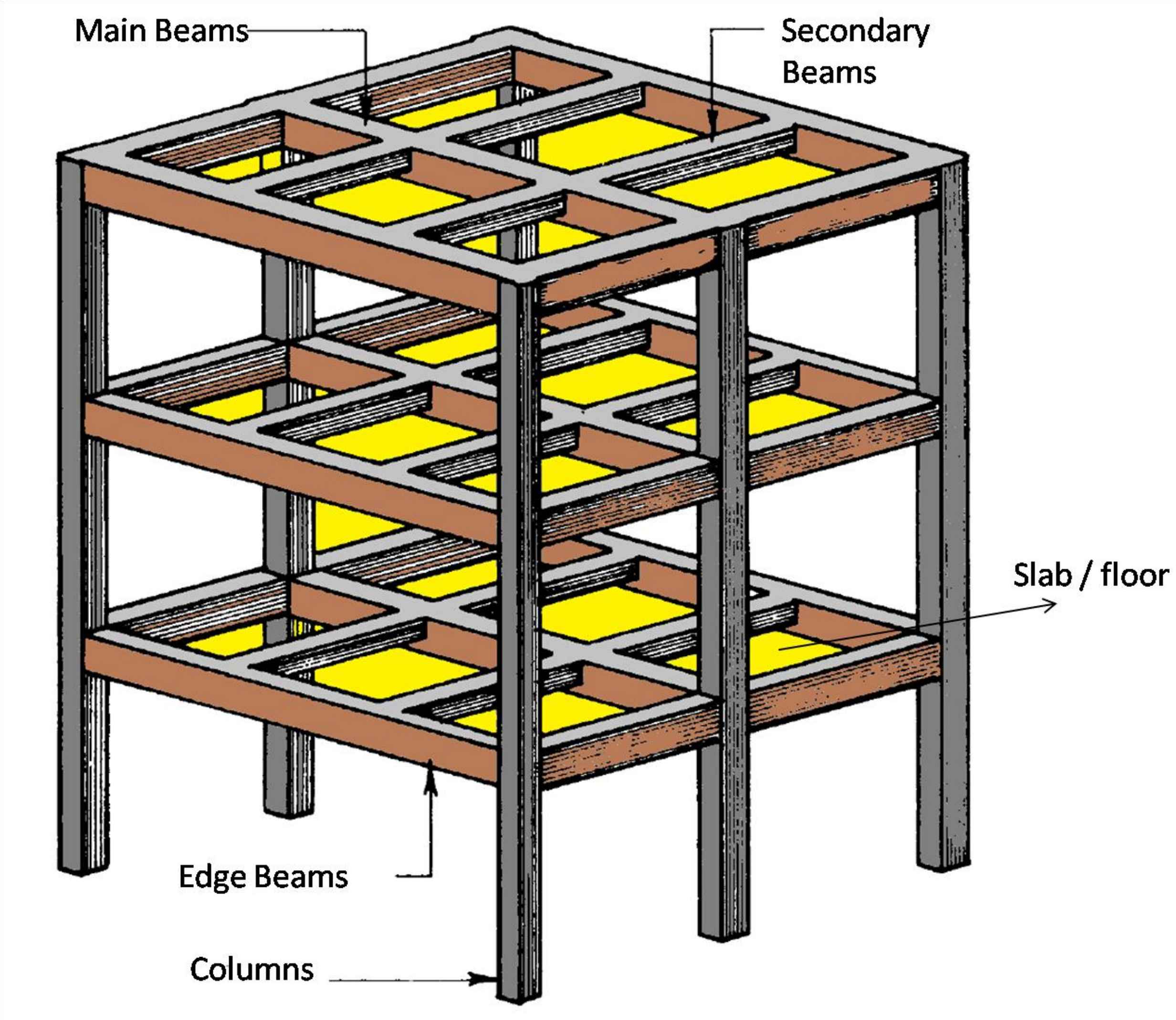

Fig 2.3 Skeletal Frame of a structure & components.

2) **Compressive strength** represents the pressure that a material can sustain before collapsing; compression is particularly important in compression member such as columns (see fig 2.3).
3) **Tensile strength** represents tension a material can sustain before fracture by stretching. This property is particularly important in tension structures.
4) **Thermal properties** describe the materials ability to conduct heat through or retain heat.

5) **The permeability** of the materials depends upon porosity of the material, size and structure of pores. The permeability of air, vapour and water has different significance for different types of structures.

   Air permeability indicates the amount of air that can pass through a material under pressure. The moisture content reduces the amount of air through it.Right specification selection of materials is important for airtight buildings.

   Vapour permeability represents the amount of vapour penetration under different pressures and depends upon the moisture content and temperature of the material. This factor is important in dealing with the damage caused by dampness.

   Water permeability is the capacity of a material to allow water to penetrate under pressure. Materials like glass, steel and bitumen are impervious.

6) **Durability** of a material is generally described in terms of weathering, frost and corrosion resistances. Weathering resistance is the ability of a material to withstand alternate wet and dry, or hot and cold conditions for a long period without considerable deformation and loss of strength.

   Frost resistance denotes the ability of a water-saturated material to sustain repeated freezing and thawing cycles which decrease the mechanical strength of the material considerably. On freezing the water contained by the pores increases in volume up to nine per cent; thus, exerting internal pressure on the walls of the pores which may collapse due to high stresses.

   Corrosion Resistance is the property of a material to withstand the action of the acids. alkalies, gases etc. which tend to corrode (or oxidize).

7) **Fire Resistance** is the ability of a material to resist the action of high temperature without any appreciable deformation and substantial loss of strength. Fire resisting materials char, smoulder, and ignite with difficulty when subjected to fire or high temperatures for long period but continue to burn or smoulder only in the presence of flame, e.g. wood impregnated with fire proofing chemicals. Some of the materials such as clay brick neither crack nor lose shape, whereas non burning materials like steel suffer considerable deformation under the action of high temperature.

   Refractoriness denotes the ability of a material to withstand prolonged action of high temperature without melting or losing shape. Materials resisting prolonged temperatures of 1580^{o}C or more are known as refractory. High-melting materials can withstand temperature from 1350 - 1580^{o}C, whereas low-melting materials can withstand temperature below 1350^{o}C.

2.6.2 Appropriateness

There are three primary areas that must be evaluated in selecting appropriate materials and assemblies. These are,

Material compatibility with climatic, cultural, and aesthetic conditions:

Climate is one of the most important factors to consider in material and assembly selection. The buildings that have not taken local environmental conditions into consideration, or a building designed for a specific site that ignores climatic issues performs poorly. Such buildings fail to keep inhabitants comfortable without excessive energy expenditures and near complete reliance on mechanical systems to rectify poor construction decisions. Materials also must be compatible with specific regional and local cultural and aesthetic conditions. For example, flat roof brick residential construction would not do well in hilly regions, where the widespread use of wood framing and pitched roof is climatically appropriate, as well as culturally embraced.

Suitability of material to occupancy and size of building:

This important issue concerning occupancy and size of building includes durability, structural and fire protection requirements. The material choices are generally legally limited by the local building bylaws for type and size, in order to protect public health, safety, and welfare. For instance, a detached single-family house has far fewer limitations than a high-rise office or residential building or a hospital, from which hundreds of inhabitants must be evacuated in case of emergency. In general, buildings with large occupancy numbers (theaters, restaurants and lecture halls) and greater enclosed area require more fire-resistant construction and more complex fire protection systems. Another concern is the added wear and tear on a densely inhabited building, such as a public school or hospital, where material durability is a major concern.

Environmental impact

Environmental impact issue concerns with the raw materials, processing and fabricating building materials, transportation impact and recycling. In addition to these easily quantifiable issues, the long term ecological effect of material production is equally important and must be analyzed holistically. The fallowing measures may help in reducing environmental impact.

- Materials should be obtained from renewable sources, such as wood harvested from sustainably managed old growth forests.
- The energy sources utilized in a material preparation, sometimes termed embodied energy must be duly considered.
- Transportation impacts and expenses should be minimized. The locally available materials often make a better than those imported or procured from long distances.
- While selecting materials due consideration should be given to durability and lie span of building. As far as possible recycled materials should be used. A construction system which is easy to dismantle should be selected so that the materials may be recycled and reused in the future.
- The use of materials containing volatile organic compounds (VOC) should be avoided and low toxicity building materials should be selected to avoid off-gassing after completion of construction. VOC are generally present in many paints, carpets, acoustic ceiling tiles, vinyl flooring and wall coverings; and adhesives.
- Construction materials should be so selected that that do not have much by-products. For instance building with reusable form work for cast-in-situ concrete construction avoids plywood and wood form work waste.

Self Assessment: REVIEW QUESTIONS

1. What is engineering level of information?
2. Briefly explain about classification of building materials.
3. What are building products and how they are different from building materials?
4. Define the physical and mechanical properties of materials.
5. What is the role of materials in construction? Explain in terms of symbolism, appropriateness and impact on the environment.