Introduction

Building materials have an important role to play in this modern age of technology. Although their most important use is in construction activities, no field of engineering is conceivable without their use. Also, the building materials industry is an important contributor in our national economy as its output governs both the rate and the quality of construction work.

There are certain general factors, which affect the choice of materials for a particular scheme.

Perhaps the most important of these is the 1- *climatic background*. Obviously, different materials and forms of construction have developed in different parts of the world as a result of climatic differences. Another factor is the 2 - *economic aspect* of the choice of materials. The rapid advance of constructional methods, the increasing introduction of mechanical tools and plants, and changes in the organisation of the building industry may appreciably influence the choice of materials.

The principal properties of building materials predetermine their applications. Only a comprehensive knowledge of the properties of materials allows a rational choice of materials for specific service conditions.

The industry of building materials gains in both quantity and quality, so that new, more efficient products are manufactured and the output of conventional materials is increased.

To develop products of greater economic efficiency, it is important to compare the performance of similar kinds of materials under specific service conditions. Expenditures for running an installation can be minimised by improving the quality of building materials and products.

Building industry economists are thus required to have a good working knowledge, first, of the building materials, second, of their optimum applications on the basis of their principal properties, and, third, of their manufacturing techniques, in order that the buildings and installations may have optimum engineering, economic performance and efficiency. Having acquired adequate knowledge, an economist specialising in construction becomes an active participant in the development of the building industry and the manufacture of building materials.

Construction material science is the engineering object that involved with the use of construction materials in constructing buildings in a way that achieve the strength, economy, safety and durability.

This science also search a new suitable materials to be used in building construction.

Types of building:

1- Lightweight building: such buildings transfer the load of the building by its bearing walls to the foundation, these buildings consist usually of one or two floors.

2- Heavy building: these buildings collect the load to the columns, by the roofs and beams, and transfer this load to the lower floor till the load reach the foundation and the soil within its bearing capacity , such buildings called "skeleton building" .

Main factors to be consider in construction:

1- Design
  a)architectural design
  b) civil desing
  c) other design such as sanitary, electric
2- Construction materials to conform the specification
3- Construction work

Mechanical properties of materials:-

Normal stress :

The application of an external force to a body cause internal resisting force within the body, whose resultant is equal in magnitude but opposite in direction to the applied force .the applied force (N or lb) on a body divided by its area (mm^2 or ft^2).

$\sigma = P/A$

There are many types of stress occurred in the material such as:

1- Compressive strength
2- Shear stress
3- Tensile stress

- Strength: the ability of the material to stand under external load
- Ultimate strength: maximum ability to bear the load after which the material failed

Engineering strain:

When a member is subjected to a tensile or compressive stress, it undergoes a deformation (A). Tensile force causes an elongation of the body, while compressive caues a shortening of the dimension of the body in the direction of the force. The elongation (or shortening) per unit length is called strain (ϵ).

1-1 physical properties

1-Density (e) is the mass of a unit volume of homogeneous material denoted by

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

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

Density of some building materials, as shown in Table (1-1)

2-bulk density (e_b) is the mass of a unit volume of material in its natural state (with pores and voids) calculated as

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

where M = mass of specimen (kg)

V = volume of specimen in its natural state (m^3)

Note: Bulk density may be expressed in g/cm^3 but this presents some inconveniences, and this is why it is generally expressed in 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.

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 densities of some of the building materials as shown in Table (1-1).

Table (1-1): Density and Bulk Density of Material

Material	*Bulk density (kg/m3)*	*Density (g/cm3)*
Wood, Pinewood	500–600	1.5–1.6
Sand	1450–1650	
Brick	1600–1800	2.5–2.8
Granite	2500–2700	2.6–2.9
Portland cement		2.9–3.1
Steel	7850	7.8–7.9

3- Density Index : is the ratio

$$\rho_o = \frac{\text{bulk density}}{\text{density}}$$

$$= \frac{\rho_b}{\rho}$$

Where e_b=bulk density

e=density

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

4-specific weight 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)
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/m3 at 4°C).

The terms *specific gravity*, and less often *specific weight*, are also used for relative density.

5-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.

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

At 4° C γ_w = 1 g/cc or 9.8 kN/m^3

a-True or absolute specific gravity (Ga): 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.

b-Apparent or mass specific gravity (Gm): 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.

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

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

$$n = \frac{V_v}{V}$$

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. Following inter relationship exists between void ratio and the porosity.

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

7-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.

There are two classes of methods commonly employed for measuring voids, the direct and the indirect. The most-used direct method consists in determining the volume of liquid, generally water, which is required to fill the voids in a given quantity of material. Since in poring water into fine aggregate it is impossible to expel all the air between the particles, the measured voids are smaller than the actual. It therefore becomes evident that the above direct method should not be used with fine aggregate unless the test is conducted in a vacuum. By the indirect method, the solid volume of a known quantity of aggregate is obtained by pouring the material into a calibrated tank partially filled with water; the difference between the apparent volume of material and the volume of water displaced equals the voids. If very accurate results are desired void measurements should be corrected for the porosity of the aggregate and moisture it contains.

8- Hygroscopicity is the property of a material to absorb water vapour from air. It is influenced by air-temperature and relative humidity; pores—their types, number and size, and by the nature of substance involved.

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

$$W_w = \frac{M_1 - M}{M} \times 100$$

$$W_v = \frac{M_1 - M}{V} \times 100$$

where

M_1 = mass of saturated material (g)

M = mass of dry material (g)

V = volume of material including the pores (mm^3)

Water absorption by volume is always less than 100 per cent, whereas that by weight of porous material may exceed 100 per cent.

The properties of building materials are greatly influenced when saturated. The ratio of compressive strength of material saturated with water to that in dry state is known as *coefficient of softening* and describes the water resistance of materials. For materials like clay, which soak readily, it is zero, whereas for materials like glass and metals it is one. Materials with coefficient of softening less than 0.8 should not be recommended in the situations permanently exposed to the action of moisture.

Weathering Resistance is the ability of a material to endure alternate wet and dry conditions for a long period without considerable deformation and loss of mechanical strength.

10-Water Permeability: is the capacity of a material to allow water to penetrate under pressure.

Materials like glass, steel and bitumen are impervious.

11-Frost Resistance: denotes the ability of a water-saturated material to endure repeated freezing and thawing with considerable decrease of mechanical strength. Under such conditions the water contained by the pores increases in volume even up to 9 per cent on freezing. Thus the walls of the pores experience considerable stresses and may even fail.

12-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.

13-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.

14-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. Non-combustible materials neither smoulder nor char under the action of temperature. 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.

15-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.

1-2 Chemical Resistance is the ability of a material to withstand the action of acids, alkalis, sea water and gases. Natural stone materials, e.g. limestone, marble and dolomite are eroded even by weak acids, wood has low resistance to acids and alkalis, bitumen disintegrates under the action of alkali liquors.

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

1-3 Mechanical Properties

The important mechanical properties considered for building materials are: strength, compressive, tensile, bending, impact, hardness, plasticity, elasticity, and abrasion resistance.

1-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.

2-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 plattens 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 and that of binding materials are of the shape of figure eight.

3-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.

4-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.

5-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.

6-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

1-4 Characteristic Behavior under Stress

The common characteristics of building materials under stress are ductility, brittleness, stiffness, flexibility, toughness, malleability and hardness.

The ductile materials can be drawn out without necking down, the examples being copper and wrought iron.

Brittle materials have little or no plasticity. They fail suddenly without warning. Cast iron, stone, brick and concrete are comparatively brittle materials having a considerable amount of plasticity.

Stiff materials have a high modulus of elasticity permitting small deformation for a given load.

Flexible materials on the other hand have low modulus of elasticity and bend considerably without breakdown.

Tough materials withstand heavy shocks. Toughness depends upon strength and flexibility.

Malleable materials can be hammered into sheets without rupture. It depends upon ductility and softness of material. Copper is the most malleable material. **Hard materials** resist scratching and denting, for example cast iron and chrome steel. Materials resistant to abrasion such as manganese are also known as hard materials.

Bonding Materials

Material with adhesive and cohesive properties which make it capable to bond mineral fragments into a compact whole. This definition embraces a large variety of cementing materials, among them:

1. Gypsum plaster
2. Lime
3. Cement

1. Gypsum plaster :

Gypsum plaster comprise all that class of plastering and cementing materials which are obtained by partial or complete dehydration of natural gypsum and to which contain materials that serve as retarders or hardeners, or that impart greater plasticity to the product, may not have been added during or after calcinations.

1.1 Raw materials - Gypsum rocks:

Pure gypsum is a hydrous lime sulfate ($CaSO_4 . 2H_2O$), the composition of which by weight is:

Lime sulfate
- Lime CaO - 32.6%
- Sulfur trioxide SO_3 - 46.5%

Water H_2O - 20.9

Total= - 100 %

Natural deposit of gypsum are very seldom pure, the lime sulphated being adulterated with silica, alumina, iron oxide, calcium carbonate and magnesium carbonate. The total of all impurities varies from a very small amount up to a maximum of about 6%.

2. Lime :

2.1 Definition and classification:

2.1.1 Quick lime:

Is the name applied to the commercial form of calcium oxide CaO, obtained by the calcinations of a stone in which the predominating constituent is calcium carbonate $CaCO_3$, often replaced, to a greater or less degree by magnesium carbonate $MgCO_3$, this product being one that will slake on the addition of water.

2.1.2 Hydrated lime:

Is quick lime has been chemically satisfied with water during manufacture.

2.2 Raw materials - Lime stone rocks:

Pure lime stone rocks consist entirely of $CaCO_3$. Pure calcium carbonate consists of 56 parts by weight of CaO to 44 parts of CO_2.

Lime stones encountered in practice depart more or less from this theoretical composition. Part of the lime is almost always replaced by a certain percentage of magnesia MgO. In addition to magnesia, silica, iron, oxide and alumina are usually present and too slight extent, sulflir, and alkalies.

The physical character of the lime stone has an effect upon the burning temperature. A naturally, coarse, porous stone is acted upon by heat much more rapidly than a dense, finely crystalline stone, and may be burned more rapidly and at a lower temperature.

2.3 Manufacture of lime - Theory of calcinations:

The burning or calcinations of lime accomplishes three objects:

a. The water in the stone is evaporated.

b. The lime stone is heated to the request temperature for chemical dissociation.

c. The CO_2 is driven off as a gas, leaving the oxides of calcium and magnesium.

2.4 Uses of quick lime:

Lime may be used as:

a. Building materials.

b. Finishing materials.

Classification of bricks according to constituent raw material:

1. Clay bricks
2. Lime - sand bricks
3. Concrete bricks

1. Clay bricks:

1.1 Raw materials:

a. Alumina

Alumina is main constituent of every clay. Loam soil (adhesive soil) forms good clay. In absencemof sand, pure clay will develop cracks due to shrinkage on drying and burning. A good clay bricks should contain about 20% of alumina.

b. Silica Free silica (sand), if added to clay in suitable proportion makes hard and prevents it from warping and shrinkage on drying. Silica, if present in greater proportion, makes a brick brittle. Silica present in the combined form (aluminum silicate) does not form good bricks, as it will shrink and develop cracks.

Both silica and alumina should be in free form.

c. Lime: This also should be present in small quantities in the brick earth. It should be in a finely produced condition and it should not be in the form lamps or clods.

Lime prevents shrinkage of raw bricks. It helps fusion of sand at the kiln temperature. This fused sand will bind the bricks particles fast.

d. Iron oxide: A small quantity of oxide of iron (5-6%) is desirable. It helps the fiision of sand like lime. It gives red colure to burn bricks. Excess of iron oxide imparts dark blue or blackish colure to brick, while, alower percentage of iron oxide makes the brick yellow in colure. Iron oxide makes the bricks hard and strong.

e. Magnesia: A small amount of magnesia helps to decrease the shrinkage of bricks. This gives a yellow tint to the bricks. But excess of magnesia is not desirable as it tends to produce the decay of bricks.

1.6 Properties of bricks:

The raw materials and the manner and degree of burning influence the physical properties greatly and therefore wide ranges in values are to be expected for each property.

1.6.1 Compressive strength:

The test is carried out in accordance with Iraqi standard No. 24. The brick placed between two plywood sheets and carefully centered between plates of the compression testing machine. The loadshall be applied at a uniform rate until failure occurs.

Compressive strength = Load at failure/ Cross sectional area subjected to load

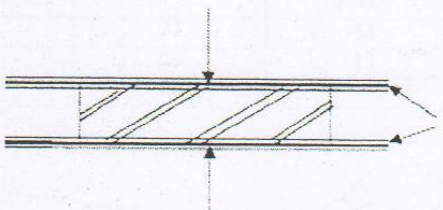
1.6.2 Water absorption:

The absorption of water by brick is often considered to be indicative of its probable durability. The test also provides a means of checking on the consistency of the bricks produced by one factory. In this test the specimen shall be dried to constant weight in a ventilated oven at 110 °C to 115 °C for about 48 hours. Next the specimen shall be completely immersed in clean water for 24 hours. Each specimen shall then be removed, the surface water wiped off with a damp cloth and the specimen weight.

Water absorption = {(W2-W1)/W1 } *100%

Where W2 - weight of brick after 24 hours in water

W1- weight of dry brick



2. Sand - Lime bricks:

2.1 Raw materials:

The raw materials required for manufacture of sand - lime bricks are as follow:

2.1.1 Sand

The sand used in sand - lime brick should meet the physical and chemical requirements of Iraqi standard No. 572:

a. Contain not less than 70% silica.

b. Well graded between 0.005 - 0.5 mm.

c. Free from impurities such as organic matter, rock, minerals and soluble salts.

d. The percentage of clay not more than 10%

e. Iron compounds not more than 1.5%.

f Gypsum content not more than 1%.

g. ($CaO + MgO$) not more than 5%.

2.1.2 Lime: The lime used in sand lime brick should meet the requirements of Iraqi standard No. 572:

a. Activity of lime shall not be less than 83%.

b. The percentage of lime retaining on 75 μm sieves should not be greater than 2%.

2.1.3 Water: Water used in sand lime brick should be fit for drinking..

2.1.4 Pigment: To make colored sand lime bricks, suitable coloring pigment should be added in the mixture of sand and lime. The quantity of pigment varies from o.2 to 3% of the total weight of the brick.

2.2 Mix proportion: The percentage of lime should be between *9-15%* of the weight of sand.

2.3 Manufacture: a. Sand, lime and pigment are taken in suitable proportions and they are thoroughly mixed with are quired quantity of water.

b. The material is then molded in the shape of the bricks under mechanical pressure (150-200 kg/cm).

c. Bricks are then placed in closed chamber and subjected to saturated steam pressure of about 8.5-16 kg/cm for 6-12 hours to speed up the interaction between lime and sand. The process is known as autoclaving.

Blocks

Introduction :

Blocks are structural units used in roofing, blocks will be loaded in the structures therefore it should not used before 14 days of production. The block should be clear from cracks or defects that reduce the bearing capacity and durability of the block. The faces of the block should be rough to ensure cohesion between the block and finishing layers.

Manufacture of blocks:

Blocks are made from cement and water and the sand will be added gradually, then mix it in the mixer for about 5 minutes to have homogeneous mix, then pour the mix in the moulds. Open the moulds and leave the block for 14 day before use. To check the strength of the block its important to test one sample before use. Blocks used in many applications such as bearing walls or filling concrete skeletons. All the problems that faces the block works related to cracking and settlement when the foundation is weak. The main purpose for block failure in structure appears when it is exposed to water; therefore it should be ensured that construction joints between blocks should be strong.

Types of blocks:

- Concrete blocks

Its dimension (200x300) mm and its height should not less than 100mm (the height less than the length or the height less than 6 times the width
There ~~are 3 ty~~pes of concrete blocks

1. Solid block: this block does not have pores except two circular holes Ø 10 cm each. This type of block used in bearing walls the modulus of rupture not less than (70 kg /cm^3)

But nowadays this type rarely used due to:

Tiles :

Tiles are thin slabs of brick earth,burnt in kiln. Tiles are thinner than bricks and have greater tendency to crack and warp in drying and burning than ordinary bricks and are more liable to breakage. Therefore, great care is needed in their manufacture. They should be dried in the shade, burnt and cooled gradually in specially made kilns.

Types,classifications and uses of tiles:

Tiles divided according to their uses in to:

1- Roofing tiles 2- flooring tiles

3-wall tiles 4-drain tiles

5-glazed tiles

1-roofing tiles:

These tiles should be strong, durable and perfectly leakproof, although they are expensive but they need less maintenance cost, the main types of roofing tiles are described below:

- Flat tiles:are rectangular in shape and of variouse dimensions. They are laid in cement or lime mortar. Many types of flat tiles are discussed below:
  (a)slate tiles: the available size (60cmx30cmx15mm)and(50cmx25cmx10mm) , these tiles should be reasonably straight, uniform in colour, good texture and free from veins, cracks, fissures and white patches.the water

Properties of building tiles

-quality : building tiles should be made from good clay of even texture, they should be well burnt and uniform in size and shape and should be free from irregularities such as bends, twists and cracks.

-warpage test:in case of flooring tiles warpage should not exceed 2% along the edge and (1.5)% along the diagonal. In case of terracing tiles should not exceed in any direction 1%.

-characteristics of good tiles: a good tiles should posses the following characteristics:

1-should posses uniform colour

2-should be properly burnt

3-should be free from cracks ,flaws or bends

4-should be hard and durable

5-should have proper shape and size

6-when placed in position, it should fit well

7-its broken surface should exhibit even and compact structure

8-it should give a clear ringing sound when struk with light hammer or with another tile.

Manufacture of tiles

The manufacture of common tiles includes:

1-preparation of clay