CHAPTER 2 CLASSIFICATION NATURE AND PROPERTIES OF MATERIALS

1. CLASSIFICATION OF MATERIALS

Materials that are used for construction purpose can be broadly classified into Metallic and Non-metallic.

a) Metallic materials

In general, metals can be classified into two major groups: **Ferrous** and **Non-ferrous.** A ferrous metal is one in which the principal element is iron, as in:

- Steel
- Wrought iron
- Cast iron

A non-ferrous metal is one in which the principal element is not iron, as in:

- Copper
- Aluminum
- Lead
- Tin
- Zinc

b) Non-Metallic

- Cementing materials (lime, cement, etc)
- Concrete
- Timber
- Stone
- Plastics.
- Ceramics.

➢ *Based on their physical nature materials can also be classified as*:

- Solid
- Liquid
- Gas

➢ *Materials can also be classified based on their mode of production as:*

- Naturally occurring materials
- Industrially produced materials
- Materials produced at construction site

2. PROPERTIES OF MATERIALS

Properties of materials have great practical significance and a broad understanding of these properties is essential. Properties which relate to materials generally are: Physical, Chemical and Mechanical.

a) Physical Properties:-

- Density and Specific Gravity
- Heat conductivity
- Acoustic(sound) permeability
- Fire resistance
- Porosity

b) Chemical Properties:-

- Corrosion resistance
- Combustibility Adhesion
- Toxicity
- Decay resistance
- Hardening

c) Mechanical Properties:-

- Strength -resistance of a material to the action of external static forces (compressive, tensile, bending, shear, and torsion strength)
- Strength- resistance of a material to various dynamic external forces (impact and vibratory loads)

Mechanical properties of materials have great practical significance and a broad understanding of these properties and the behavior of materials under load are essential. Selection of materials for construction purpose mainly depends on its mechanical properties.

3. BEHAVIOR OF MATERIALS UNDER LOAD

Application of external forces on a solid body in equilibrium results in:

- Internal resisting forces are developed in the body which balance the externally applied force
- The body is deformed to varying degree

The intensity of the internal force is called **STRESS** and the deformation per unit length is called **STRAIN**

Depending upon the arrangement and direction of the external forces, the stress produced in a body may be tensile stress, compressive stress, shear stress, bending stress, tensional stress, and various combinations of the above stresses.

When a body, which has been deformed under the action of external forces, is released from such action, the deformed bodies may or may not recover their original form depending on the magnitude of the applied load and the elastic property of the material that they are made out of it. If a body recovers the original form, it is said to be elastic. If it fails to recover its original form, it is said to be plastic.

A perfectly elastic body is one that fully recovers its original size and shape after the application and removal of load. Most engineering materials are in part elastic and in part plastic. Stiffness is the measure of the ability of the material to resist deformation .In other words, a body is said to be stiff if it sustains large loads without to much deformations.

Depending on the magnitude of the applied load and the elastic property of the material the deformation produced may be permanent or temporary. As the magnitude of the applied load increase the deformation increases, a point is reached beyond which the original form is not fully recovered; this point is **elastic limit of the material.**

3.1 Testing of Materials for Mechanical Properties

Mechanical tests are those used to examine the performance of construction materials under the action of external forces. Mechanical tests may be classified under the following headings:-

A) With reference to the arrangement and direction of *the external forces.*

B) *With reference to the rate and duration* of *the load Application.*

C) *With reference to the effect of the test on the specimen.*

A) With reference to the arrangement and direction of the external forces

i) Tension test

Under tension test:

- The specimen is subjected to an axial tensile force
- Tensile stress is produced on cross sectional area perpendicular to the line of action of the force.
- The specimen increases in length.

ii) **Compression test**

Under compression test:

- The specimen is subjected to an axial compressive force
- Compressive stress is produced on cross sectional area Perpendicular to the line of action of the force
- The specimen decreases in length.

iii) **Shear test**

The shearing stress in a specimen is determined on cross-sectional areas parallel -to the line of action of the external force.

iv) **Bending test**

Under bending test: -

- A specimen is subjected to forces that give rise to bending moments
- The resulting stresses are compressive on one side of a neutral plane and tensile on the other side
- Shear stresses exist throughout the beam

v) **Torsion test:**

is an indirect test used to determine the shearing strength of materials. Test specimens for torsion test are generally cylindrical shape, solid or hollow.

B) With reference to the rate and duration of the load application

i) **Static tests:** are made with gradually increasing load, such as the ordinary tests in tension, compression tests

ii) **Dynamic tests**: are made with suddenly applied loads, as by falling weight or pendulum. Such as drop impact test.

iii**) Wear tests:** are made to determine resistance to abrasion and impact as in the case of paving materials.

iv) **Long-time tests:** are made with loads applied to the object under test for a long period. They are used for materials such as concrete.

v) **Fatigue tests:** are made with fluctuating stresses repeated many a times.

C) With reference to the effect of the test on the specimen

i) **Destructive test:** under these test methods the specimens are either crushed or ruptured and made useless at the end of the test. Examples under this category of test are tension in steel and compression test in concrete.

ii) **Non-destructive test**: these are usually used to test the strength of members of existing structures without affecting their performance. Example of this test is hammer test in concrete.

3.2 Stress-Strain Properties in Simple Tension Test

In the standard conventional tension test, a specimen is subjected to a gradually increasing axial tensile force P by means of a testing machine. At various increment of force, the change in length ΔL of the specimen for an initial gage length L_o are measured by a strain gage .It is generally assumed that, for a gage length L_o of the specimen, the stress is uniformly distributed for all points on each cross section and for all cross sections perpendicular to the line of action of the force.

$$\sigma = P/A$$

Where: σ = the tensile stress

P = applied load

A=area of the cross section perpendicular to the line of action of the applied force.

It is also assumed that this uniform stress will produce a uniform elongation ΔL. The value of the elongation per unit length, strain, is expressed as:

$$\varepsilon = \Delta L / L_o$$

Where: ε = strain

ΔL= total elongation

L_o =original length of the specimen

With the values of the stress and strain known for various tensile load values, a diagram showing the relation between the stress and strain, called the stress-strain diagram, can be plotted.

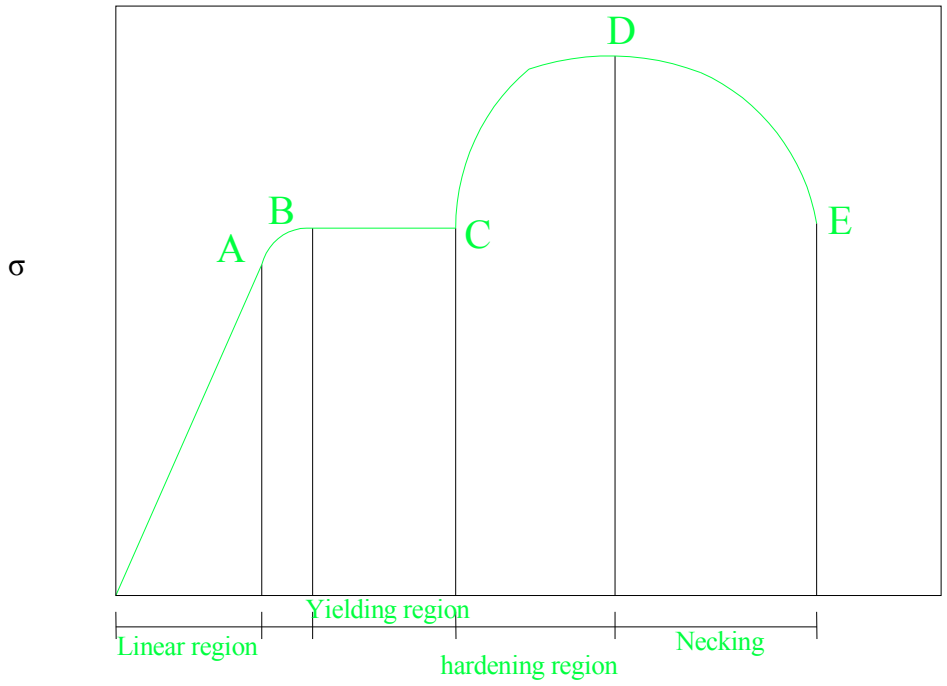
It should be noted that as the specimen stretches, the cross sectional area reduces and the gage length increases in value. However, the stress and strain values as defined by the above equations do not include these changes of area and gage length but are based on

the original values of area A and gage length Lo. For this reason the stress σ and strain ε are called the *nominal stress and strain.* The amount of deformation, which the material will undergo before rupture, varies widely with different materials.

3.3 Stress-Strain Diagram *for* a Typical Structural Steel in Tension

A stress- strain diagram for a ductile material such as a steel alloy will show a large deformation after yield point before the specimen ruptures, whereas that for brittle materials will show small deformation before rupture. This means that a ductile material will exhibit a large deformation before complete failure whereas a brittle material will fail without showing much deformation.

A structural steel, also known as mild steel or low-carbon steel, is one of the most widely used metals and is found in buildings, bridges, cranes, towers and many other types of construction. A stress-strain diagram for a typical structural steel in tension is shown below. Strains are plotted on the horizontal axis and stresses on the vertical axis.



The diagram begins with a straight line from the origin 0 to point A, which means that the relationship between stress & strain in this initial region is not only linear but also proportional. These stress- strain relations may be represented approximately by the

equation:

$$\sigma = E\varepsilon \quad \text{(Hook's Law)}$$

E, the slope of the straight line, is called the Modulus of Elasticity or Young's Modulus. Modulus of elasticity has the same unit as stress.

Beyond point A, the proportionality between stress and strain no longer exists; hence, the stress at A is called the proportional limit. For low-carbon steels, this limit is in the range 210 to 350 MPa.

With an increase in stress beyond the proportional limit, the strain begins to increase more rapidly for each increment in stress. Consequently, the stress strain curve has a smaller and smaller slope, until, at point B, the curve becomes horizontal. Beginning at this point, considerable elongation of the test specimen occurs with no noticeable increase in the tensile force (from B to C). This phenomenon is known as Yielding of the materials, and point B is called the yield point. The corresponding stress is known as the Yield Stress of the steel. In the region from B to C, the material becomes perfectly plastic, which means that it deforms without an increase in the applied load. After undergoing the large strains that occur during yielding in the region BC, the steel begins to strain harden.

During strain hardening, the material undergoes changes in its crystalline structure, resulting in increased resistance of the material to further deformation. Elongation of the test specimen in this region requires an increase in the tensile load, and therefore the stress- strain diagram has a positive slope from C to D. The load eventually reaches its maximum value, and the corresponding stress (at point D) is called the ultimate stress. Further stretching of the bar is actually accompanied by a reduction in the load, and fracture finally occurs at a point E. The yield stress & ultimate stress of a material are also called-the yield strength & ultimate strength, respectively.

4. CHOICE OF CONSTRUCTION MATERIALS

Modern structures often comprise vast number of components. Many of them pre-manufactured & assembled on site, some of them are manufactured at a construction site like concrete. In each case satisfactory operation of the building as a whole depends on the performance of the materials from which its components are made as on how they interact with each other in the structure.

The following questions show some of the main factors which needs to be considered in choosing construction materials:

- Is the material produced locally, or is it partially or entirely imported?
- Is it cheap, abundantly available, and/or easily renewable?
- Has it been produced in a factory far away (transportation costs!); does it require special machines and equipment, or can it be produced at lower cost

on the building site? (Good quality and durability are often more important than low procurement costs).

- Does its production and use require a high energy input, and cause wastage and pollution? Is there an acceptable alternative material which eliminates these problems?
- Is the material and construction technique climatically acceptable?
- Does the material and construction technique provide sufficient safety against common natural hazards (e.g. fire, biological agents, heavy rain, and earthquakes)?
- Can the material and technology be used and understood by the local workers, or are special skills and experience required?
- Are repairs and replacements possible with local means?
- Is the material socially acceptable? Is it considered low standard, or does it offend religious belief? Does it match with the materials and constructions of nearby buildings?

CHAPTER 3 PRODUCTION AND USE OF BINDING MATERIALS

General

Binders are substances which are used to bind inorganic and organic particles and fibers to form strong, hard and/or flexible components. This is generally due to chemical reactions which take place when the binder is heated, mixed with water and/or other materials, or just exposed to air. Cementing materials that are widely used for construction are materials that exhibit characteristic properties of setting and hardening when mixed to a paste with water

There are four main groups of binders:

- Mineral binders
- Bituminous binders
- Natural binders
- Synthetic binders.

Mineral Binders

These can be divided into three categories:

- Hydraulic binders, which require water to harden and develop strength.
- Non-hydraulic binders, which can only harden in the presence of air.
- Thermoplastic binders, which harden on cooling and become soft when heated again.

Hydraulic binders

The most common hydraulic binder is ***cement***. Hydraulic binders are usually available in the form of a fine powder: the finer they are ground (usually in a ball mill), the larger is the specific surface area (of the sum of the particles) per unit weight. And the larger the surface area, the more effective and complete is the chemical reaction with the water that it comes into contact with.

Hydraulic and semi-hydraulic limes are obtained from burning limestone, which contains a large or moderate amount of clay. This can be easily understood, since limestone and clay are the main raw materials for cement production. On account of their affinity to water, hydraulic binders must be stored in absolutely dry conditions, to avoid premature setting and hardening. Even humid air can cause hydration.

Non-hydraulic binders

The most common non-hydraulic binder is ***lime*** **(CaO).** Hardening depends in its combination with carbon dioxide from the air (carbonation), by which it again becomes calcium carbonate (limestone).

Another common non-hydraulic binder is ***clay***, which is present in most soils, causing them to harden on drying and soften when wet. Its main uses are in earth constructions

and in the manufacture of burnt clay products.

Gypsum is a non-hydraulic binder which occurs naturally as a soft crystalline rock or sand. The chemical name is calcium sulphate anhydrate **($CaSO4.2H_20$).** By gentle heating up to about 100 ^oC calcium sulphate semi-hydrate ($CaSO4.1/2H_20$) is produced, more commonly known as ***"Plaster of Paris",*** which when mixed with water sets in 8 to 10 minutes.

Thermoplastic binders

Thermoplastic materials require ***heat*** in order to be processed, and harden on cooling. Probably the only thermoplastic mineral binder used for building is sulphur.

Bituminous Binders

Bitumens are mechanical mixtures of different ***hydrocarbons*** (compounds of carbon and hydrogen) and a few other substances, and are obtained as a residue in the distillation of crude oil, either in petroleum refineries or in nature (in pores of rocks or in the form of lakes, close to petroleum deposits). Bitumens are generally dark black, oily, fluorescent thermoplastic substances, which are highly viscous to almost solid at normal temperatures.

Compounds consisting of at least 40 % of heavy hydrocarbons are called bitumen.

Asphalts are defined as mixtures containing bitumen and a substantial proportion of inert mineral matter (sand, gravel, etc.). In the USA, bitumen is called asphalt, thus causing some confusion.

When bitumen is used, it must be either heated or mixed with solvents like gasoline, kerosene or naphtha, which is called ***"bitumen cutback";*** or dispersed in water, which is called ***"bitumen emulsion".***

Natural Binders

Varieties of binders are obtained from plants and animals, and can be used in their natural form or after processing.

Examples of natural binders are plant juices (e.g. juice of banana leaves; latex of certain trees). Natural binders have played an important role in traditional constructions since ancient times, but, nowadays face low social acceptance.

Synthetic Binders

These binders are generally produced by industrial processes and, therefore, often expensive. Some synthetic binders are toxic.

They can be used as admixtures, as adhesives or as surface coatings and are either applied hot, or as an emulsion, or with a solvent.

Synthetic admixtures which bond loose particles together are mainly resins derived from plant materials or mineral oil. The variety of commercial products is very large and their use depends on the required performance (strength development, waterproofing, elasticity etc.)

Adhesives are used to stick larger particles, components, membranes, sheets, boards, tiles, etc. on another surface.

Lime

Lime one of the oldest known cementing materials, which is readily available and inexpensive: Lime is found in many parts of the world in its natural form as a rock of varying degree of hardness. It is mainly composed of calcium oxide (CaO), which in its pure form associates with CO_2 to give white $CaCo_3$. However, lime deposits are generally found mixed with impurities such as Co_2, $Fe_2\ 0_3$, and $MgCo_3$. Depending on the impurities, lime deposits acquire different colors.

Production of lime

The production of lime for use in building construction involves burning of the raw material and then slaking. The amount of heat applied and the method of slaking depend on, whether the product is hydraulic or non-hydraulic lime.
Lime is mostly burnt in vertical kilns (the one which is used in Guder near Ambo). The raw material is fed in at the top and the finished product drawn off through an opening at the bottom. To avoid over burning, which injures the setting properties, high-magnesium limes should not be subjected to temperatures above 1000 ^{0} C and high-calcium limes should be burnt at temperatures lower than 1300 ^{0} C. Limestone, the basic raw material for lime production, can have $CaCO_3$ contents exceeding 98 % (as in chalk and various types of shells and *coral) or as low as 54 % (in pure mineral dolomite). Each type of limestone* yields a different quality of lime, depending on the type and quantity of impurities. The purest forms of lime are needed for chemical and industrial use. Vertical shaft kilns are designed mainly for continuous production: the stone, fed in from the top, gradually drops into the burning zone, then into the cooling zone, and is finally extracted from below, making room for the next load, and so on. The top layer is preheated by the exhaust gases and the air intake below is preheated by the cooling quicklime, thus achieving maximum use of the available heat (fig 3.1)

Classification of Lime

- ✓ **Quick lime**

The manufacture of non-hydraulic lime consists in heating or burning the lime stone in

some form of vertical kilns to a temperature of 1000 ^{0}C calcium carbonate is decomposed into calcium oxide and carbon dioxide according to the following reaction.

$$CaCO_3 \sim CaO + CO_2\uparrow$$

The CO_2 is driven off, leaving the CaO (calcium oxide), which is known as quick lime or caustic lime, white in color and having a specific gravity of about 3.4 in its pure form.

> *This quick lime is highly caustic and possesses a great affinity for water, readily combining with about 30% of its own weight. It is slow in sculling & takes much time in hardening. It is Used for plastering and white washing but not suitable for being used as mortar because of its poor strength & slow hardening.*

- ✓ **Hydrated Lime (Slaked Lime)**

Quick Lime can never be used as such for construction purposes but must be mixed with water. The quick lime in the presence of water reacts to form calcium hydroxide together with a great evolution of heat.

$$CaO + H_2O \Rightarrow Ca(OH)_2 + \text{heat}$$

This process is called ***slaking*** & the product (calcium hydroxide) is called ***slaked lime*** or ***hydrated lime***. The rate of reaction depends mainly on the purity of the lime. In slaking process, the following phenomena are observed:

- considerable heat is energetically evolved
- excess water in the form of vapor is driven off
- considerable & sudden expansion that makes the lime burst into pieces & finally become powder or pasty
- an increase in absolute volume in forming calcium hydroxide $Ca(OH)_2$

*There are two types of slaking: **Wet-Slaking** and **Dry-Slaking**, Depending on the amount of water added.*

- ➢ **<u>Wet-Slaking</u>**

Lime is slaked or hydrated at the building site by mixing quicklime, which is delivered in lump form, ***with an excess of water*** and the resulting slaked lime (milk of lime) should be passed through a fine sieve to remove slow slaking particles (lime putty) and then left to mature for several days. If the mixing is made directly in a watertight box or a hole dug in the ground the lime must be continually stirred by a shovel or a stick during the slaking process to reduce all un-hydrated particles which might hydrate later in the building and cause popping, pitting, and disintegration, ***especially objectionable in wall plaster or expansion of brickwork***.

- **Dry-Slaking**

If the operation is carefully controlled, as it can be in a factory so that just sufficient water is added to hydrate the quick lime, the lumps break down in to a dry powder known as ***Dry hydrate*** or ***hydrated lime***. It is obtained by adding almost exactly the theoretical quantity of water required to change the burnt lime into hydrate of lime. The proportion of lime and water and stirring are scientifically carried out by mechanical means, and the product is very dependable (trustworthy). It is reduced to a fine powder and shipped in paper bags ready for use. Lime has a certain advantage over quicklime. It is a better product and is of uniform quality because it is manufactured under controlled conditions.

Preserving Quicklime

Fresh burned lime has so much affinity for water that it will quickly absorb moisture and carbon dioxide from the atmosphere and becomes ***air-slaked***, and loses its cementing qualities. It must therefore be kept in dry storage and carefully protected from dampness until used.

- ✓ **Hydraulic lime**

This lime, which hardens to some extent by an internal reaction, is prepared by burning impure limestone that contains clay producing compounds similar to those present in Portland cement. It is strong but less fat or plastic than non-hydraulic lime.

Hydraulic lime is manufactured in the same way as quick lime, although a somewhat higher temperature is required in burning. Hydraulic lime presents some difficulty in slacking. While it must be thoroughly slacked, like non-hydraulic lime; *considerable care is required to provide just sufficient water and no excess*, since excess water would lead to ***premature hardening***. The exact amount of water required can only be determined by experience with the particular lime concerned. Clearly, hydraulic lime cannot be soaked overnight to improve its *workability*.

Setting and hardening of lime

Slaked lime hardens or sets by *gradually losing the water through evaporation and absorbing carbon dioxide from the air* thus changing back from calcium hydroxide, $Ca(OH)_2$ to calcium carbonate, $CaCO_3$ or limestone.

The cycle is completed in the chemical changes from the original limestone, through burning, slaking, and setting.

1. When burnt, the limestone loses its carbon dioxide and becomes oxide of lime or quicklime.

$$\mathbf{CaCO_3 + Heat \Rightarrow CaO + CO_2}$$

2. When slacked, the oxide of lime combine with water and becomes hydroxide, slacked, or hydrated lime.

$$\mathbf{CaO + H_2O \Rightarrow Ca(OH)_2 + Heat}$$

3. When setting, the calcium hydroxide loses its water through evaporation and absorbs carbon dioxide from the air, becoming Ca C03 or limestone once more.

$$\mathbf{Ca(OH)_2 + CO_2 \Rightarrow CaCO_3 + H_2O}$$

Precautions taken in handling lime

In handling lime the following precautions should be taken

1. Quick lime shall not be allowed to be ***exposed to water*** before slaking.
2. During slaking, quicklime gives out immense heat, as such all precutting against ***fire hazard*** should be taken.
3. Since lime dust ***causes irritation***, workers handling lime should be provided with suitable goggles & respirators.
4. Since lime ***cause skin burns***, particularly if the skin is moist, as such workers should be provided with rubber gloves, boots & skin protective cream.
5. *After working with lime, exposed portions of the body should be washed with abundant fresh water.*
6. Workers handling milk of lime, which is hot, should oil their skin daily to avoid skin burns.

Uses of Lime

Lime is a very useful material that finds extensive applications in building construction, in industry and agriculture. Its use will be described under three headings.

1. Lime as a material of construction

As mentioned earlier, lime was used as main binding material in all types of construction till 19th century when Portland cement was manufactured. Even now, lime can compete with Portland cement quite satisfactorily in many types of construction. It is used:

- As mortar (lime mortar) mixed with sand. *The usual mixtures for mortar are 1 part of lime to 3-6 parts of* ***sand*** *by volume*. Lime mortar will not harden under water, and in all cases exposure to air is necessary for prompt (timely) setting. ***Lime mortar without addition of cement should never be used in foundations or where exposed to moisture.***
- Lime is used in cement mortars and plasters ***to make it more workable***. The resulting mortar is called ***compo-mortar***
- As plaster (lime plaster)

- As a whitewash, it gives a sparkling white finished at a very low cost.
- As lime concrete, which is similar to cement concrete and is made ***by mixing lime, sand and coarse aggregate in proper proportions.***
- As an important constituent of ***sand -lime bricks***, which are quite popular in advanced countries
- Lime is used as a ***stabilizer in soil constructions with clayey soils***, because the lime reacts with clay to form a binder.

2. Lime as an industrial material

In industry, lime finds many applications:

- As a flux in the metallurgical industry
- As a refractory material for lining metallurgical furnaces
- As a raw material for the manufacture of glasses.

3. Lime as an agricultural input:

Lime is used for improving the productive qualities of soils. It is added to the poor soils to enrich their lime content.

Advantages

- Lime is produced with less energy input than cement. Making it cheaper and environmentally more acceptable.
- In mortars and plasterwork, lime is far superior to Portland cement, providing gentle surfaces which can deform rather than crack and help to control moisture movement and condensation.
- White washes are not only cheap paints, but also act as a mild germicide.

Problems

- *Soil stabilization with lime requires more than twice the curing time needed for soils stabilized with cement.*
- *If quicklime is stored in moist conditions (even humid air), it will hydrate.*
- *Hydrated lime, stored for long periods, gradually reacts with the carbon dioxide in the air and becomes useless.*
- *Lime bursting (hydration of remaining quick lime nodules) can take place long after the component has dried, causing blisters, cracks and unsightly surfaces.*
- *Plain whitewashes take a long time to harden, and are easily rubbed off.*
- *Traditional lime burning in intermittent kilns wastes a great deal of fuel (usually firewood) and often produces non-uniform, low quality limes (over-burnt or under-burnt).*

Gypsum

Gypsum is a combination of ***sulfate of lime*** with ***water of crystallization***. It occurs naturally as either hydrous sulfate of lime (Ca $S0_4$ $2H_2O$) which is generally 76% $CaS0_4$ and 24% H_2O, or as anhydrate (Ca $S0_4$). The gypsum rock usually contains silica, alumina, lime carbonate, carbonate of magnesia, iron oxide, and other impurities. To be classed as *gypsum rock at least 65% by weight must be Ca $S0_4$ $2H_2O$*. Pure gypsum is known as alabaster and it is a white translucent crystalline mineral, so soft that it can be scratched with the fingernail. When heated to pure gypsum it loses its luster and its specific gravity is increased from 2.3 to 2.95 due to the loss of water of crystallization.

Gypsum Plasters

Gypsum plasters are used in the arts and in building construction. In all these powders, gypsum in a more or less dehydrated state is the essential element. When water is added to these substances they become dehydrated, forming compounds similar to those existing before calcinations.

Manufacture of plasters

Gypsum plasters are manufactured by heating the raw material gypsum at either moderate or high temperatures the results being plaster of Paris or hard-finish plaster.

- ✓ ***Plaster of Paris***

Gypsum as pointed out before contains a good deal of water of crystallization (as much as 24% by weight). If some of the water is driven off by incompletely dehydrating pure, finely ground gypsum at a temperature just above the boiling point of water 100 ^{0}C, a semi hydrated plaster is obtained which is known as plaster of Paris.

$$(CaS0_4.2H_2O) + \text{Moderate heat} \Rightarrow (CaS0_4.1/2\ H_2O) + H_2O$$

Plaster of Paris is a white powder having a specific gravity of 2.57. This plaster is also known as ***low-temperature gypsum derivative or semi-hydrated plasters*** (semi hydrate). When mixed with sufficient water to form a plastic paste it sets very rapidly, the whole process taking only 5 to 10 minutes. The setting of gypsum derivative is not a chemical change as in the setting of carbonate of lime but is due to the recombination of the dehydrated lime sulfate, $CaSO_4$ or $CaSO_4$.1/2 H_2O with water to form the original hydrated sulfate $CaSO_4$.$2H_2O$. Re-crystallization takes place, the dehydrate precipitates from the solution to form a solid mass of fine interlocking crystals, the material hardening back to its original state and attaining its ultimate strength on drying.

In many instances, in order that the workman may properly handle Plaster of Paris (stucco), it is necessary to delay the time of setting. This is accomplished by adding a

fraction of 1 percent of a retardant like glue and sawdust after the plaster has cooled. Plaster of Paris while setting under water does not gain strength and ultimately, on continued water exposure, will disintegrate. In hardening, plaster of Paris first shrinks and then expands. The latter property makes the material valuable in making casts, since a sharp impression of the mold can be secured. Owing to the rapidity of set and difficulty in working its use in structures is limited to ornamental work. It produces hard surfaces, sharp contours, and is sufficiently strong.

- ✓ ***Hard-Finish Plaster***

By burning gypsum to a considerably higher temperature than in the previous case, there may be produced un-hydrous sulfate, which is known as ***un-hydrous plaster or high-temperature gypsum derivative.***

$$(CaSO4.2H_2O)+\text{High heat} \Rightarrow CaSO_4+ 2H_2O \uparrow$$

This Plaster is less soluble with consequent reluctance to absorb water in the process of re-crystallization, which must occur in order to develop a plaster comparable with the original gypsum formula. *The result is a plaster too slow in setting action for practical purpose.*

Portland Cement

Portland cement is one of the most widely used construction materials and is the most important hydraulic cement. It is used in concrete, mortar & plaster. It is used in all types of structural concrete (walls, floors, bridges, tunnels, etc.) It is further used in all types of masonry (foundations, footings, dams, retaining walls, and pavements). When Portland cement is mixed with sand and lime, it serves as ***mortar*** for laying brick or stone. When Portland cement is mixed with coarse aggregate and fine aggregate (sand) together with enough water, to ensure a good consistency, we will get ***concrete***.

History of Portland cement

The origin of the name “Portland cement" is usually attributed to Joseph Aspdin, a brick mason in England who in 1824 took out a patent for making a powder made from the calcined (dehydrated) mixture of limestone and clay, He called this product Portland cement because when the mortar made with it hardened produced a material resembling the stone which was quarried near Portland, England. The method of making cement has been improved upon since that time but the basic process has remained.

Raw materials

Modern Portland cement is made from materials which must contain the proper proportions of lime (CaO), silica (SiO_2), alumina (Al_2O_3), iron (Fe_20_3) with miner

amounts of magnesia and sulfur trioxide.

Table 1 indicates the range of oxide composition usually found in normal Portland cement.

Table 1:

Oxide composition of Normal Portland Cement

Oxide Ingredients	Range, %
Lime, CaO	60-66
Silica, SiO_2	19-25
Alumina, Al_2O_3	3-8
Iron,Fe_2O_3	1-5
Magnesia, MgO	0-5
Sulfur trioxide, SO_3	1-3

The main component being lime (60-66%) and therefore manufacturing plants are usually located to take advantage of one of the various source of lime.

Lime does not occur in nature but is found in a suitable form in carbonate. Silica & alumina are found free in nature in the form of clay, shale, or slate.

Limestone (calcium carbonate) contains impurities of magnesia, silica, iron, alkalis and sulfur. ***Magnesia*** in the form of carbonate of magnesia often occurs in limestone and, if present in the amount of 5% or more, will make the limestone unsuitable**.** ***Silica*** by itself does not combine with lime in the kiln; thus, small quantities of free silica in the limestone make the limestone unacceptable. However, if silica is combined with alumina in the limestone, it will combine with lime in the kiln and is acceptable.

Iron in limestone can occur either as an oxide (Fe_20_3) or as a sulfide (FeS). If the iron is in the form of an oxide, it acts as a flux in combining the lime & silica in the kiln. As a sulfide it reacts very strongly and can prove to be quite injurious to the production of Portland cement. *If the iron in the form of iron sulfide is present in limestone by 4% or greater, the limestone should be rejected.*

One of the major roles of alumina in the limestone is to *combine with silica* such that the limestone will combine with the lime in the kiln and thus make the limestone an acceptable product. Sulfur, the impurity in limestone, exists in two forms: lime sulfate and iron pyrite. If each is present in amount of 3% or more, the lime stone should be rejected.

Manufacture of Portland cement

The manufacture of Portland cement occurs through a series of steps:

- Quarrying
- Crushing
- Grinding
- Mixing
- Calcining
- Addition of retardant
- Packing

Portland cement is made by burning an intimate mixture composed of *calcareous (Ca is the key element)* & *argillaceous (silicates of alumina)* materials, at a **clinkering** temperature up to about **1500 º C**. This partially sintered clinker is then ground to a very fine powder with a very small amount of gypsum (3 to 5%) as a retardant. The cement is then packed into 50Kg bags or it may be bulk-stored.

Steps in the Manufacture of Portland cement

The methods of manufacture depend on the hardness of the raw materials used and on their moisture content.

The mixing and grinding of the raw materials can be done either in water or in dry conditions and named ***wet and dry processes*** respectively.

> *The main difference between the two processes is that in dry process the raw materials are fed into the burning kiln in a perfectly dry state. In the wet process, however, these materials are supplied to the kiln in the form of slurry (a liquid of creamy consistency, with a water content of between 35 & 50%).*

Dry Process:

The four main steps in this process are:

1. Treatment of raw materials
2. Burning of the dry mix
3. Grinding of the clinker &
4. Packaging& storage.

1. <u>Treatment of Raw Materials</u>

The raw materials are subjected to processes as: *crushing, drying, grinding and proportioning & blending (mixing)* before they are fed into the kiln for burning. The crushing stage involves breaking the raw materials to small fragments that vary in size between 6-19mm. Primary crusher machines are used for this purpose. The drying stage is typical of the dry process. **Drying** of the crushed materials is essential and is achieved by heating the materials separately at temperatures sufficiently high to drive out uncombined water. Heating is done in a rotary drying kiln.

The grinding of each material as obtained from the dryers is done in two stages. First preliminary grinding in which the materials are reduced to 0.3mm and then the fine grinding in which the size of the materials are reduced to 0.075mm. Each raw material is thus reduced to a required degree of fineness and is stored in suitable storage tanks called

silos or bins where from it can be drawn out conveniently in requisite quantities.

Predetermined proportions of finely dried and ground materials are mixed before they are fed into the kiln. The proportioned raw material is known as raw meal. The raw meal has moisture content of about 0.2 %.

2. <u>Burning or calcinations:</u>

The well- proportioned finely powdered mixture (raw meal) is charged into long steel cylinder, called rotary kiln. Rotary kilns differ in design and dimensions in accordance with the production requirements. Thus, these may be 100-180m in length, 3- 5m in diameter and have rotation of 60-90 revolutions per hour.

The raw mixture is burnt in the kiln till the proper burning is achieved. This is indicated by its taking a greenish black color and virtuous luster. This burnt material called ***clinker*** is cement in composition but not in size: it is in about walnut sized lumps when it comes out of the kiln.

> *During the burning process water is completely driven off at a very initial stage of burning at a temperature as low as 400 ^{0}C and dissociation of carbonates in to calcium oxide and carbon dioxide takes place at 800-900^{0}C temperature range. Then finally compound formations will proceed and it starts at 1200 ^{0}C and requires a temperature as high as 1500^{0}C*

3**. <u>Grinding of the Clinker</u>**

The completely burnt or calcined raw materials of cement are converted to lump-shaped product called clinker, which is drawn out from the lower end of the rotary kiln. It is extremely hot when discharged, and is therefore first cooled and both (clinker and gypsum) are sent for pulverizing. The mixture is reduced to an extremely fine powder by grinding it.

4. <u>Packing and Storage of Cement</u>

Cement is most commonly stored after its manufacture in specially designed concrete storage tanks called silos where from it is drawn off mechanically for the market. For convenience, the cement come customer in bags containing measured quantity. The standard bag of cement as distributed in Ethiopian is commonly 50kg.

Wet process:

It is considered a better and convenient process for the manufacturing of cement, specifically where limestone of soft variety is available in abundance. We can discuss this process under three headings

1. Preparation of slurry

2. Burning or calcinations and

3. Treatment of clinker.

1. Preparation of Slurry

In wet process, raw materials are supplied to the kiln in the form of an intimate mixture with a lot of water in it. This is called ***slurry***. To obtain the slurry of standard composition, the raw materials are first crushed separately using crushers for limestone and grinding mills (wet) for clays. These crushed materials are stored in separate tanks or silos. They are drawn from the silos in prefixed proportions in to the wet grinding mills where, in the presence of a lot of water, thus ground to fine thin paste. This is slurry, which is stored in a silo (storage tower). Its composition is tested once again and corrected by adding limestone slurry in required proportions such ***corrected slurry is then fed into the rotary kiln***

2. Burning:

For burning of slurry, a rotary kiln of almost similar type is used as described under dry process. All the moisture is driven off the slurry as it passes through the drying zone. Chemical compounds will be produced in the burning process.

3. Grinding of Clinker:

As the lump-shaped clinker comes out from the kiln, it is extremely hot. It is, therefore, passed through cooling rotary cylinders. There after it is mixed with 3-5 percent of gypsum and ground to a very fine powder as in dry process. The fine cement obtained is stored and packed in paper bags.

Properties of the main compounds in cement clinker

As indicated, in the manufacture of Portland cement, the raw materials are ground up, mixed to produce the desired proportion of minerals, and burned in a large kiln. The temperature in the kiln reaches about 1200-1500°c. This drives off water and gases and produces new chemical compositions in particles called clinker. The four major compounds of cement produced are:

3 $CaO.SiO_2$ (Tri-calcium silicate), abbreviated C_3S

2$CaO.SiO_2$ (Di-calcium silicate), abbreviated C_2S

3$CaO.Al_2O_3$ (Tri-calcium Aluminate) abbreviated C_3A

4$CaO.Al_2O_3.Fe_2O_3$ (Tetra calcium Alumino-ferrite) abbreviated C_4AF

The relative amounts of these four chemicals in the final product depend on the desired properties of the cement concrete such as rate of hardening, amount of heat given off, and resistance to chemical attack.

1. **C_3S (Tri-calcium Silicate)**

The most desirable constituent is that of tri-calcium silicate (C_3S), because it ***hardens rapidly and accounts for the high early strength of the cement***. When water is added to tri-calcium silicate, a rapid reaction occurs as follows:

$$2C_3S + 6H_2O \Rightarrow 3\ CaO.2SiO_2.3H_2O + 3Ca\ (OH)_2$$

The main product, **$3CaO.2SiO_2.3H_2O$** is calcium silicate hydrate ***gives cement its strength***. The total amount of water required to complete the hydration of the cement is *about 25% of the mass of the cement*. The proportion of C_3S ranges from 25-60%.

2. C_2S (Di-calcium Silicate)

Di-calcium silicate ***hardens slowly & contributes to strength increase at ages beyond one week***. In the presence of water, di-calcium silicate ($2CaO.SiO_2$) hydrates slowly and forms a hydrated calcium silicate ($2CaO.SiO_2.\ xH_2O$). The proportion of C_2S ranges from 13- 50%

3. **C_3A (Tri-calcium Aluminate)**

Tri-calcium aluminate ***liberates a large amount of heat (heat of hydration)*** during the first few days of hardening. About 50% of the total heat of hydration is released in the first three days. It also ***contributes to early-strength development***. Tri-calcium aluminate hydrates with water to form hydrated tri-calcium aluminates $3CaO.Al_2O_3.6H_2O$. *If gypsum is added it acts as* ***a retardant***, and the heat of evolution is less and *the setting occurs more slowly.* This is due to the fact that gypsum when present, results in the formation of calcium sulfoaluminate ($3CaO.A1_2O_3.3CaSO_4$) rather than hydrated tri-calcium aluminate. The proportion of C_3A ranges from 5-15%. Sulfates are often found in soils and groundwater. These may combine with C_3A to produce an expanding compound, which could result in disintegration of the concrete.

4. C_4AF (Tetra calcium Aluminoferrite)

Tetra-calcium aluminoferrite formation ***reduces the clinkering temperature***, thereby assisting in the manufacture of Portland cement. It hydrates rather rapidly but contributes very little to strength. The proportion of C_4AF ranges from 8-15%

Table2:

Characteristics of Four Compounds of Clinker

Characteristics	C_3S	C_2S	C_3A	C_4AF
Rate of hydration	Medium	Slow	Fast	Slow
Strength -early -ultimate	High high	low high	Medium low	low low
Amount of heat liberated	Medium	low	high	low
Resistance to chemical attack	Good	Good	Poor	Good

Types of Portland cement

The difference in properties of the various kinds of cement arises from the relative proportions of the four major compounds.

ASTM recognizes ***eight*** types of Portland cement under specification ASTM C150. The standard five types of Portland cement (this excludes the three that are air-entrained) are the types that are usually produced.

Type I or Normal Portland cement

Normal Portland cement is general-purpose cement. It is used when the special properties specified for any other type are not required. *It is used where there would be no severe climate changes or severe exposure to sulfate attack from water or soil*, its use include reinforced-concrete buildings, pavements, sidewalks, bridges, railings, tanks, reservoirs, floors, curbs, culverts, and retaining walls. *In general, it is used in nearly all situations calling for* ***Portland cement.***

Type II or Moderate Portland cement

Moderate Portland cement is a general-purpose cement *to be used when moderate sulfate resistance or moderate heat of hydration is desired*. It is used in structures of **considerable mass**, such as abutments and piers and retaining walls. Its use also minimizes temperature rise when concrete is placed in warm weather.

Type III or High-Early-Strength Portland cement

As it can be inferred from the name this type of Portland cement is used when high early strength is desired, usually less than one week. *It is usually used when a structure must be put into service as quickly as possible*. This cement is made by changing the proportions

of raw materials, by fine grinding, and by better burning, such that **di-calcium silicate is less and the tri-calcium silicate is greater.**

Type IV or Low -Heat of Hydration Portland cement

Low -Heat of Hydration Portland cement is used, when a low heat of hydration is required. This type of cement *develops strength at a slower rate* than does Type I. However, it is **intended for mass structures** such as large gravity dams where the temperature rise on a continuous pour is great. If the temperature were not minimized large cracks or flaws would appear and the structure might prove to be unsound.

Type V or Sulfate -resisting Portland cement

Sulfate -resisting Portland cement is used ***when high sulfate resistance is desired***. It is used when concrete is to be exposed to severe sulfate action by soil or water.

The three types of air -entraining cements, Types IA, IIA, IIIA as given by ASTM C150, are used in concrete for improved resistance to freezing and thawing action and the action of salt scaling and chemical attack.

Disintegration due to freezing and thawing is caused by the expansion of the water, as it freezes. The pressure caused by this expansion forces the pore open after thawing; the large pore is re saturated with water and subsequent freezing increase the pore volume again.

Table 4:

Typical Compound Composition for Various Portland Ct

Types of Portland Cement	Compound Composition			
	C_3S	C_2S	C_3A	C_4AF
I. Normal	50	24	11	8
II. Moderate	42	33	5	13
III. High early strength	60	13	9	8
IV. Low-Heat	26	50	5	12
V. Sulfate-Resisting	40	40	4	9

Table 5:

Approximate Relative Strength of Concrete as Affected by type of Cement

Types of Portland Cement	Compressive strength(% of Normal Portland cement)				
	1Day	3Days	7 Days	28Days	3 months
I. Normal	100	100	100	100	100
II. Moderate	75	80	85	90	100
III. High early strength	190	190	120	110	100
IV. Low-Heat	55	55	55	75	100
V. Sulfate-Resisting	65	65	75	85	100

Other Types of Portland Cement

1. Portland-Pozzolana Cement (PPC)

Portland-pozzolana cement is manufactured by blending 10-30% by weight of *pozzolanic material* with ordinary Portland cement (OPC); either by simple mixing or by inter - grinding with cement clinker. The calcium hydroxide librated during the process of hydration of the cement combines slowly with the pozzolana to give it cementitious properties, thereby ***contributing to water tightness*** and ***long continued gain in strength*** of the concrete. The term pozzolana is used to describe naturally occurring and artificial **siliceous materials**, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with **calcium hydroxide** at ordinary temperatures to form compounds possessing cementitious properties. The most important effects accompanying the use of PPC in Concrete Construction Work are:

- Improved workability
- No increase in dry shrinkage
- Improved resistance to sulfate attack etc.

Special types of Portland Cement

A variety of special cements exist that are limited for specific uses and purposes. The following are few examples:

1. White Portland cement
2. Colored Cements
3. Oil-Well Cements
4. Regulated cements
5. Waterproofed Cement
6. Hydrophobic cement
7. Antibacterial cements
8. Barium and Strontium cements etc.

Properties and Tests of Portland cement

Most specifications place specific physical property and chemical composition requirements for Portland cement.

1. Phvsical Properties

The physical properties of Portland cement are fineness, setting time, soundness, compressive strength, heat of hydration and specific gravity.

1.1 Fineness

The *fineness* of the cement has an important effect on the *rate of hydration*. The finer the cement the quicker the rate of hardening and the greater is the heat evolution at early ages. For these reasons a finely ground cement is more liable to suffer from shrinkage cracking than a coarser cement but this statement can be applied only to cements of the same chemical composition. The fineness of grinding does not affect the total heat evolved but only the rate at which that heat is evolved. ***Extremely fine size does not improve the ultimate strength of the cement.*** The fineness of cement can be measured in a number of ways. The sieve test, specific surface test by Wagner Turbid meter method and the ***Blaine air permeability methods*** are used. The Ethiopian Standard specifies the fineness of grinding should not be less than 2250 cm^2/gm for OPC and 2500 cm^2/gm for sulfate resisting Portland cement by Blaine air permeability method.

1.2 Setting time

Setting is the term used to describe the **stiffening** of the cement paste, although the definition of the stiffness of the paste, which is considered, set is somewhat arbitrary. ***Broadly speaking, setting refers to a change from a fluid to a rigid stage***. Although, during setting, the paste acquires some strength, for practical purposes it is important to distinguish *setting from hardening,* which refers to the gain of strength of set cement paste. Some cement set quickly, within few minutes, others may take comparatively longer time. Moreover, setting is not an abrupt process, which may complete immediately after its start; it is rather a progressive phenomenon, which has beginning, full development and an end. It is on this latter basis, ***setting is distinguished into initial and final setting*** qualified by the time required in each case.

Time required for setting is influenced by:

1. *Temperature:* the setting time of cement decreases with a rise in temperature, but above 30 ^0C a reverse effect may be observed. At low temperatures setting is retarded.

2. *Water content*: the quantity of water required in making a paste must be right quantity for complete hydration of cement. Less water result in ***incomplete hydration***, extra quantity will ***bleed out*** after cement is set.

3. *Humidity*: the humidity of the atmosphere in which setting is allowed to take place acts through temperature and moisture conditions.

4. *Fineness of the Cement*: the greater the cement fineness the greater the rate of hydration and hence the shorter the setting time.

5. *Chemical Composition*: Setting is caused by a selective hydration of cement compounds: the two first to react are C_3A and C_3S.

The setting times of cement are measured using the ***Vicat apparatus*** with different penetration attachments. The test is performed at standard conditions of temperature and humidity and on cement pastes of *standard consistency*. Initial setting time is the duration of cement paste of standard consistency related to 25 mm penetration of the Vicat needle into the paste in 30 seconds after it is released while the final setting time is that related to zero penetration of the Vicat needle into the paste.

> ***Ethiopian standard recommends that the initial setting time for cement not be less than*** *45 minutes* ***and the final setting time*** *not to exceed 10 hours.*

1.3 Soundness

Incomplete combination of the lime with other raw constituents through under burning of clinker, results in free or uncombined lime (CaO) in the finished cement. If this is present in excess amount **expansion and disruption** of concrete may eventually occur. This phenomenon is known as ***soundness***. It is essential that cement paste, once it has set, does not undergo a large change in volume. In particular, there must be no appreciable expansion, which under conditions of restraint, could result in disruption of the hardened cement paste. Such expansion may take place due to the delayed or slow hydration, or other reaction, of some compounds present in the hardened cement, namely free lime, magnesia, and calcium sulfate.

> *If the raw materials fed into the kiln contain more lime that can combine with the acidic oxides; or if burning or cooling are unsatisfactory, the excess lime will remain in a free condition*. This hard burnt lime hydrates only slowly and because slaked lime occupies a large volume than the original calcium oxide (CaO) expansion takes place. Cement which exhibits such properties are described as ***unsound.***

Cement can also be unsound due to the presence of **MgO**, which reacts with water in a similar manner to CaO**. Calcium sulfate** is the third compound to cause expansion: In this case calcium sulfoaluminate is formed. It may be recalled that a hydrate of calcium sulfate ***-gypsum*** is added to cement clinker ***in order to retard quick setting*** but if gypsum is present in excess of the amount that can react with C_3A during setting, unsoundness in the form of a slow expansion will result. For this, standards limit very strictly the amount of gypsum that can be added to clinker. The limits are well on the safe side as far as the danger of unsoundness in concerned. A very fine size of cement may be the cause of unsoundness in cement. In order to determine the soundness of cement the Le Chatelier

test is used. The Le Chatelier apparatus consists of a small brass cylinder split along its generatrix. Two indicators with pointed ends are attached to the cylinder on either side of the split; in this manner, the widening of the split caused by the expansion of the cement, is greatly magnified and can easily be measured. The cylinder is placed on a grass plate filled with cement paste of standard consistency, and covered with another glass plate. The whole assembly is then placed in a cabinet at 20°c and relative humidity of note less than 98% at the end of the period, the distance between the indicators is measured, and the mold is immersed in water and gradually brought to the boil in 30 minutes. After boiling for.1 hr the assembly is taken out and, after cooling, the distance between the indicators is again measured the increase in this distance represent the expansion of the cement, and for Portland cement is limited to 10 mm by Ethiopian Standard.

1.4 Compressive strength

The mechanical strength of hardened cement is the property of the material that is perhaps most obviously required for structural use. Strength tests are not made on a neat cement paste because of difficulties of molding and testing with a consequent large variability of test results. Strength of cement can be determined by two methods i.e. ***mortar test*** **and** ***concrete test***. In the mortar test, a 1:3 cement-sand mortar is used. The sand is standard sand (of single size). The mass of water in the mix is 10% of the mass of the dry materials. Expressed as a water/cement ratio, this corresponds to *0.40* by mass. A standard procedure, prescribed by British standard is followed in mixing, and 70.7mm cubes are made using a vibrating table with a frequency of 200Hz applied for two minutes. The cubes are demolded after 24 hours and further cured in water until tested in a wet-surface condition. In the concrete test, three-water/cement ratios can be used *0.60, 0.55* and *0.45,* depending on the type of cement. The amounts of coarse and fine aggregate, which have to come from particular quarries, are specified. Batches of 100mm cubes are made by hand in prescribed manner, the temperature and humidity conditions of the mixing room, curing chamber, testing room, and the temperature of the water curing tank are specified.

The compressive strength of mortar & concrete cubes has to confirm to the following according to Ethiopian standard.

For Ordinary Portland cement:

- 3 days (72±1 hr): not less than 8N/mm2 (8MPa)
- 7 days (168±2hrs): not less than 14N/mm2 (14MPa)

1.5 Heat of hydration

Heat of hydration is the quantity of heat in joules per gram generated when cement and water react. The most common method of determining the heat of hydration is by measuring the heats of solution of unhydrated and hydrated cement in mixture of nitric and hydrofluoric acids: the difference between the two values represents the heat of hydration.

For practical purpose, it is not necessarily the total heat of hydration that matters but the rate of heat evolution. *The amount of heat generated is dependent chiefly on the chemical composition, fineness of the cement, and the temperature of curing time*.

> *Because in the early stages of hydration the different compounds hydrate at different rates, the rate of heat evolution, as well as the total heat, depends on the compound composition of the cement. It follows that by reducing the proportions of the compounds that hydrate most rapidly (C_3A& C_3S) the high rate of heat evolution in the early life of concrete can be lowered.*

The fineness of the cement also influences the rate of heat development, an increase in fineness speeding up the reaction of hydration and therefore the heat evolved. It is reasonable to assume that the early rate of hydration of each compound in cement is proportional to the surface area of the cement. However, at later stages, the effect of the surface area is negligible and the total amount of heat evolved is not affected by the fineness of cement.

- For massive structures such as dams and retaining walls cement, such as low heat cement is used which generates lesser rate of heat of hydration to avoid cracks due to the fairly rapid rise in temperature and the subsequent cooling.

Table 6:

Heats of Hydration of the Pure Compounds of Portland cement

Compound	Heat of Hydration
C_3S	503 J/g = 120cal/g
C_2S	260 J/g = 62 cal/g
C_3A	867J/g = 207cal/g
C_4AF	419 J/g = 100 cal/g

Table 7:

Heats *of* Hydration *of* the Compounds In Cement

Compound	Heat of Hydration, J/g at the age of					
	3 days	7 days	28 days	90 days	1 Year	6 ½ years
C_3S	243	222	377	436	490	490
C_2S	50	42	105	176	226	222
C_3A	888	1559	1378	1303	1169	1374
C_4AF	289	494	494	410	377	465

Table 8:

Comparison *of* Total Heat *of* Hydration *of* Different Kinds *of Cements*

Types of cement	Heat of Hydration, J/g at the age of			
	3 days	7 days	28 days	90 days
Ordinary Portland cement	23-46	47-75	66-94	80-105
Low heat Portland cement	-	55	65	75
Portland blast furnace	20-26	30-62	70-85	75-90

2. Chemical Composition Requirements of Portland cement.

Chemical Properties

The manufacturer on regular basis normally conducts chemical tests in order to check on the quality of the product. They (chemical tests) may also be conducted in research laboratories in order to determine the compound composition of cement used in a particular research. Otherwise they are of little importance to the ordinary consumer.

The results of chemical tests are reported in terms of oxides, which are used to calculate the compound composition by ***Bogue method***. The four major oxides-calcium oxide (CaO), Silicon dioxide ($Si0_2$), aluminum oxide ($A1_2O_3$) and ferric oxide (Fe_20_3) are important in this respect. It is also important to know the amounts of free lime (free calcium oxide), sulphur trioxide ($S0_3$), and magnesium oxide because of their adverse effects on soundness. The percentages of sodium and potassium (Na_20, K_2O) oxides play also importance incase the cement is used in concrete with alkali reactive aggregates.

Ethiopian Standard ES.C.D6.201 sets quality requirements of Portland cement as follows:

a) Lime Saturation Factor(LSF)

The lime saturation factor (L.S.F) shall not be less than 0.66 or more than 1.02 when calculated by the following formula:

$$L.S.F = \frac{CaO - 0.7(S0_3)}{2.8(Si0_2) + 1.2\,(A1_2O_3) + 0.65\,(Fe_20_3)}$$

The symbol in parenthesis refers to the percentage by weight of total cement. A lime saturation factor within the given limits indicates that the proportion of the raw materials was satisfactory and did not lead to, especially, excess of lime beyond that can combine with silica and alumina. An increase of silica, at the expense of the lime content, reduces the rate of development of strength, whereas, an excess of lime beyond that combined with silica and alumina (free lime) promotes unsoundness in the hardened paste.

b) Alumina Ratio (AR)

$AR = Al_2O_3 / Fe_2O_3$

The ratio of the percentage of alumina (aluminum oxide) to the percentage of iron oxide shall not be less than 0.66.

The decrease in the ratio may result from an increase in ferric oxide content, which reduces the proportion of C_3A and increases that of C_4 AF in the cement.

C) Magnesia (MgO)

The mass of magnesia (magnesium oxide) contained in Portland cement shall not exceed 5.0 percent. The upper percentage limit is to avoid the long-term unsoundness that results from higher percentage content of MgO.

d) Sulfur trioxide (SO_3)

The mass of sulfur trioxide contained in Portland cement shall not exceed 3% if the tricalcium aluminate (C_3A) is 8 % or less, and shall not exceed 3.5 % if the tricalcium aluminate exceeds 8 %.

An upper limit on $S0_3$ is specified in order to avoid unsoundness resulting from the delayed hydration of the sulphate phase.

e) Loss In Mass On Ignition.

The total loss in mass when Portland cement is heated to a temperature of $925 \pm 25\ ^0C$ shall not exceed 4 percent. The loss in mass on ignition is determined in order to check on possible pre hydration or carbonation that may result from improper or prolonged storage of the clinker or resulting cement.

f) Insoluble Residue

The mass of insoluble residue shall not exceed 1.5 percent. The insoluble residue is that part of a cement sample which is insoluble in hydrochloric acid (HCl). It derives from the clay minerals of the raw materials, which have not reacted to form the cement compound, which are soluble in this acid. Hence the amount of insoluble residue indicates the efficiency of the burning process the completeness of the reactions in the kiln.

Field Testing of Cement

Cement is manufactured in factories under controlled conditions, but during its transit and storage there are chances of its deterioration or being adulterated. Therefore whenever cement is received at site for use and it is not possible to conduct any laboratory tests its quality can be judged by the following methods.

1. Visual inspection

A sample of cement taken from the bag showing bright gray color (as specified by the manufacturer) gives an indication of freshness & purity of cement.

2. Adulteration

2.1) Place about 100 grams of cement on a steel plate and heat it for about 20 minutes. No change in color is again an indication of unadulterated cement.

2.2) Shake a small quantity of cement in glass jar ½ full of water and allow it to settle; Adulterated particles (coal, ash etc) if any shall float on the surface.

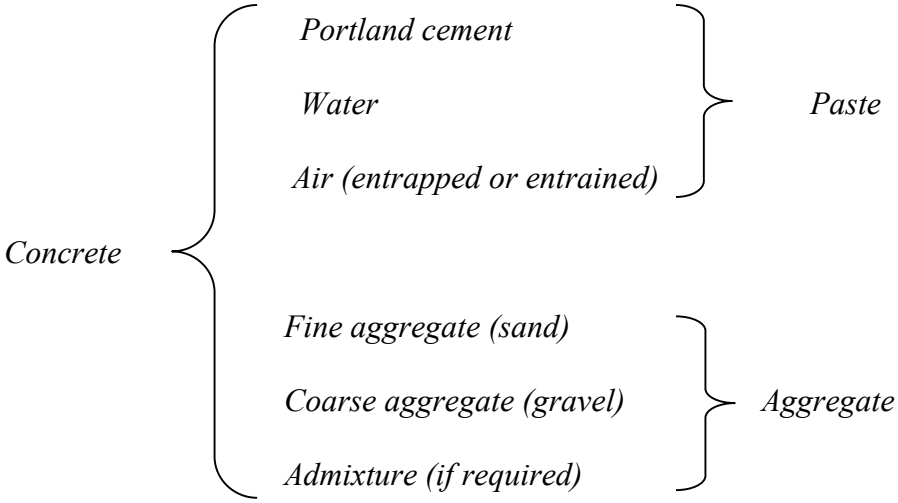
Storage of Cement

At all stages up to the time of use, cement must be kept dry so as to prevent or minimize deterioration from the effects of moisture, atmospheric humidity and carbonation. Airtight drums and internally coated bulk silos are ideal storages. Cement in multi wall paper bags should be stored in a waterproof building with close-fitting doors, which should be kept closed as much as possible. The bagged cement should be stacked on pallets or on a dry board platform; some 150mm clear of the surface. In regions of high relative humidity, insulation and a storage temperature of 45 °c are advisable.

Bags of cement should be stacked close together, so as to restrict the circulation of air around them. The stacks should be kept 150-300mm clear of the walls and be arranged so that stored cement can be removed in the order in which it is received. Cement which is four months old should be classified as aged and be restricted before use

CONCRETE TECHNOLOGY

Concrete is a composite material made up of *inert materials* of *varying sizes, which are bound together by a binding medium*. Concrete contains coarse aggregate in addition to cement, water, air and fine aggregate. *The cement, water, and air combine to form a paste that binds the aggregates together. Thus, the strength* of *concrete is dependent on the strength* of *the aggregate matrix bond.*



The entire mass of the concrete is deposited or placed in a plastic state and almost immediately begins to develop strength (harden), a process which, under proper curing conditions, may continue for years. Because concrete is initially in a plastic state; it lends itself to all kinds of construction, regardless of size or shape.

TYPES AND USES OF CONCRETE

Concrete is a very versatile material and can be made to satisfy a large variety of requirements; whether it is used for foundations, floor slabs, monolithic walls cast in situ or for prefabricating concrete blocks.

1. ***Plain mass concrete,*** with graded or predominantly small sized aggregate, for foundations, floors, paving, monolithic walls (in some cases), bricks, tiles, hollow blocks, pipes.

2. ***No-fines concrete,*** a lightweight concrete with only single size coarse aggregate (dense or lightweight) leaving voids between them, suitable for load bearing and non-load bearing walls, in-fill walls in framed structures or base coarse for floor slabs. No-fines concrete provides an excellent key for rendering, good thermal insulation (due to air gaps), and low drying shrinkage. The large voids also prevent capillary action.

3. ***Lightweight aggregate concrete,*** using expanded clay, foamed blast furnace slag, sintered fly ash, pumice, or other light aggregate, for thermal insulating walls and components, and for lightweight building blocks.

4. ***Aerated concrete,*** made by introducing air or gas into a cement-sand mix **(without coarse aggregate**). Used for thermal insulating, non-structural uses and lightweight building blocks. Disadvantages are low resistance to abrasion, excessive shrinkage and permeability. However, it is easy to handle and can be cut with a saw and nailed like timber.

5. ***Reinforced concrete,*** also known as RCC (reinforced cement concrete), which incorporates steel bars in sections of the concrete which are in tension (to supplement the low tensile strength of mass concrete and control thermal and shrinkage cracking), for floor slabs, beams, lintels, columns, stairways, frame structures, long-span elements, angular or curved shell structures, etc., all these cast in situ or pre cast. *The high strength to weight ratio of steel, coupled with the fortunate coincidence of its coefficient of thermal expansion* being about the **same as concrete**, make it the ideal material for reinforcement. Where deformed bars (which have ribs to inhibit longitudinal movement after casting) are available, they should be given preference, as they are far more effective than plain bars, so that up to 30 % of steel can be saved.

6. ***Pre-stressed concrete,*** which is reinforced concrete with the steel reinforcement held under tension during production, to achieve stiffness, crack resistance and lighter constructions of components, such as beams, slabs, trusses, stairways and other large-span units. By pre stressing, less steel is needed and the concrete is held under compression, enabling it to carry much higher loads before this compression is overcome. Pre stressing is achieved either by pre-tensioning (in which the steel is stressed before the concrete is cast) or by post-tensioning (after the concrete has reached an adequate strength, allowing the steel to be passed through straight or curved ducts, which are filled with grout after the reinforcement has been tensioned and anchored). This is essentially a factory operation, requiring expensive, special equipment (jacks, anchorages, pre stressing beds, etc.), not suitable for low-cost housing.

PROPERTIES OF CONCRETE

Concrete has many properties that make it a popular construction material. The correct ***proportion of ingredients, placement, and curing*** are needed in order for these properties to be optimal.

Good-quality concrete has many advantages that add to its popularity.

- It is economical when ingredients are readily available
- Concrete's long life and relatively low maintenance requirements increase its economic benefits
- Concrete is not as likely to rot, corrode, or decay as other building materials.
- Concrete has the ability to be molded or cast into almost any desired shape.
- Concrete is a non-combustible material which makes it fire-safe and able withstand high temperatures
- It is resistant to wind, water, rodents, and insects. Hence, concrete is often used for storm shelters.

- Building of the molds and casting can occur on the work-site which reduces costs.
- High compressive strength, resistant to weathering, impact and abrasion.
- Low tensile strength (but can be overcome with steel reinforcement)

DISADVANTAGES OFCONCRETE

Some of disadvantages of concrete are:

- High cost of cement, steel and formwork (in developing countries)
- Difficult quality control on building sites, with the risk of cracking and gradual deterioration, if wrongly mixed, placed and insufficiently cured with water.
- In moist climates or coastal regions, corrosion of reinforcement (if insufficiently protected), leading to expansion cracks.
- Demolishing concrete is difficult.

INGREDIENTS OF CONCRETE

1. CEMENT

Usually, Portland cement is specified for general concrete construction work and should confirm to standard specifications. Various types of Portland cement as well as physical & chemical requirements were discussed in the previous sessions.

2. WATER

Water serves two purposes in making concrete. First of all, it causes the ***hydration of cement*** and secondly, it makes the mix ***fluid and workable***. Clean water is important for the same reasons, as is clean aggregate; any impurities present will affect *bond strength between the paste and aggregate*.

Almost any water that is potable may be used to make concrete. Drinking water with a noticeable taste or odor should not be used until it is tested for organic impurities.

Impurities in mixing water may cause anyone or all of the following:

1. *Abnormal setting time*
2. *Decreased strength*
3. *Volume changes*
4. *Efflorescence*
5. *Corrosion of reinforcement*

Some of the impurities in mixing water that cause these undesirable effects in the final concrete are

1. *Dissolved Chemicals.*
2. *Seawater*
3. *Sugar*
4. *Algae*

*Dissolved chemicals may **either accelerate or retard** the set and can substantially reduce the concrete strength further such dissolved chemicals can actively attack the cement sand bond leading to early disintegration of the concrete.*

Sea water containing less than 3% salt is generally acceptable for plain concrete but not for reinforced concrete. The presence of salt can lead to corrosion of the reinforcing bars and a decrease in concrete strength by some 10-15%.

If sugar is present in even small amounts, it can cause **rapid setting** and **reduced concrete strength**. Algae can cause a reduction in the strength of concrete by increasing the amount of air captured in the paste and reducing the bond strength between the paste and the aggregate.

Although water is an essential ingredient, too much water added during mixing results in a weak concrete. Very little water is necessary to cause the hydration process. Therefore, as a general rule, no more water should be added than necessary to make the mix workable.

3. AGGREGATES

Aggregates are the filler materials which make up a large portion (roughly 70- 75%) of the concrete volume. Considerable care should be taken to provide the best aggregates available.

Aggregate can be obtained from various sources; natural or manufactured. Natural aggregates are taken from natural deposits without change in their nature during production, with the exception of crushing, sizing or grading during production. In this group, crushed stone, gravel, and sand are the most common. Manufactured aggregates include blast furnace slag and lightweight aggregates.

AGGREGATE TERMS AND TYPES

The terms used to describe aggregates are many and varied. These descriptive terms are based on source, size, shape, type, use and other properties.

Some typical terms used in describing aggregates are:

1. *Fine aggregate-* aggregate particles passing the No.4 (4.75mm) sieve and retained on the No. 200 *(75-*μm) sieve.

2. *Coarse-aggregate-* aggregate predominantly retained on the No.4 (4.75mm) sieve.

3. Crushed gravel (gravel and sand) - that has been put through a crusher either to break many of the rounded gravel particles to a smaller size or to produce rough surfaces.

4. *Crushed rock-* aggregate from the crushing of rock. All particles are angular, not rounded as in gravel.

5. *Screenings-* the chips and dust or powders that are produced in the crushing of rock for aggregates.

6. ***All-in-aggregate-*** aggregate composed of both fine and coarse aggregate.

7. *Concrete sand-* sand that has been washed (usually) to remove dust & fines.

8. *Fines-* silty-clay or dust particles smaller than 75 μm (No. 200 sieve) usually undesirable impurities in aggregates.

PROPERTIES OF AGGREGATES

Important properties of aggregates include:

- Gradation (grain size distribution)
- Shape and surface texture
- Bulk unit weight
- Specific gravity (relative density)
- Absorption
- Hardness (resistance to abrasion or wear)
- Durability (resistance to weathering)
- Crushing strength
- Cleanliness (deleterious substances)
- Chemical stability

1. Gradation

The gradation or grain size distribution of the aggregate influences:

- The amount of paste required
- The workability of the concrete
- The strength and
- Water tightness of the finished product.

In general, it is desirable that the size increases uniformly from fine sand to the maximum allowed for a given job.

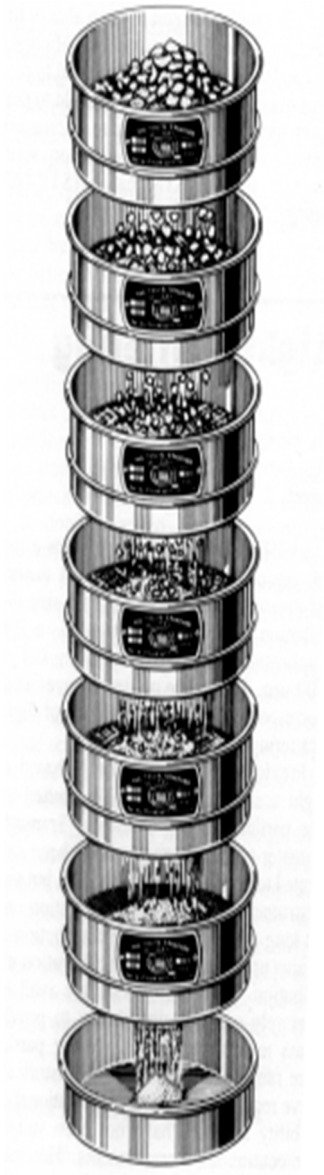
Most specifications for concrete require a grain size distribution that will provide a ***dense, strong mixture.***

> *Aggregates may be dense, gap-graded, uniform, well graded, or open-graded. The terms "dense" and "well-graded" are essentially the same, as are "gap", "uniform" and "open-graded"*

The use of well graded mixture of aggregates results in improved workability of the concrete and economy of the cement since such aggregate has a decreased amount of voids between the particles and consequently requires less cement paste. For a given consistency & cement content, a well-graded aggregate produces a stronger concrete than a poorly graded one because less water required to give suitable workability.

SIEVE ANALYSIS

The grading or particle size distribution of aggregate is determined by sieve analysis. The table below gives standard series of sieves of square openings, which are used in the sieve analysis of fine & coarse aggregates.



Standard size and square openings

Sieve Designation	
Traditional	**Metric**
3″	75mm
2″	50mm
1 ½″	37.5mm
1″	25mm
¾″	19mm
½″	12.5mm
3/8″	9.5mm
No.4	4.75mm
No.8	2.36mm
No. 16	1.18mm
No. 30	600 μm
No. 50	300 μm
No. 100	150 μm
No. 200	75 μm

Fig1: Sieves

For sieve analysis, a sample of aggregate is first surface dried and then sieved through the series, starting with the largest. The weight retained on each sieve is recorded and the percentage computed. The summation of the cumulative percentage of the material retained on the sieves (not including the intermediate sieves) divided by 100 is called *Fineness modulus (FM)*

Fineness modulus is used as an index to the fineness or coarseness and uniformity of aggregate supplied, but it is not an indication of grading since there could be an infinite number of grading which will produce a given fineness modulus.

Six sieves are used in the determination of fineness modulus of sand

37.5mm, 19mm, 9.5mm, 4.75mm, 2.36mm, 1.18mm, 0.60mm, 0.30mm and 0.15mm.

Smaller sieves are not included but coarse ones are used if necessary. The smaller the value of fineness modulus, the finer is the sand. The finesse modulus for good sand should range between 2.25 -3.25.

Very fine sand and very coarse sand are objectionable, fine sand is uneconomical and coarse sand give harsh unworkable mixes. Fineness modulus of sand varies as under:

- Fine sand: 2.25 to 2.6
- Medium sand: 2.6 to 2.9
- Coarse sand: 2.9 to 3.25

Note: 2", 1", ½ ″ sieves are called "Intermediate" & are not included for the fineness modulus calculations.

Maximum Size of Aggregate

It is not necessary that 100% of the particles of an aggregate be within the specified size range for construction purposes. A small amount, usually 5% or 10% is allowed to be either larger or smaller than the specified size, as it would be economically impossible to ensure that 100% of the particles are within any specified range. Therefore, if 19mm (3/4") is the maximum size of aggregate desired for concrete mix, specifications would indicate that the nominal maximum size is 19mm. In this case, 90% of the sample must be smaller than 19mm and 100% smaller than the next higher standard size, 25mm (1 ").

Fine aggregate has a nominal maximum size of 4.75 (No.4 sieve) Therefore specifications will require that 100% of the aggregate pass the 9.5mm (3/6") sieve, and 90 (or 95%) pass 4.75mm.

With a given sectional dimension of a concrete structural member and spacing of reinforcements, it is in general recommended to select the maximum possible size of aggregate.

The maximum size and grading are important because they affect:

1. *The relative volume occupied by the aggregate, hence the economy in producing concrete*

2. The surface area of the aggregate which determines the amount of water necessary to wet all the solids

3. The workability of the mixture

4. The tendency of segregation

5. The porosity & shrinkage





Fig2: sieves in Oven ***fig 3: sieves on vibrator***

2. Shape and Surface Texture

The particle shape and the surface texture of aggregates influence the properties of ***fresh concrete more than those of hardened concrete***. Sharp, angular, and rough aggregate particles require more paste to make good concrete than do rounded ones. Flat, slivery pieces make concrete more difficult to finish and should be limited to not more than 15 percent of the total. This requirement is particularly important for *crushed fine aggregate*, since material made in this way contains more flat and elongated particles.

3. Bulk Unit Weight

The bulk unit weight of an aggregate is the weight of the aggregate divided by the total volume occupied by it. The total volume includes the volume of aggregate particles and the volume of voids. In other words it is the amount of material which can be placed in a container of unit volume. The amount may vary, depending on the method used to fill the container, grading and shape of the aggregates. The normal range of bulk unit weight for aggregates for normal weight concrete is from 1200 to 1760 kg/m^3.

- The range of aggregates that could be used in concrete is as follows: -
  - Heavy weight
  - Light weight
  - Normal Weight

The highest volume of material in concrete is the ***aggregate*** and as consequence the properties of the aggregate can have a major influence on the performance and appearance of the concrete.

The majority of concrete that is placed uses normal weight aggregate, however heavy weight can be used for special nuclear shielding purpose and lightweight concrete applications include reduced weight and fire resistance.

4. Specific Gravity

The specific gravity of an aggregate is another characteristic of the material which needs to be determined. It is not a measure of aggregate quality but is used in making calculations related to mix design. The specific gravity of most normal weight aggregate will range from 2.4 to 2.9

5. Absorption

Over a 24-hr period lightweight aggregates may absorb water in the amount of 5 to 20 percent of their own dry weight, depending on the type of aggregate and its pore structure. A tendency of this sort must be taken into account when concrete is made with lightweight aggregate. To make light weight mixtures as uniform as possible, however, aggregates should be pre-wetted, but not saturated, 24 hr before they are to be used.

6. Moisture Content

Two types of moisture are recognized in aggregates: absorbed moisture and surface moisture. Absorbed moisture is that which is taken in by the voids in aggregate particles and may not be apparent on the surface, while surface moisture is that which clings to the surface of the particle.

The absorption and surface moisture of aggregate is need to be determined in order to control the net water content of a concrete mix and to make adjustment in batch weights of the materials. The moisture conditions of aggregates are designated as follows:

- ***Oven-Dry****:* In this condition they are fully absorbent.
- ***Air-Dry****:* Particles are dry at the surface but contain some interior moisture. They are therefore somewhat absorbent.
- ***Saturated surface-Dry*****:** In this condition there is no water on the surface, but the particle contains all the interior moisture it can hold. It will neither absorb moisture from nor contribute moisture to the mix.
- ***Damp or Wet*****:** The particles contain an excess of moisture on the surface and will contribute moisture to the mix.

Surface moisture in fine aggregate is the cause of a phenomenon known as ***bulking* of *sand.*** *Surface moisture holds the particles apart,* causing an increase in volume over the same amount of sand in a surface dry condition. The amount of bulking will depend on the fineness of the sand.

The moisture present in the aggregate affects the total water needed for the mix. The ideal moisture is "**saturated surface dry**" where in all pores of the material are filled with water but no free moisture exists on the surface. Most problems occur with the use of very wet or very dry fine aggregate. Allowance must be made for the amount of water added under such conditions.

7. Crushing Strength and Durability

One measure of the strength of an aggregate is its resistance to ***freeze-thaw***. This resistance is an important characteristic in concrete which is exposed to severe weather. The freeze-thaw resistance of an aggregate is related to its porosity, absorption, and pore structure. If a particle of the aggregate absorbs so much water that there is no enough pore space available, it will not accommodate the expansion, which takes place when the water freezes, and the particles will fall. Freeze-thaw tests on aggregates are commonly carried out on specimens of concrete made with the aggregate.

Another test of the strength of aggregates is their ability to withstand compressive stresses. This test is made by subjecting hardened concrete specimens made with the aggregate in question to compression testing.

8. Cleanliness (Deleterious Substances)

The cleanliness of the aggregate affects the bond between the paste and the aggregate surface, and therefore, affects the strength and water tightness of the concrete. Coarse aggregates may be checked visually.

Deleterious (harmful substances) have the following effects on concrete:

- *weaken bondage between cement paste and aggregates*
- *Interfere with hydration*
- *Reduce strength and durability*
- *Affect water tightness of the concrete*
- *Modify setting action and*
- *Cause efflorescence*

Examples: -***Iron pyrites, coal, silt and clay, mica, chemical salts***.

Iron pyrites affect concrete surfaces: staining and disruption of concrete paste. Coal affects appearance and strength of concrete. Dirt, silt and clay form coating on aggregates. If they are much in quantity, they affect strength and durability of aggregates and water demand for mixing. Mica is also responsible for weak strength and durability. Chemical salts resulting in efflorescence.

***Remedial* measures:**

- Washing to remove deleterious materials
- Avoiding aggregates with reactive tendency or using them with cement of low alkali.

SILT TEST

Fine aggregates can be checked by placing the material in a glass jar, which is then filled three-fourths full with clean 5 cm water and sealed. Turn the jar on its side and shake vigorously for one minute. Set the jar upright, level the sand by shaking sideways, and let it stand for about three hours. Any silt present will be suspended by the shaking and will settle back on the sand surface when allowed to stand. If more than (3mm) of silt skim is formed, then the sand is too dirty to form strong concrete. In the field, a sample test may be performed by rubbing a moist sample of sand between the palms; suitable sand will leave the hands only slightly dirty.

A *colorimetric (organic impurity) test* determines whether fine aggregate contains injurious amounts of organic matter.

9. Hardness

The hardness of aggregates is expressed in terms of their resistance to ***abrasion***. This characteristic is important if the aggregate is used in concrete intended for such purposes as heavy duty floors. A common method of making this test is the ***Loss Angeles abrasion test*** and consists of placing a specified quantity of the aggregate to be tested in a revolving steel drum. The percentage of material worn away during the test is then determined.

10. Chemical stability

Aggregates need to be chemically stable so that they will neither react chemically with cement nor be affected chemically by outside influences. In some cases aggregates with certain chemical constituents react with alkalis in cement. This reaction may cause abnormal expansion and will results cracking of concrete.

Handling and stockpiling of aggregates

The purpose of appropriate handling and stock piling of aggregate is to avoid ***segregation of aggregates.***

Precautions:

- Storing on hard and dry ground or on platforms of planks, sheets, lean concrete
- Storing separately each aggregate size in compartments
- Avoiding segregation of aggregates resulting from free fall
- Damping consignments at different places,

FRESH CONCRETE

Fresh concrete is also known plastic concrete. The major Properties of concrete in its plastic state are **(1) workability, (2) consistency, (3) segregation, (4) bleeding and (5) Stiffening and Setting**.

PROPERTIES OF FRESH CONCRETE

1. Workability: - Workability is the measure of the ease with which we can place and cast fresh concrete. Factors that affect workability are:

- Water content
- Shape of aggregate
- Grading of Aggregates
- Size of Aggregates
- Surface Texture of Aggregates

If water content is increased in the concrete mix, particles settle and bleeding occurs. Cement slurry can escape through joints of form works. Large sizes of aggregates consume less quantity of water and cement, therefore are economical. Appropriate size depends on handling, mixing and placing equipment, thickness of section and reinforcement bar spacing. Angular shape, flakiness, and elongation of aggregates reduce workability. Non absorbent aggregates and optimum percentage of fine aggregate contributes to workability.

2. Consistency: - refers to ease of flow of concrete and indicates wetness of concrete and thus ***workability***. Concrete could have *dry, plastic, semi-fluid, and fluid consistency*. Concrete of plastic consistency can be shaped into ball, while that of semi-fluid consistency spreads out slowly and with out segregation of aggregate. Concrete of fluid consistency spreads out fast and results in segregation of aggregates, and hence unacceptable.

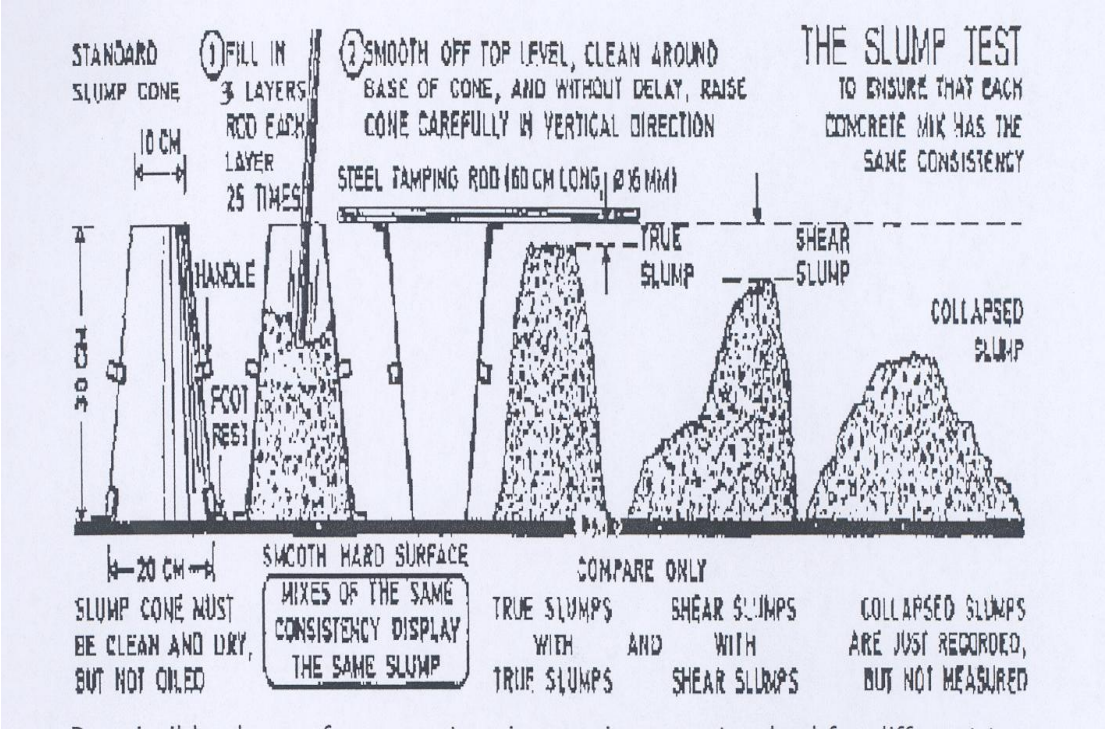
- ✓ ***MEASUREMENT OF WORKABILITY***

The methods of measuring workability that is wetness or fluidity are ***slump test and compacting factor test.***

Slump Test: Slump is the subsidence of concrete cone after mold is lifted up. Slump test is made in laboratory and on site to measure subsidence of a pile of concrete in a mold (slump test apparatus of dimensions: base diameter = 20 cm, top diameter = 10cm, and height =30 cm.) compacted with a steel rod (16 mm diameter and 60cm long).

Types of slump (results of Slump)

- ***True Slump*** -Has even subsidence
- ***Shear Slump*** -Half *of* the cone slides, difficult to measure, and results from harsh mixes-deficient in fine aggregate.
- ***Collapse slump***-difficult to measure, results from very wet mixes



Permissible slumps for concrete mix are given as standard for different types of construction activities and placing conditions. The slump values shall be referred before using the concrete mix.

Slump test gives the advantage of detecting water content of successive batches of concrete of identical mix. However, there are some limitations of slump test. These are:

- *Not applicable for aggregates size greater than 40 mm*
- *Applicability to plastic mixes only*
- *Not applicable to harsh and wet mixes*

Compacting Factor Test: drier mixes do not give slump. Therefore, compaction factor test should be done to determine degree of compaction (compacting factor) by making the mix fall through successive hoppers with standard height using a compaction factor test apparatus.

$$\text{Compacting Factor} = \frac{weight - of - partially - dry - compacted - concrete}{weight - of - fully - compacted - concrete}$$

Table: Permissible Values of Compacting Factor

Workability	**Compacting factor**
Good workability	0.95
Medium Workability	0.92
Low workability	0.85

For different placing conditions, degree of workability (extremely low, very low, medium, and high), and aggregate sizes, corresponding values of Compacting factor are given as standard to compare with.

3. Segregation: - or separation of coarse aggregates from the mass of concrete results from:

- Uncontrolled pumping or falling
- Placing under waters
- Placing concrete in heavily reinforced members

Precautions to control segregation:

- Careful handling, placing, and consolidation of concrete.
- Placing concrete near its final position, instead of falling from greatest heights.

4. Bleeding: - is the appearance of water on concrete surface. As a consequence of bleeding, slum layer will be formed making concrete weak and porous. Slum layer shall be removed before casting new layer.

Measures to minimize bleeding:

- *Using well graded and proportioned aggregates*
- *Increasing amount of cement*
- *Applying air entering agents*
- *Reducing amount of water*

5. Stiffening and Setting: - Concrete is required to remain plastic for the time to be taken to transport, place, and consolidate it. Temperature influences the stiffening of concrete. That is, low temperature delays while high temperature, accelerate the stiffening of concrete.

VOLUME OF FRESH CONCRETE

The volume of fresh concrete is equal to the sum of the absolute volumes of its components, including the naturally entrapped or purposely entrained air.

If V_a = Volume of air

V_w = volume of water

V_c= absolute volume of cement

V_{fa} = absolute volume of fine aggregate

V_{ca} = absolute volume of coarse aggregate

Then the total volume of the fresh compacted concrete will be:

$V = V_a + V_w + V_c + V_{fa} + V_{ca}$..... (1)

From the point of view of concrete technology it would be best to prescribe mix proportions by the "absolute volume" of the ingredients, because the volume of the resulting concrete and its properties are dependent on the absolute volume and not on

their weight or bulk volume. But this is an impractical way to proportion materials, because the absolute volume of the ingredients cannot be measured in the field.

However, the absolute volume can easily be calculated from the relationship of the weight and specific gravity of the material:

$$V = \frac{W}{1000\,G} \quad \text{..... (2)}$$

Where: **V** is the absolute volume in m^3

W is the weight of the material in kg

G is the specific gravity *of* the material & 1000 is the density or unit weight *of* fresh water in kg/m^3

The specific gravity *of* cement may be taken, for all practical purposes, equal to 3.15. For calculating the volumes *of* the aggregates we use their specific gravity (bulk, saturated surface dry basis), which is defined by " the ratio *of* the weight in air or the S.S.D. aggregates (i.e., including their voids) to the weight *of* an equal volume *of* water:

Substituting weight and specific gravities in equation (2) for absolute volumes in equation (1) we get the volume *of* concrete in m^3 as follows

$$V = V_a + \frac{Ww}{1000} + \frac{Wc}{1000Gc} + \frac{Wfa}{1000Gfa} + \frac{Wca}{1000Gca} \quad \text{..... (3)}$$

Where: Va = Volume of air

W_w= weight of water

W_c =weight of cement, Kg.

W_{fa}= weight of fine aggregate, Kg

W_{ca}= weight of coarse aggregate, kg

If the cement, water, and air contents per m^3 *of* fresh concrete are known, then the required weight *of* the aggregates for a cubic meter *of* fresh concrete can easily be calculated from Eq. (3).

If the cement and aggregates on the job are to be measured by volume, the weight proportion as obtained by the above procedure can be volumetric proportion. This is done dividing the weight *of* the cement and aggregates by their respective loose unit weights in kg/m^3 as obtained in the measuring devices on job conditions.

$$VolumeofBulkmaterial = \frac{Weightofmateria, Kg}{Unitweight, Kg/m3}$$

Example: 1

Given: quantities per m^3 of fresh concrete:

- Cement: 350 kg
- Water: 190 l(litter)
- Air : 1% = 10 l
- Bulk sp. Gravity of aggregates = 2.65
- Specific gravity of cement = 3.15

Solution:

Absolute volume of air $= 0.010\ m^3$

Absolute volume of water $= \frac{Ww}{1000} = \frac{190}{1000} = 0.190\ m^3$

Absolute volume of cement $= \frac{Wc}{1000(3.15)} = \frac{350}{1000(3.15)} = \frac{0.111}{0.311}\ m^3$

Absolute volume of aggregates = 1.000 -0.311 = 0.689 m^3

Weight of aggregates = 0.689 (2.65 x 1000) = 1825.85 kg

For convenience of calculation it can be written in the form of the following table:

	Weight (kg)	**Absolute volume (m^3)**
Air	**-**	**0.010**
Water	190	0.190
Cement	350	0.111
Total	**540**	**0.311**
Aggregates	1826	0.689
Total	**2366**	**1. 000**

The above total weight of the concrete is the unit weight in kg per m^3 of the fresh concrete. If the proportion of the fine to coarse aggregate by weight is **1: 2**, then the quantities of aggregates will be

$$\text{Fine Aggregate (sand)}\ \frac{1826\ *1}{3} = 609\ kg$$

$$\text{Coarse Aggregate}\ \frac{1826\ *2}{3} = 1217\ kg$$

The mix quantities and proportions by weight will be:

	Kgs	Parts
Water	**190**	**0.543**
Cement	**350**	**1**
Sand	**609**	**1.74**
C.A.	**1217**	**3.48**

Example: 2

If the loose unit weights of the surface dry materials in example 1 were

Cement: 1300kg/m^3 (under the given condition of measurement)

Sand (S. S. D) 1600 kg/m^3

C.A (S.S.D) 1450kg/m^3

Then the total amount of dry materials in loose volume per m^3 of concrete is:

Cement 350/1*300* = 0.27 m^3

Sand 609/ 1600 = 0.38 m^3

C. A 1217/ 1450 = 0.84m^3

Total loose volume = 1.49 m^3

The volume of loose aggregates needed per m^3 of concrete is 1.22 m^3. The mix proportions by volume are then:

Water cement sand C. aggregate

$$\frac{0.190}{0.27} : \frac{0.27}{0.27} : \frac{0.38}{0.27} : \frac{0.84}{0.27}$$

0.703 1 1.41 3.11 or cement to aggregates (1: 4.52)

Example: 3

If in example 1 the sand as delivered contains 3% free moisture on its surface and weighs 1200 kg/ m^3

Note: *When sand is delivered damp and contains free moisture on its surface. The film of water on the surface of the sand particles holds them*

apart and prevents them from adjusting themselves to occupy a minimum volume. This causes a considerable increase in volume when measured loose, or a corresponding decrease in the unit weight. This phenomenon increases rapidly with increase in moisture content. The finer the sand, the more it will bulk.

The loose volume of fine aggregate needed for $1m^3$ of concrete will be:

$$\frac{609 + (609 * 3/100)}{1200} = 0.523m3 \quad \textit{(Instead of } 0.38m^3\textit{)}$$

When using damp sand the weight has to be increased by the percentage of free water in the sand. The amount of water added to the mix decreases accordingly:

$$\text{Water} = 190 - (609 * \frac{3}{100}) = 172l = 0.172m3$$

The total volume of aggregates needed will be

$$0.84(C.A) + 0.523(F.A) = 1363\ m3$$

The mix proportions by volume (with damp sand)

$$\frac{water}{\frac{0.172}{0.27}} : \frac{Cement}{\frac{0.27}{0.27}} : \frac{sand}{\frac{0.523}{0.27}} : \frac{C.A}{\frac{0.84}{0.27}}$$

$$0.638 : 1 : 1.94 : 3.11$$

Or cement to aggregates: **1:5.05**

Failure to allow for the bulking of sand when batching volumetrically will reduce yield of concrete and result in an under-sanded and harsh mix, which is difficult to place as may be seen from the following calculation:

If only $0.38m^3$ sand is taken then the actual weight of sand in the mix will be:

(0.38 x 1200) -3% (0.38x1200) = 456 -14 = 442 kg

Its absolute volume: $\frac{442}{1000 * 2.65} = 0.167m3$ and the volume of produced concrete will be:

	Weight	Absolute Volume
Air	**-**	0.01
Water	**(190-14)=176**	0.176
Cement	**350**	0.111
Sand	**442**	0.167
C.A.	**1,217**	0.460
Total	**2,185kg**	0.924m^3

The amount of cement per m^3 $\frac{350}{0.924} = 380kg$ *Instead of* 350 kg

As can be concluded from the above calculations, weight batching is much preferable to volume batching, because it is almost impossible to make exactly the correct allowance for bulking all the time. There are more factors involved like the shape, the size of the measuring device and the person who fills it.

From the above results it is possible to calculate the cement factor (CF) and the yield (y) of the concrete. **The cement factor for a concrete mix is the cement content expressed in terms of sacks of cement per cubic meter of concrete**. In example 1, 350 kg of cement is used to produce $1m^3$ of concrete; taking 50 kg as the weight of one sack of cement we have

$$CF = \frac{350}{50} = 7sack/m3$$

The yield of concrete is the amount of fresh concrete in m^3 produced per sack of cement.

$$y = \frac{1}{7} = 0.143m3/sack$$

Basic Relationships

Concrete proportions must be selected to provide ***workability, consistency, density, strength, and durability*** *for* the proposed application.

Workability*:* The property of the concrete that determines its capability to be placed and consolidated properly and finished without happening of segregation.

Consistency: It is the relative mobility of the concrete mixture and is measured in terms of the slump; the greater the slump value, the grater the mobility of the mixture.

Strength: The capacity of the concrete to resist compression at the age of 28 days.

Water-cement* (w/c) ratio:* Defined as the ratio of weight of water with the weight of cement this ratio is used in mix design and considerably controls concrete strength.

Durability: Concrete must be able to resist severe weather condition such as freezing and thawing, wetting and drying, heating and cooling, chemicals and the like. An increase of concrete durability will enhance concrete resistance to severe weather conditions.

Density: For certain applications concrete may be used for its weight characteristics. Examples are counterweight, weight for sinking pipelines under water, shielding from radiation and insulation from sound.

Background Data

To the extent possible, selection of concrete proportion should be based on test data or experience with the materials actually to be used. The following information *for* available materials will be collected

- Sieve analyses of fine and coarse aggregates.
- Unit weight of coarse aggregate
- Bulk specific gravities and absorption of aggregates
- Mixing-water requirements of concrete developed from experience with available aggregates.
- Relationship between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials
- Specific gravity of Portland cement and other cementitious materials, if used
- Optimum combination of coarse aggregates to meet the maximum density grading for mass concrete
- Estimate of proportions of mix for preliminary design.

Table: 1 Recommended slumps for various types of construction

Types of Construction	Maximum Slump (mm)	Minimum Slump (mm)
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

Table:2 Mixing water and air content

NON-AIR-ENTRAINED CONCRETE								
Approximate mixing water (kg/m^3) for indicated nominal maximum sizes of aggregate								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50 mm**	**75 mm**	**150 mm**
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	-
More than 175	-	-	-	-	-	-	-	-
Approximate amount of entrapped air in non-air-entrained concrete (%)								
Slump (mm)	**9.5 mm**	**12.5 mm**	**19 mm**	**25 mm**	**37.5 mm**	**50 mm**	**75 mm**	**150 mm**
All	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

Table:3 Water cement ratio

Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete	
Compressive strength at 28 days (MPa)	**Water-cement ratio by weight (Non-air-entrained concrete)**
40	0.42
35	0.47
30	0.54
25	0.61
20	0.69
15	0.79

Important! **Check the maximum permissible water-cement ratio from the Table below and revise the water-cement ratio entered in the box above accordingly.**

Table:4 Maximum permissible water-cement Ratio

Maximum permissible water-cement ratios for concrete in severe exposure		
Type of Structure	**Structure wet continuously and exposed to frequent freezing and thawing**	**Structure exposed to sea water or sulfates**
Thin section (railings, curbs, sills, ledges, ornamental work) and sections with less than 25 mm cover over steel	0.45	0.40
All other structures	0.50	0.45

Table:5 Coarse Aggregate Per Unit volume Of Concrete

Volume of oven-dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate				
Nominal maximum size of aggregate (mm)	**2.40**	**2.60**	**2.80**	**3.00**
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Mix Design Example:

Concrete is required for a portion of a structure that will be below a ground level in a location where it will not be exposed to severe weathering or sulfate attack. Structural considerations require it to have an average 28- day compressive strength of 24MPa with slump of 75 to 100 mm. The coarse aggregate has a nominal maximum size of 37.5 dry-rodded mass of 1600 kg/m^3. Ordinary Portland cement will be used and its specific gravity is assumed to be 3.15. The coarse aggregate has a bulk specific gravity of 2.68 and absorption of 0.5 percent. The fine aggregate has a bulk specific gravity of 2.64, absorption of 0.7% and a fineness modulus of 2.8.

Solution:

Step 1: The slump is required to be 75 to 100 mm.

Step 2: The aggregate to be used has a nominal max size of 37.5mm

Step 3: The concrete will be non-air entrained since the structure is not exposed to severe weathering. From table 2 the estimated mixing water for a slump of 75 to 100 mm in non air entrained concrete made with 37.5 aggregate is found to be 181 kg/m^3.

Step 4: The water-cement ratio for non-air entrained concrete with strength of 24MPa is found from table 3 to be 0.62.

Step 5: From the information developed in step 3 and 4. The required cement content is found to be 181/0.62 = 292 kg/m^3.

Step 6: The quantity of coarse aggregate is estimated from 5. For a fine aggregate having a fineness modulus of 2.8 and 37.5 mm nominal maximum size coarse aggregate, the table indicated that **0.71 m^3** of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete. The required dry mass is therefore, 0.71 *1600 = **1136 kg**.

Step 7: With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the cubic meter of concrete must consist of fine aggregate and whatever air will be entrapped. The required fine aggregate may be determined on the basis of either mass or absolute volume as shown below.

Step 7.1 Mass basis: The mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be **2410kg**.(Table 6)

- Masses already known are:
  - Water (net mixing) 181 kg
  - Cement 292 kg
  - Coarse aggregate 1136 kg

  Total 1609 kg

The mass of fine aggregate, therefore, is estimated to be ***2410-1609 = 801 kg***.

Step 7.2 Absolute volume basis: with the quantities of cement, water and coarse aggregate established, and the approximate entrapped air content (as opposed to purposely entrained air) of 1 percent determined from table 2 the sand content can be calculated as follows:

$$Volume\ of\ water = \frac{181}{1000} = 0.181 m^3$$

$$Solid\ volume\ of\ cement = \frac{292}{3.15 * 1000} = 0.093 m^3$$

$$Solid\ volume\ of\ coarse\ aggregate = \frac{1136}{2.68 * 1000} = 0.424 m^3$$

Volume of entrapped air = 0.01 * 1 = 0.010 m^3

Total solid volume of ingredients 0.708 m3 except fine aggregate then volume of fine aggregate then is =**1-0.708=0.292m^3**

PROPERTIES OF HARDENED CONCRETE

The compressive strength of concrete is usually at least ten times its tensile strength, and five to six times its flexural strength. The principal factors governing the compressive strength of concrete are given below.

- Water-cement ratio is by far the most important factor.
- The age of the cured concrete is also important. Concrete gradually builds strength after mixing due to the chemical interaction between the cement and the water. It is normally tested for its 28 day strength, but the strength of the concrete may continue to increase for a year after mixing.
- Character of the cement, curing conditions, moisture, and temperature. The greater the period of moist storage (100% humidity) and the higher the temperature, the greater the strength at any given age.
- Air entrainment, the introduction of very small air voids into the concrete mix, serves to greatly increase resistance of the final product to cracking from freezing-thawing cycles. Most outdoor structures today employ this technique.

The final strength of the finished concrete depends on:

1. The proportions of the components (i.e. whether the correct quantities of gravel, sand, cement and water have been used)

2. The quality of the components

3. The distribution of the grain sizes of the gravel and sand

4. The way the components are mixed

5. The way the mixture is transported, placed, compacted and cured.

INTRODUCTION TO ADVANCED CONCRETE TECHNOLOGY

Admixtures

An admixture is defined as a material other than water, aggregates, hydraulic cements, or fiber reinforcement that is used as an ingredient of concrete or mortar and added to the batch immediately before or during mixing. Admixtures are generally added to the basic ingredients that make up concrete to modify various properties of the concrete to make it more suitable for use. They are used only when the desired properties can not be achieved by altering the design mix. Admixtures consist broadly of:

- *Air-entraining admixtures*
- *Water reducing admixtures*
- *Setting-time controlling admixtures (retardants - accelerators).*
- *Mineral admixtures*

Fresh concrete contains some air bubbles because of the difficulty of eliminating all air during mixing. Some of these bubbles are lost shortly after mixing. Others are entrapped in concrete. They are usually large in size and could form continuous channels in the concrete that may increase the permeability and reduce durability. ***The air-entraining agent*** stabilizes the air bubbles that are originally formed during mixing. By stabilizing the air bubbles, they introduce minute voids in concrete that are discontinuous.

> *The most important application of air-entraining chemicals is to increase the resistance of concrete to freezing and thawing.*

Water reducing and set controlling admixtures

Different types of admixtures of this group are:-

Water-reducing admixtures: - it reduces the quantity of water required to produce concrete of a given consistency.

Retarding admixtures:-they are used to lengthen the setting time and improve workability of a concrete mixture. The most important application of retardant is in hot weather climate especially if delays in transportation and placing of concrete are expected.

Accelerating admixtures: - accelerates the setting and early-strength development of concrete. Accomplishing this will result in better scheduling of the

workload, earlier removal of construction forms, and compensation effect of low temperature on early strength development. In constructions like road repairing accelerating admixtures have a great application. They will give the concrete early strength and enable us to make the road ready for use in a short time. The most common accelerator is ***calcium chloride***.

WATER-REDUCING AND RETARDING ADMIXTURES: - water reducing and retarding admixtures reduce the quantity of mixing water required to produce concrete of a given consistency and retard the setting of concrete.

WATER-REDUCING AND ACCELERATING ADMIXTURES:-water reducing and accelerating admixtures reduce the quantity of mixing water required to produce concrete of a given consistency and accelerate the setting and early-strength of concrete.

Fiber-reinforced concrete

The technology of fiber-reinforced building materials goes back to ancient times. *Sun-baked bricks reinforced with straws were used in buildings; animal hair was used to strengthen plaster*. Plain concrete possess low-tensile-strength and tensile-strain capacity making it a brittle material. To use concrete economically as a construction material, reinforcement must be provided. Traditionally, reinforcement has been in the form of continuous reinforcing bars placed at selected location to with stand resulting tensile stress. Fibers added to concrete are short, discontinuous, and randomly distributed throughout the matrix. Experimental studies showed that with volumes and sizes that could be conveniently incorporated into conventional cementitious composites without handling difficulties, fibers were not able to offer a substantial improvement in strength in strength over corresponding mixtures without fibers. Therefore, fibers are not generally considered highly efficient in resisting tensile stresses. However, because they are closely spaced, they are very effective in providing better crack control and improving the composite toughness. Despite the limited contribution of fibers to the tensile strength of cementitious composites, there are certain applications in which fiber reinforcement is better than conventional reinforcing bars.

Thin sheet materials: in which traditional reinforcing bars cannot be used because of space limitations and in which the fibers therefore constitute the primary reinforcement.

Structural components: in which fibers' main role is to control cracking and to improve the post failure behavior.

Similar to all construction materials, the evaluation of the properties of fiber-reinforced cementitious composites is of major importance. Most of these properties are matrix dependent and can be measured by the methods commonly used for conventional concrete (example: compressive strength, freeze-thaw durability) but some properties like workability should be tested and evaluated with different methods which are special to fiber-reinforced cementitious composites. Time of flow of fiber reinforced concrete through inverted slump cone is used to measure the workability of fiber reinforced

composites.

There are numerous types of fibers used in cementitious composites, namely, steel fibers, glass fibers, synthetic fibers, and natural fibers. These types of fibers vary considerably in properties and effectiveness.

High strength concrete

High strength concrete refers to concrete that has a uniaxial compressive strength greater than the usual strength obtained in a particular region. Using conventional concrete production techniques we can produce high strength concrete. However, more stringent quality control, better quality materials and increased care in the proportioning of mortar and choosing admixtures must be maintained continuously.

Material properties of high strength concrete

Stiffness of concrete increases with the increase of its compressive strength.

Higher compressive strength results in higher strain at ultimate loading

The fracture strain (maximum sustained strain) seems to decrease with increase in strength leading to a more brittle and explosive type of failure.

Using high strength concrete in structures results in both technical and economical advantages. Most applications of high strength to date have been in high-rise buildings, long span bridges, and some special structures. Tall structures whose construction using normal strength would not have been feasible in the past have now been completed using high-strength concrete in tall structures. Major application of high strength concrete in tall structures have been in columns and shear walls, which resulted in decreased dead weight of the structure and an increase in the amount of the rental floor space, in the lower storey.

Asphalt cement

Definition: - Asphalt or bituminous materials (or bitumen) are hydrocarbons which are usually fairly hard at normal temperatures; when heated, they soften and flow. When mixed with aggregates in their fluid state they solidify and bind the aggregates together, forming a pavement surface.

Asphalt as paving material

Bitumen that has been used in paving includes:

Native Asphalts: obtained from asphalt lakes and these were used in some of the earliest pavements.

Rock asphalt: These are rock deposits containing bituminous materials which have been used for road surfaces in localities where they occur.

Tars: tars are bituminous materials obtained from the distillation of coal.

Petroleum asphalts: These are products of the distillation of crude oil. These asphalts are by far the most common bituminous paving materials in use today.

Grades of asphalt materials and temperature at which they are used depend to a great extent on their viscosity. The viscosity of asphalt varies greatly with temperature, ranging from a solid to a fairly thin liquid. Viscosity-temperature relationships are extremely important in the design and use of these asphalt materials.

Viscosity decrease (that is, materials becomes more fluid) as temperature increases. A very viscous fluid is very "thick."

Absolute (or dynamic) viscosity is measured in Pa. s (SI unit) and poises (traditional units). [1 poise=0.1 Pa. s] kinematic viscosity is the ratio of the absolute viscosity divided by density and measured in cm^2/s.

Asphalt cements were originally graded according *to penetration value.* This is an empirical test in which the amount the needle penetrates a prepared asphalt sample in five seconds is measured in tenths of a millimeter under standard conditions. For example, if the needle penetrated 9.8 mm-or 98 tenths of a mm-the penetration value would be 98.

Plant temperatures for mixing asphalt- paving materials are usually specified in terms of viscosity, for this indicates how fluid the material is and how well it will coat the aggregates without overheating. Temperature limits corresponding to viscosities of 1.5 to 3 cm^2 are sometimes used.

The minimum temperature for spraying (as in pavement seal coats) is often specified as that corresponding to a viscosity of 2cm2/s.

The major paving products are:

Asphalt cements: These are primary asphalt products produced by the distillation of crude oil. They are produced in various viscosity grades, the most common being AC 2.5, AC 5, AC 10, AC 20, and AC 40. These roughly correspond to penetration grades 200-390, 120-150, 85-100, 60-70, and 40-50, respectively. The viscosity grades indicate the viscosity in hundreds of poises ± 20% measured at 60 ^{0}C. For example, AC 2.5 has a viscosity of 250 poises ± 50. AC 40 has a viscosity of 4000 poises ± 800.

Cutback asphalts (liquid asphalts) are asphalt cements mixed with a solvent to reduce their viscosity and, thus, make them easier to use at ordinary temperatures, they are commonly heated (if required) and then sprayed on aggregates. Upon evaporation of the solvent, they cure or harden and cement the aggregate particles together.

Types and grades are based on the type of solvent, which governs viscosity and the rates of evaporation and curing.

Rapid Curing (RC) types use gasoline as a solvent, and therefore cure rapidly.

Medium Curing (MC) types use kerosene.

Slow Curing (SC) types use diesel fuel, or they may be produced directly from the refinery during distillation. Solvent contents are commonly from 15% to 40% of the total. Grades of liquid asphalts are governed by viscosity.

Asphalt emulsions are mixtures of asphalt cement and water. As these components do not mix themselves, an emulsifying agent (usually a type of soap) must be added. The emulsifying unit breaks up the asphalt cement and disperses it, in the form of very fine droplets, in the water carrier. When used, the emulsion sets as the water evaporates. The emulsion usually contains 55%-75% asphalt cement and up to 3% emulsifying agent, with the balance being water.

Two general types of emulsified asphalts are produced, depending on the type of emulsifier used

- *Cationic emulsions*, in which the asphalt particles have a positive charge;
- Anionic, in which they have a negative charge.

Anionic emulsions adhere better to aggregate particles which have positive surface charges (e.g. silica). Cationic emulsions also work better with wet aggregates and in colder weather.

Aging or hardening of asphalt is due to the evaporation and oxidation of the lighter oily constituents during mixing at high temperatures and to the oxidation of the oils to resins and resins to asphalt when used over a period of years. Design of asphalt mixtures must take into account these possible effects on the useful life of a pavement.

An emulsion's rate of hardening depends on the amount and type of agent used. There are three grades of the two types of asphalts (C indicates cationic types);

Rapid setting (RS or CRS)

Medium setting (MS or CMS)

Slow setting (SS or CSS).

Tests for asphalt

Quality control; tests for asphalt material include Viscosity, Ductility, Thin film oven test, solubility, and Flashpoint tests.

Metals

Materials that are used for construction purpose can be broadly classified into metallic and non- metallic material. Metals again are classified as ferrous and non- ferrous metals based on the principal element of the metal. In this section we are going to see some important characteristics of metals.

Mechanical properties of metal

*Slip (Inelastic action):-*Slip is a phenomenon of movement along gliding planes of crystals due to the application of stress beyond the material's elastic limit. When a material undergoes slip, one will observe slip lines or slip bends (fine lines) across the faces of a number of the crystalline grains of the overstressed metal.

Slip is an inelastic action that does not occur to any appreciable extent in any of the ordinary materials of construction until fairly well defined limiting stress has been applied; and if slip occurs, it does not continue indefinitely under load but ceases after a short time. As slip takes place, the crystalline grains of metal are fragmented into thin plates and the surfaces of the sliding plates tend to "dig into" each other, causing increasing resistance as slip proceeds. In addition to this, adjacent grains, in general, have slip planes lying in different directions, and as slip proceeds, the slip in one grain tends to hinder the slip in the adjacent grain. Moreover, in metals composed of two or more different kinds of crystalline grains, the stronger grain act as "keys," tending to stop or hinder slip in weaker grains. Slip interference theory further holds that a metal may contain definite, very small grain sizes that will be more effective as brakes on slip than larger, more widely scattered grains, and also more effective than extremely small grains, grains so small that slip can proceed right by them with out much deviation from its direct path. In the case of steel, such an "optimum" size can be produced by heat treatment.

Flow or Creep:-Creep is the very slow flow of material at elevated temperatures under sustained stress. The rate of flow of a given metal depends on the magnitude of the stress and temperature. Lead and Zink, for example, will creep under normal temperatures at relatively low stresses. However, most metals require a relatively high temperature before they begin to flow under low stresses. Creep may continue for an indefinite amount of time under a sustained load tending to distort the material and eventually cause failure of the material by rupture. Unlike repeated loads (fatigue), creep affects the entire body of the material under stress instead of producing a localized rupture.

Corrosion and wear:-These damages take place gradually. They seldom cause sudden or dramatic structural disasters, as parts damaged by corrosion or wear can be replaced or repaired before failure occur but incase of reinforcement bar care should be taken before placement and by providing sufficient concrete cover as it is difficult both to detect and treat the problem.

Tensile strength: - it is the maximum axial load (ultimate load) observed in tension test divided by the original cross-sectional area. In design one can not base the working stress on the ultimate strength because excessive strain cannot be tolerated. Thus, one must find the ultimate unit stress produced by the design loads in the member and reduce it by a factor of safety such that one works with an allowable unit stress.

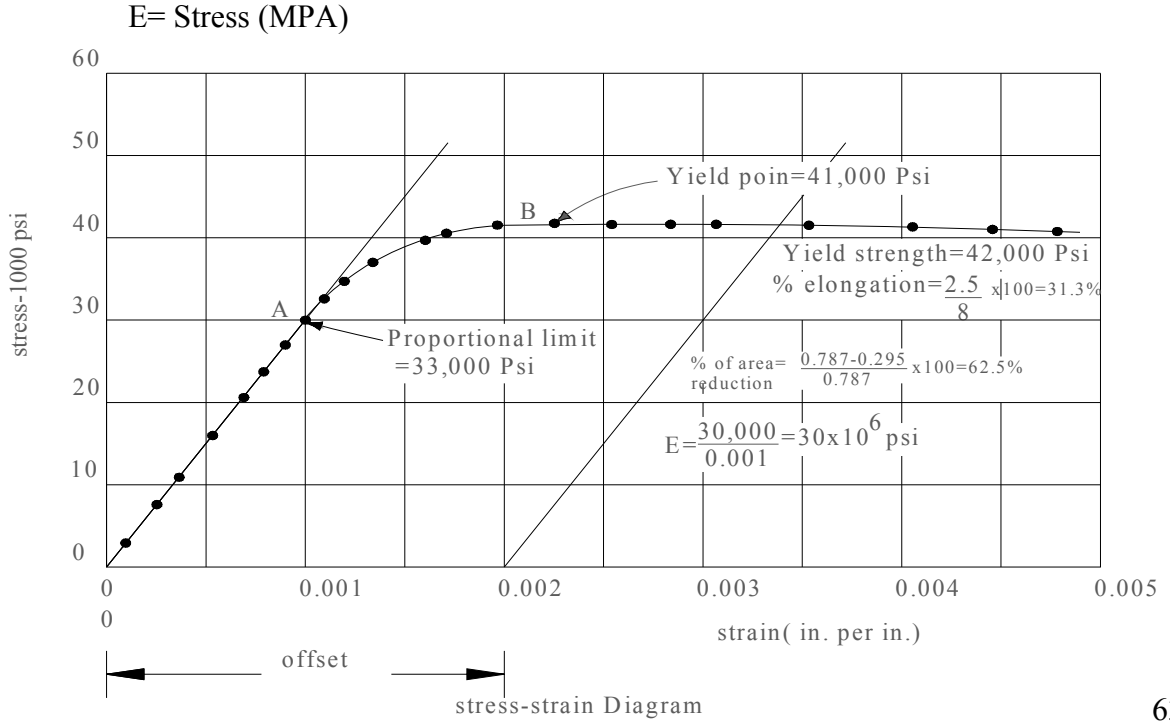
Ductility: - it is the ability of a material to undergo large deformation with out fracture. Thus the material will deform in the inelastic (plastic) range. Ductility is measured by the elongation and reduction of area in tension test and is expressed as a percentage:

$$\text{Percentage elongation} = \frac{finallength - orginallength}{orginallength} \times 100 \qquad \text{and}$$

$$\text{Percentage reduction in area} = \frac{originalarea - finalareaafterfracture}{originalarea} \times 100$$

Modulus of elasticity (E):- it is given by the slope of the straight line portion of the stress-strain curve. It is a measure of the inherent rigidity or stiffness of a material. For a given geometric configuration, a material with a large E deforms less under the same stress

The modulus of elasticity (young's modulus) is a ratio of the unit stress to unit strain in the elastic range of the stress-strain curve as follows:



stress-strain Diagram

Yield point. At the termination of the linear portion of the stress-strain curve, some materials (such as low-carbon steel) develop a yield point. The yield point is the first load at which there is a marked increase in strain without an increase in stress. This behavior may be consequence of inertia due to the effect of the testing machine and the deformation characteristics of the test specimen. The yield point is some times taken as the proportional limit and elastic limit, which is an incorrect practice. Most metals do not have a yield point, and thus offset method is used.

Offset yield strength. The offset yield strength is defined as the stress corresponding to a permanent deformation, usually 0.10 to 0.20 percent (0.001 or 0.002 in. /in.). The offset method is usually used with materials that have a definite straight-line portion to their stress-strain curve. One measure the corresponding offset percentage on the stress-strain curve and projects upward a straight line parallel with the straight- line portion of the stress-strain curve. Where the line intersects the strain-stress curve, the value is read off as the offset yield strength.

Proportionality limit. The proportionality limit is the greatest stress that a material is capable of without deviating from the law of proportionality of stress to strain (Hook's law). Hook's law is defined as

$$f = E \epsilon$$

Where: f = unit stress

E = Young's modulus of elasticity

Є = unit strain

Elastic limit and Inelastic limit. The elastic limit is the largest unit stress that can be developed with out a permanent set remaining after the load is removed. In most cases the elastic limit is difficult to determine, and many material do not have a well defined proportional limit, or any at all; thus, the offset yield strength is used to measure the beginning of plastic deformation (inelastic limit).

Ferrous Metals

In general, metals can be classified into two major groups: ferrous and nonferrous. A ferrous metal is one in which the principal element is iron, as in cast iron, wrought iron, and steel. A non-ferrous metal is one in which the principal element is not iron, as in copper, tin, lead, nickel, aluminum, and refractory metals. In this chapter we discuss ferrous metals. Special attention will be placed on the production techniques of steel.

Production of metals

Four operations are required for the production of most metals:

- Mining of the ore
- Preparing the ore
- Extracting the metal from the ore
- refining the metals

The extraction of metals from the ore is accomplished through chemical processes. These chemical processes reduce the compounds, such as oxides, by releasing the oxygen from chemical combinations and thus freeing the metal.

Basically, three types of processes of extraction are used:

Pyrometallurgy: - in this process the ore is heated in a furnace producing a molten solution, from which the metal can be obtained by chemical separation. The blast furnace or reverberatory furnace is used in this process.

Electrometallurgy:-in this process metals are obtained from ores by electrical processes utilizing an electric furnace or an electrolytic process.

Hydrometallurgy or leaching: involves subjecting the ore to an aqueous solution from which metal is dissolved and recovered.

As the result of the extraction process, the metals will contain impurities, which must be removed by the refining process. If the metal is extracted by the pyrometallurgy process, the most common method of refining is by oxidizing the impurities in a furnace (steel from pig-iron). However, other methods are utilized, such as liquidation (tin), distillation (zinc), electrolysis (copper), and the addition of a chemical reagent (manganese to molten steel).

Ferrous metals comprise three general classes of materials of construction:

- Cast iron
- Wrought iron
- Steel

All of these classes are produced by the reduction of iron ores to pig-iron and the subsequent treatment of the pig-iron to various metallurgical processes.

> *Both cast iron and wrought iron have fallen in production with advent of steel, as steel tends to exhibit better engineering properties than do cast and wrought iron*.

The application of steel and steel alloys is so widespread it has been estimated that there are over million uses. In construction, steel has three principal uses which are structural steel, reinforcing steel and forms and pans.

Classification of iron and steel products

Iron products may be grouped under six headings:

- Pig iron
- Malleable cast iron
- Ingot iron.
- Cast iron
- Wrought iron
- steel

Pig iron: is obtained by reducing the iron ore in a blast furnace. This is accompanied by charging alternate layers of iron, ore, coke, and limestone in a continuously operating blast furnace. Blasts of hot air forced up through the charge to accelerate the combustion of coke while raising the temperature sufficiently to reduce the iron ore to molten iron. The limestone is a flux that unites with impurities in the iron ore to form slag. The blast furnace accomplishes three functions *(reduction of iron ore, absorption of carbon, and separation of impurities)*. The amount of carbon present in pig iron is usually greater than 2.5 % but less than 4.55. The iron may be cast into bars, referred to as pigs.

Iron ores and extraction of Iron

Iron is never found in its pure form in nature. It has to be extracted from ores which are classed according to the iron material which is predominant.

Magnetite: Brown or steel gray to black in color, it is very hard and magnetic. It is also the richest iron ore, containing 65.75% iron when mined.

Hematite: Another oxide of iron, red to brown in color, found in hard or soft deposits, it contains 45-65% iron.

Limonite: Hydrated iron ore or hydrated hematite ore yellow in color, becomes red hematite when dehydrated at high temperature. It normally contains 20-50% iron.

Siderite: The carbonate of iron, gray in color and usually hard and stone like, contains about 30% iron.

Iron ores are sometimes classified according to their phosphors content because these impurities cannot be removed in the blast furnace, and because it has a bad effect on the properties of iron and steel. These are:

- Low phosphorous ores, containing up to about 0.04% phosphorus. They usually have a relatively high silicon content, and
- High phosphorus or basic ores, with up to about 2.5% phosphorous.

The mining of iron from its ores and production of iron based materials follows specific steps which include smelting, purification and manufacture.

The smelting operation is meant to remove the impurities from the ore. It is done in the blast furnace where the prepared iron ore (mined and broken into small pieces) is charged with coke and limestone in alternating layers after being carefully weighed. The coke, or fuel, is normally coal. When heated by the hot air forced through the bottom of the blast furnace the coal liberates CO_2, which, coming in contact with the hot ore, reduces it to molten metallic iron which drips down towards the bottom of the furnace. The use of lime or flux is to unite with the earthly impurities and form a molten slag, which is a non metallic substance, lighter than the metal product and consequently floats. The smelting operation converts the iron ore into iron by simple chemical reduction which begins at

temperature as low as 200ºC and proceeds by progressive formation of Fe_2O_4, FeO, and Fe. Because of the presence of associated elements and impurities, the reduction in the blast furnace is partially complete at about 800ºC very much below the fusion point of iron, the fusion point of which is lowered from 1539ºC when pure to about 1200ºC.

As the iron sinks towards the bottom of the furnace, it becomes better and absorbs carbon monoxide that rises towards the top. A blast furnace metal, or iron-carbon, containing about 3.5 % carbon is collected into containers at the bottom outlet of the furnace together with the slag which is produced by the dissociation of the lime. The slag is scraped from the top of the container and the remaining metal, pig iron, which is the crudest form of iron, is cast into rough bars called pigs. Pig iron which contains as much as 10% impurities made of carbon, silicon etc, is then passed to the foundry or steel plant for further refining.

The refining of pig iron is also based on the oxidation process. Raised to high temperatures (1200ºC and plus), in open-hearth, Bessemer converter or electric furnace, pig iron melts and oxygen unites with the impurities to form gases (CO and CO_2) and molten oxides. The gases bubble through the bath and escape while the molten oxides rise to the top as slag because they are insoluble in the molten iron and lower specific gravity. Thus the process gives pure molten iron. The purest form of iron which the total impurities do not exceed 0.5 percent is known as *wrought iron.*

Alloy of Iron

Pure iron is a relatively soft and readily cold-worked metal. Its typical mechanical properties are:

- Tensile strength= 310 MPa
- Yield point= 207MPa
- Elongation in 50 mm= 35.40%
- Reduction in area= 75%

With such high percentage elongation and reduction in area, pure iron can not be used effectively for structural purposes. In order to improve some of its properties and make it a useful and effective material, pure iron is alloyed with other chemical elements. There are certain additional elements, predominantly other metals, which will combine with a pure metal in such a way that resulting solid solution called an alloy which is also metallic. This is possible only if the alloying element lies within specific boundaries of size and valence. The size factor divides alloys into two distinct groups: substitutional and interstitial alloys. In the substitutional alloy, the alloying element replaces the primary elements in random positions in its lattice. To accomplish this with out destroying the structure, the alloying element must have an atomic radius within 15 percent of that of the primary element. If the radial difference is greater, that the energy required placing the alloying element in position is more than the structure can accommodate and still retain its crystalline form.

As the name implies, an interstitial alloying element fits into the spaces or interstices of the primary element's lattice. There is a definite geometrical restriction on the size of the interstitial atom: to fit into the lattice spaces, the alloying element's radius must be less

than approximately six-tenths that of primary elements.

A large number of elements form alloys with iron. These include carbon, chromium, manganese, nickel, silicon which combined with iron form commercially important alloys. Out of these alloying elements, carbon is the most important. Carbon atoms readily dissolve interstitially in iron lattices because they are small compared to the relatively big iron atoms.

Steel

Alloy of iron and carbon, and at times other elements added for special purpose, make up the important classes of ferrous metals known as steel and cast iron. To the civil engineer, steel is by far the most important metal of iron base. Depending on the percentage of the carbon content different types of steel can be manufactured. At one extreme are the very soft steels used for making rods, wire for nails, and metal sheets. At the other are the very hard and tough steels used for making gears and bulldozer plates. Hence, by varying the carbon content one can impart desired characteristics to the final product. For engineering purposes, however only the iron-carbon system between zero and 6.67% carbon by weight is of importance in the study of steel and cast iron. The iron-carbon alloys containing from a trace to about 2% carbon with only negligible amount of other elements are called plain carbon steels. With carbon content between 2% and 6.67% the alloys are referred to as cast iron. While the iron containing a trace of carbon is refereed to as cast soft or dead mild steel, that containing 6.67%, and represented by the formula Fe_3C(iron carbide), is commonly called cementite. Cementite is a very hard and brittle alloy. Ferrites is a soft, ductile, readily cold-worked (malleable) and has low strength. It has a maximum of 0.04% carbon content.

Pearlite is a mixture of 88% ferrite and 12% cementite. Pearlite is harder and less ductile than ferrite but is softer and less brittle than cementite

Reinforcing steel

Concrete exhibits great compressive strength but little tensile or flexural strength. Thus, deformed bars of structural steel are embedded in the concrete to take up the tensile or flexural forces. These deformed bars have been developed in such a way as to force the concrete between the deformations such that failure in shear will occur before slippage.

Properties of plain carbon steels

Plain carbon steels are elastic materials with relatively high compressive, tensile and shear strength. They are also relatively stiff having generally high modulus of elasticity. Almost all of their mechanical properties are influenced by three important factors which are (1) Chemical compositions, (2) heat treatment and (3) Mechanical work. Controlled changes in these factors introduce variation in the properties over wide ranges.

Influence of the carbon content

Since plain carbon steel is a binary alloy its properties obviously depend upon the proportion of each of the micro- constituents present. In general the mechanical properties vary linearly from zero percent carbon (100% ferrite) to the *eutectoid* proportion i.e. 0.83% carbon (100% paralite). After 0.83% carbon, the linear relationship doesn't hold any longer because free cementite appears in the microstructure. (Figure 2)

The linear relationship between the carbon content and ultimate tensile strength is attributed to the relatively ultimate mature and the fine state of aggregation of the constituents of the pearlite. With a decrease or increase of carbon the ferrite or cementite, respectively, becomes an excess substance forming a grain network which has a weakening influence on the metal. The relation between carbon content and tensile strength for steel below 0.83% carbon content is suggested as:

$$S=300+65{,}000C$$

Where S = ultimate tensile strength, N/mm^2

C = carbon content, percent

The yield point of steel in tension also increases with carbon content, but as shown in figure 2, it increases at a lower rate. For low and medium-carbon steels the yield point is usually between 60 and 70 percent of the ultimate strength and for high- carbon steels it is between 50 and 60 percent.

The ultimate compressive strength of steel, in short members not affected by column action(l/r less than 50) is proportional to the carbon content up to 0.83%, and the relationship can be roughly expressed as

$$Sc=200+38{,}000C$$

Where Sc =ultimate compressive strength, N/mm^2

C = carbon content, percent

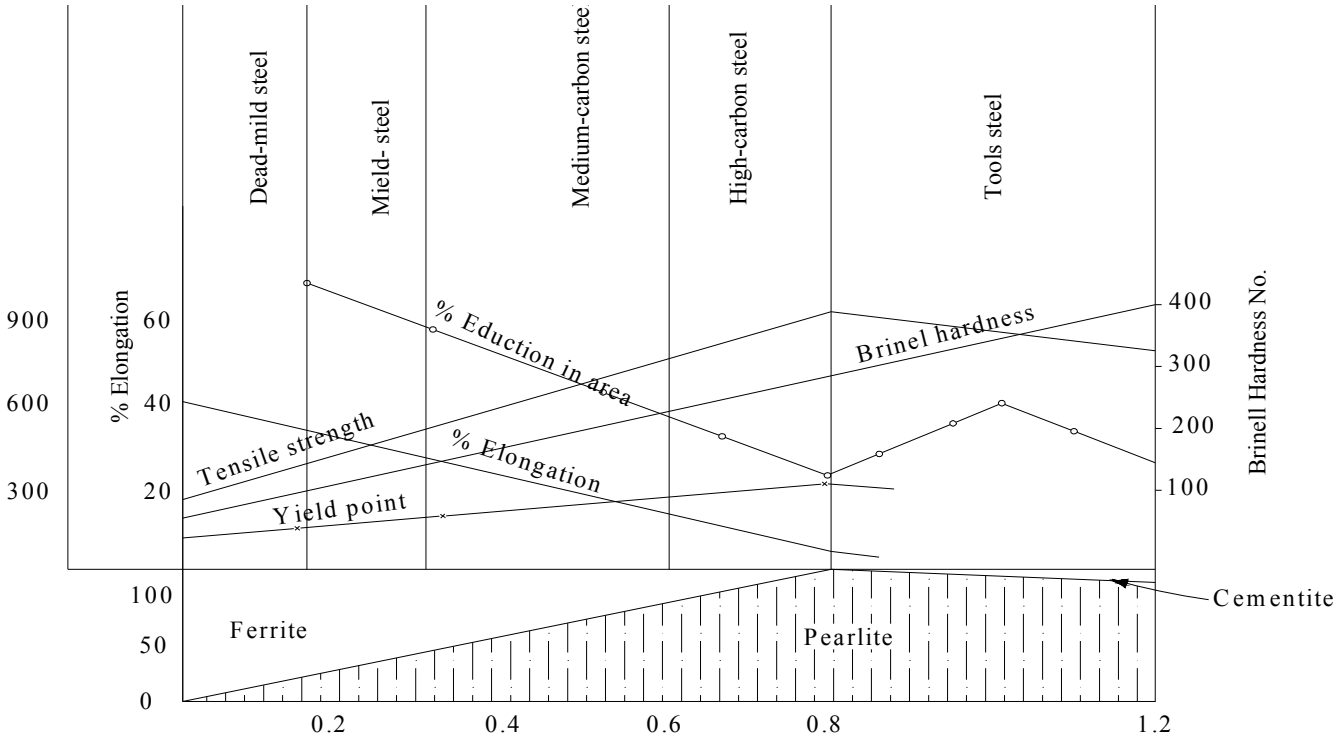


Figure2. Effect of carbon on the microstructure and mechanical properties of plain carbon steels in normalized condition

Dead mild steel subjected to tension test will draw down and elongate extensively before rupture takes place; however this behavior changes with increasing carbon content. As seen in figure 3 there is a marked decrease in elongation and accompanying increases in the proportional limit and ultimate strength with increasing amounts of carbon which causes the diagrams to increase in height and decrease in width.

As could be observed in the diagrams, the modulus of elasticity in tension is independent of the carbon content. The modulus of elasticity in compression which is also independent of the carbon content is equal to that in tension and both lie between 200GPa and 215GPa with 200GPa often used for structural calculations. The shearing strength of steel also increase with carbon content and is approximately 80% of the tensile strength for mild and medium-carbon steel, but decreases to 60% for high-carbon steel. This makes steel not different than other construction materials which ultimately fail in shear. In fact, structural steel specimen subjected to tension shows necking which begins at the point of plastic instability where the increase in strength due to strain hardening fails to compensate for the decrease in cross-sectional area. This occurs at maximum or ultimate load.

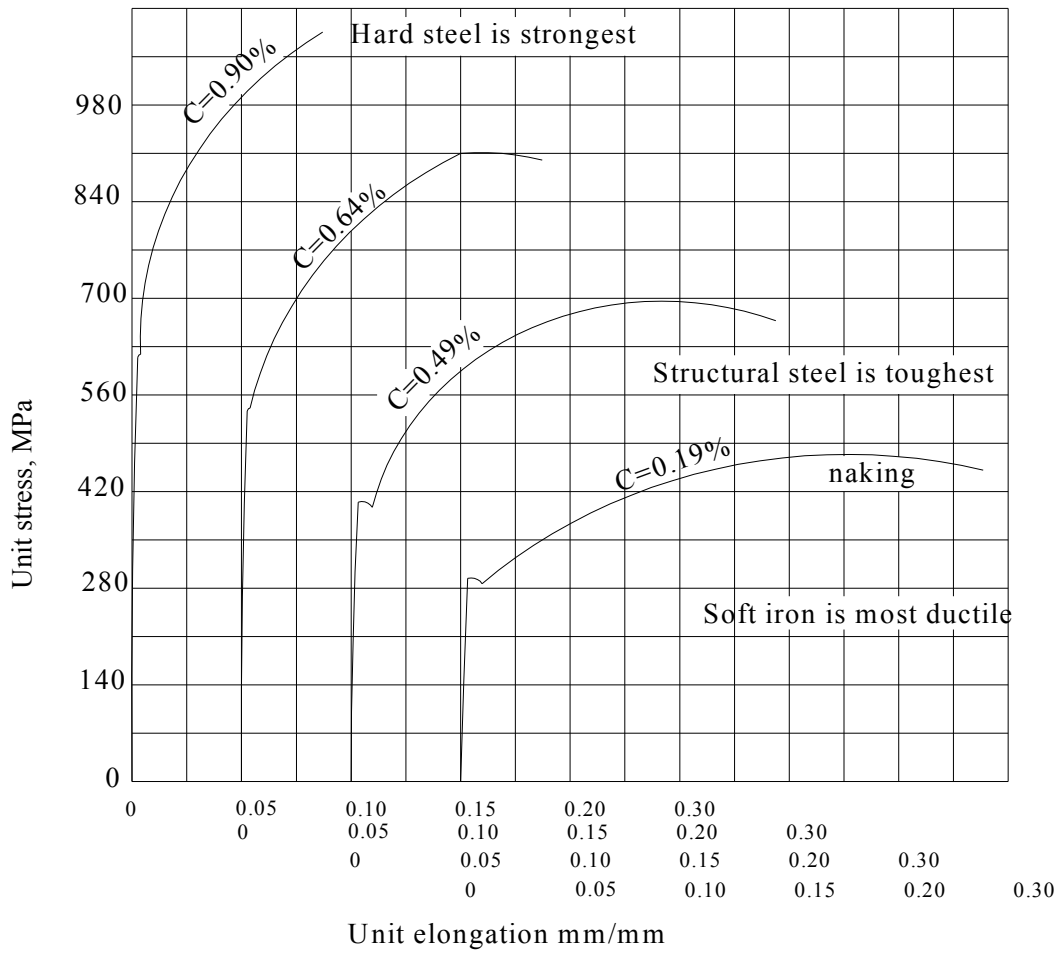


Figure3. Tension stress-strain diagrams of hot-rolled steel bars.

The formation of a neck introduces a tri axial state of stress in the region. Many fine cavities form in the region of the neck and under continued straining these grow and coalesce (join together) into a central crack (figure 4). The crack grows in a direction perpendicular to the axis of the specimen. It then propagates along the localized shear planes at roughly 45^{o} to the axis showing that final failure is in shear. This mode of fracture, refereed to as cup-and fracture, gives a section of very fibrous appearance in the central cup region much as if the individual element of the specimen were split into longitudinal fibers and were then drawn down to a point before rapture. The outer cone of the fracture which has been subjected to highly localized shear and beating shows a smoother surface since deformation occurs by the sliding of grains over one another. The modulus of elasticity in shear (modulus of rigidity) of steel determined from torsion tests usually varies between 80 and 86 MPa. An average value of 83MPa is frequently used. It can also be calculated using the relationship:

$$G=E/2(1+\nu)$$

Where G= modulus of rigidity of steel, GPa

E=modulus of elasticity of steel in tension or compression, MPa

ν=poison's ratio of steel (=0.35)

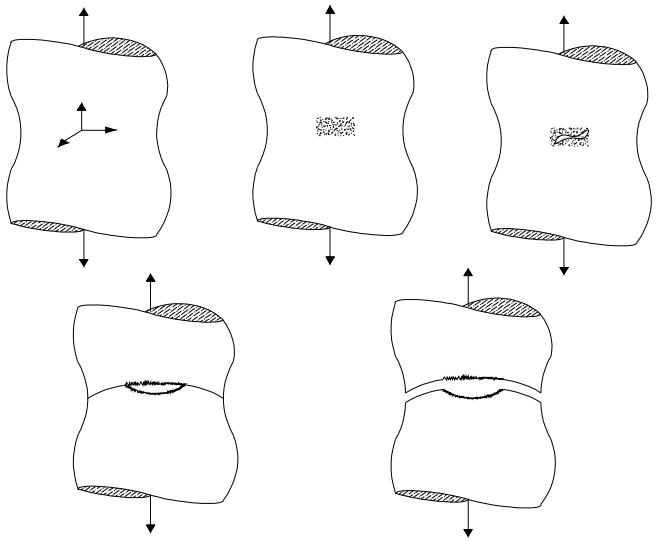


Figure 4.Stages in the failure of mild-steel rod.

Influence of heat treatment and mechanical work

In general the ultimate strength, yield point, modulus of elasticity, and hardness of steel decrease with increase in temperature. Mechanical work performed on a steel product affects its internal structure and properties. The effect on the properties depends to a certain extent on the temperature at which the mechanical work is performed, i.e., hot working or cold working. Hot working of steel is done by hot rolling, forging, hydraulic or mechanical pressing and extrusion. Cold working is carried out by cold rolling, cold drawing, and cold extrusion.

If, at the manufacturing stage, steel is cooled slowly and undisturbed, it solidifies to give crystals of large size , Rolling, forging, or hammering while the steel is hot above the critical temperature, promotes the formation of fine-grained structure which has greater – strength and ductility than the coarse-grained castings of the same chemical composition. This is so because small metal crystals are generally stronger than large ones.

Cold working is generally done at room temperature and the properties of cold- worked steel depend on the method and amount of cold work. In general, cold working leads to a marked increase in ductility, and toughness; however, extensive cold working can adversely affect the properties of steel. Cold working has a marked effect on high-carbon than low-carbon steels.

Alloy steels

From the above discussion it is clear that alloying iron with carbon affects the characteristics of the product. Unalloyed iron, like any other structural metal, shows a tendency of being weaker and more ductile than corresponding alloyed iron. In some instances other metallic elements are added to give the product different properties. Hence, while alloys of iron and carbon are referred to as plain carbon steels, the term alloy steels is applied to alloys of iron and carbon and one more metallic elements, such as chromium, cobalt, copper, manganese, molybdenum, nickel, silicon and vanadium.

The important reason for adding alloys other than carbon is to increase the strength and hardness of the steel. For instance, next to carbon, molybdenum is the most effective hardening element, chromium also gives great hardness. Nickel, silicon and tungsten increase strength. Another beneficial effect of some alloying elements, such as chromium, is the increased resistance to corrosion. A combination of 18 percent chromium, 8 percent nickel and 0.07 to 0.16 percent carbons added to iron results in a particularly effective stainless steel.

Corrosion

If left unprotected, plain carbon steel corrodes. Corrosion starts at the surface of the steel and in due course proceeds inwards and if not arrested, will destroy the metal. Corrosion is the result of chemical action of plain carbon steel which goes in solution with moist air or water containing dissolved oxygen. At first contact with damp air plain carbon steel forms a few atoms thick film which is very thin and usually invisible has a protective effect over the surface of the metal and may retard or even stop further corrosion. If however, free oxygen is abundant it readily combines with the hydrogen film and permits further progress of corrosion. In construction, the least expensive and common method of protecting steel against corrosion is the application of one or several coats of paint over its surface. The paint coating is usually weak and it cracks and wears out. Thus, to do a satisfactory job the paint must be renewed every 2 to 3 years. Before the structure is painted it should first be cleaned and the rust removed. For under water construction as the paint will not provide sufficient protection coating of the submerged part with asphalt or coal tar gives better protection.

Metals under stress, especially those beyond their elastic strength, corrode more rapidly than do unstressed metals.

Timber

Timber has been one of the basic materials of construction since the earliest days of humankind. Today it has been largely superseded by concrete and steel. However, the use of timber remains quite extensive. Different species of tree exist and one variety of trees might make a better building product than another. Therefore, the engineer should have some knowledge of the classification of trees, as well as their growth and structural ability, to understand the physical and mechanical properties of each.

Classes of trees

- *Exogens and Endogens*

Botanists classify trees into two main categories: Exogens and Endogens. These terms refer to the pattern of growth of particular species. Exogenous trees are those that grow diametrically, by adding new cells in a layer between the existing wood and the bark. Almost all wood that is of commercial use falls in this category. The exogenous growth pattern forms a characteristic transverse section with concentric annual rings that correspond to each year's growth. At the center of a cross-section of a tree is pith, a dark area of small diameter that does not increase in size after the first year of growth. Encircling the outermost annual ring is a layer of microscopic thickness called the cambium ring, and it is here that new growth is formed. The outer most layer is known as bark.

Endogenous trees add new living fiber to the old by allowing new fiber to intermingle with the old, thus producing growth both diametrically and longitudinally. Most endogens are fairly small plants, such as corn, sugar cane, palm, and bamboo. The latter two plants are used extensively as a structural material.

- Hardwoods and Softwoods

Exogenous trees are further classified as hardwoods and softwoods. These are some what misleading terms, because they refer not to quality of the wood, but to the type of tree the wood comes from. Hardwoods comprise the broad-leafed trees, mostly deciduous, which are in general slow growing, forming heavy and hard wood that is used more extensively for furniture, interior finishing, and cabinetwork than for structural purposes. The softwoods are the conifers trees.

Wood structure

Many of the qualities of wood for use as a building material arise from the structure of wood. Wood is formed mostly of filamentous cells. Perforated pits in the cells make possible the flow of sap between cells.

Wood cells are composed primarily of the polymer cellulose and hemicelluloses which are cemented together by a third polymer, lignin. Wood is typically 50 to 60 percent

cellulose material and 20 to 35 percent lignin, with small amounts of other carboxydrates, such as resin and gum. It is the cellulose that gives wood its axial strength and elastic properties, and the lignin that is responsible for its compressive strength. These carboxydrats, although indigestible by man, are a favorite food for some other forms of life, such as termites, and measures much often be taken to protect wooden structure from these species.

Over a period of several years the wood ceases to function as part of the living tree and has only structural value for the tree. The living part is called sapwood: the older wood is heartwood. Heartwood is easily distinguished from sapwood because it is darker in color. It is more highly valued because it is more resistant to decay than sapwood, although the strength of each is about the same.

Season of cutting; slash and rift cutting

The first step in the manufacturing process of lumber is to select and fell the trees. This is normally done in the fall and winter when the flow of sap is minimal and destructive fungi and insect are least active. The logs are cut into standard-size boards at sawmills. The lumber must be then dried or seasoned

The angle of the plane of the cut of the boards will have an effect on the resulting lumber. Wood that is quarter sawed rift-cut is cut parallel to the axis of the tree and radially across the annual-rings. When the wood is cut tangential to the annual rings, it is called slash-cut. Rift-cut lumber generally warps less in the drying process and wears more evenly, but in the interest of practicality, more wood is slash-cut.

Seasoning of timber, moisture content

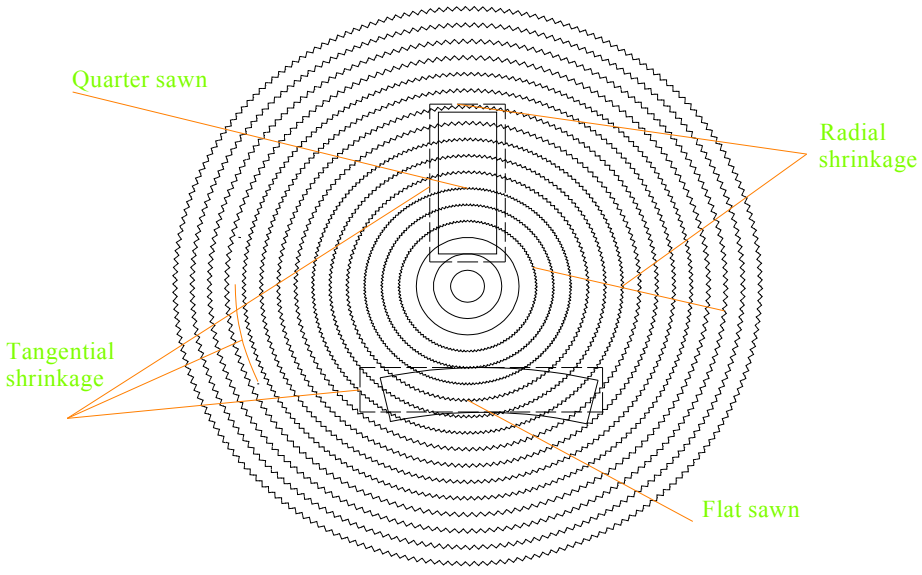


Figure sawing pattern

Wood must be seasoned before it is put to use so that its moisture content will become stabilized. Unseasoned wood readily takes up and retain moisture, and this moisture will adversely affect the wood in a number of ways. One is that changes in the moisture content will produce dimensional changes in the timber. Also, high moisture content diminishes the strength of the wood. Wood that is properly dried may be up to two and one-half times stronger than a comparable piece of green wood.

Other problems, such as the presence of harmful fungi, occur when wood is cut. The moisture in wood is in two forms: free and combined. Free moisture is moisture outside the cell, and combined moisture is water that has been incorporated in to the cell walls. In green wood, moisture will constitute from 25 to 200 percent of the oven-dry weight of the lumber, and most of this must be evaporated from the wood in the seasoning process.

The timber can be either air-dried or kiln- dried. As the wood dries, the free moisture is evaporated from the surface and moisture from the interior of the porous lumber equalizes with drier surface. When the moisture content stabilizes, the drying process is complete.

Air drying will reduce the moisture content to about 15 percent, a level that is acceptable for most construction purposes. Lumber that is to be used for purposes such as furniture, flooring, and cabinetwork is kiln-dried in few days using temperature of 68 to 82^{o}C. *Hardwood warps most easily*.

All woods have the ability to reabsorb moisture from the atmosphere, depending on the humidity of its surrounding. This can cause a certain amount of dimensional instability, which may lead to problems in certain applications. Wood that has been subjected to temperature of 100^{o}C for a length of time during boiling, steaming, or soaking will, with time, become less able to absorb humidity from the atmosphere.

Shrinkage, warping, and checking

Shrinkage will occur in the drying of wood when the combined moisture begins to be evaporated from the cell walls. The contraction will be across the cell walls rather than longitudinal, cells shrinking proportional to the thickness of their cell walls. When shrinkage occurs unequally for any reason, warping results. If drying proceeds at unequal rates over different portions of a piece of lumber, warping will occur. When wood is cut tangentially, the dried piece will be convex because of unequal tangential shrinkage. Irregularities in the grain of the wood will produce more pronounced irregularities in the dried boards.

Checks are longitudinal cracks across the growth rings that can occur during drying of timber. Unequal shrinkage produces strains within the wood, and checks can result. They can be temporary, occurring when the outer portion of a piece of wood dries too rapidly and contracts over the inner portion. These checks that appear in the outer layer of the wood may close up and become imperceptible as the wood of the inner part of the lumber dries and contracts. Other checks of a more serious nature can occur when the difference

in tangential shrinkage is too great relative to the radial shrinkage to be accommodated. Large radial checks such as those sometimes seen in posts can then occur.

Defects in lumber

Anything that adversely affects the strength, durability, or utility of a piece of wood is a defect, and these may be within the wood itself or be produced by warping.

Shakes are longitudinal cracks in the wood that follow the growth rings and develop prior to the lumbers being cut. They are sometimes a result of heavy winds.

Checks, as described earlier, are longitudinal splits across the growth rings resulting from uneven drying.

Knots are formed at the base of branches where they extend into the wood of the tree. Only wood that comes from the base of the tree where there are no branches is free of knots. If the branch was dead, a loose knot is formed. A spike knot occurs when the cut is longitudinal to the branch. The effect of the knots depends on the use of the wood and the location and size of the knots. They have little effect on the wood in shear or in compression members. For beams in bending however a knot in the part of the beam subjected to tension can significantly reduce its maximum load.

Pitch pockets are accumulation of resins in openings between the annual rings.

Bark pockets are formed when the bark is wholly or partially encased in wood.

Compression wood is formed on the lower side of the branches or leaning tree trunks. It is darker than the normal wood, has a high lignin content, higher specific gravity, greater longitudinal shrinkage, and is not as tough as normal wood. The strength of compression wood is not predictable, and many failures in wood members have been found to be caused by compression wood.

Unequal shrinkage during the drying process produces warped lumber. The different types of warping are bow, crook, twist, and cup.

Mechanical properties of timber

Strength of wood

Considering the fact that it is relatively strong in compression and tension and that it has low density, timber can be classified as one of the material of high strength: weight-ratio. Because of the structure of wood, the fibers act like so many cylindrical tubes firmly bound together in the way that they withstand stress. Loads applied parallel to the grain are carried by the strongest of the fibers; in loads perpendicular to the grain, the weakest fiber have to take their share of the load.

Tensile strength

Tensile strength in wood parallel to the grain is much higher (three times as much) than compressive strength. Thus the limiting factors in tension members are usually compression and shear at the point of concentration. Thus far, no means have been developed to connect tension members with out it somehow compressing and eventually resulting in failure.

Tensile loads perpendicular to the grain of wood fibers cause the fibers to split apart. The tensile loads that can be carried are one-tenth or less of the tensile load that can be withstood by the wood in the parallel direction with the grain.

Compression strength

Compression loads parallel to the grain can be carried by the strongest fibers, whereas compression loads perpendicular to the grain are carried by both weak and strong fibers. Wood in compression parallel to the grain can carry three to four times the load that wood in compression perpendicular to the grain can carry.

Compression failure of wood perpendicular to the grain involves the complete crushing of the wood fiber. Compression failure of wood parallel to the grain involves the bending or buckling of the wood fibers.

Flexural strength and stiffness

For timber beams in flexure, the critical factors in evaluating the load that can be carried are the compressive strength parallel to the grain and the shear strength parallel to the grain. The resistance of the shear strength parallel to the grain is very low. However, if the wood is free of defects the initial failure will be compressive. Stiffness also plays a role in timber beams, since deflection is usually limited to 1/360 of span. Stiffness can be measure of strength, in that stiffer timber beams are usually denser.

Elastic properties of timber

The modulus of elasticity in wood is high relative to its compressive strength, compared with other building materials. Wood does not, however, exhibit a well defined yield point, and therefore the proportional limit is used to measure elastic strength. Therefore, for specified load requirement and sufficient wood to carry such a load, there is a high degree of elastic strength. For this reason, wood members are considered to have good elastic properties.

Factors affecting timber strength

Many factors affect the strength of timber, such as direction of the wood fibers, moisture, weight, and rate of growth. *The direction of the wood fibers is called the grain*. The strength of timber depends too heavily on the direction of the loads with respect to the

grain that is an important consideration in design. Diagonal grain is measured by the tangent of the angle it makes with the cut edge of a piece of lumber. The diagonal grain or direction of the wood fibers will affect the strength ratios of lumber as shown in the table below

Strength ratios corresponding to various slopes of grain

Slopes of Grain	Maximum strength ratio (%)	
	For stress in extreme fiber in bending(Beams and stringers of joists and planks)	For stress in compression parallel to grain (Posts and Timbers)
1 in 6	--	56
1 in 8	53	66
1 in 10	61	74
1 in 12	69	82
1 in 14	74	87
1 in 15	76	100
1 in 16	80	--
1 in 18	85	--
1 in 20	100	--

From the table it can be seen that tensile strength is much more sensitive to grain angle than is compressive strength. The low strength in tension is mainly due to the collapse of the cell walls and/or lateral bending of the cells and fibers. In most specimens subjected to compression along the grains, failure occurs along planes inclined about 60^o to 75^o with the axis of the cells making it probable that final collapse is due to the weakness of the cell wall in transverse shear. The comparatively low strength in compression as well as tension across the grains is attributed to the weak bond between the cells and fibers.

As indicated earlier wood that is properly dried is far stronger than wood that has high moisture content. When all the free water is evaporated and all the moisture is removed from the cell walls, the fiber saturation point is said to have been reached. The presence or absence of free moisture does not, in general, affect the strength properties. However, if drying occurs beyond the fiber saturation point there will be an increase in strength. The increase in strength beyond the fiber saturation point may be two or three times the value of wet wood.

All other things being equal (cetrisparibus), the denser the wood, the stronger it will be. This is so true that a formula is based on it:

Modulus of rupture= 26,200 x (specific gravity) 1.25 (air-dry timber)

Modulus of rupture= 18,500 x (specific gravity) 1.25 (green timber)

These formulas were developed by the forest products laboratory and are very accurate, regardless of species.

Finally, rate of growth greatly affects the strength of timber. In general, most timber used for construction will exhibit an optimal number of annual rings per inch of wood. Usually, the greater number of rings per inch will be the stronger one.

Perhaps the single most important factor that affects the strength of timber is the time of loading. Test results on timber reveal that it can sustain greater loads for short time than it can over a long period. This dependence of the strength of timber on the duration of loading is termed *creep rupture or static fatigue*. Since the strength of timber decreases with time of application of force, working stress derived from test results must take into account the rate of straining. Generally to be on the safety side relatively high safety factor (3 and above) is taken in the design of timber structural elements. Because the behavior of timber under load is time dependant, it might not be classified as a truly elastic material. However, a timber specimen loaded in short term tension, compression or bending deforms approximately in proportion to the applied load. The inflection point, otherwise known as the limit of proportionality of the load deformation diagram below which the relationship between load and deformation is linear occurs at about 30% to 50% of the corresponding ultimate load.

With in the proportionality limit the modulus of elasticity of timber can be calculated from the ratio of the unit stress and unit strain.

$E=s/v$

If the test results are obtained from the bending test then

$Eb=PL^3/48I\delta$

Where P=Mid-span load

L= distance between supports

I =moment of inertia of the cross-section about the neutral axis

δ=deflection at mid-span.

The modulus of elasticity of timber is affected by the number of factors such as the grain direction, density, moisture content and defects.

Decay and preservation of timber

Wood is an organic material so it can be attacked and its tissues destroyed by the action of solvent chemicals secreted by bacteria and fungi. It can also be damaged or eaten up by- insects such as pole-bearers and termites or destroyed by fire which decomposes it

into carbon dioxide, water vapor and ash. For this reason, timber used for construction purpose should be preserved and protected.

Proper seasoning, natural or artificial, is the most effective means of preservation. The resistance to decay and deterioration of seasoned timber is further improved by impregnation with preservatives chemicals, brush treatment with paint or varnish, damp proofing when appropriate and providing as much as possible free circulation of air where ever it is used.

Characteristics of common Ethiopian timber

Because of the rather unique climate and topographic conditions, various types of trees can grow and are found in Ethiopia. Unfortunately, however, very little investigation has been done so far in the way of determining the characteristics of the different species for building purposes. The table below presents the available information of the most common timber used in the construction industry.

Some characteristics of common Ethiopian Timbers

Local Name	Botanical Latin or Trade name	Characteristics
1. Bahrzaf	Eucalyptus	• Broad-leaf tree • Low resistance to termite • Difficult to treat or impregnate • g=670kg/m^3
2. Kararo	Aningeria Adolfi Friderici	• Low resistance to termite • Ease to treat or impregnste • g=450kg/m^3
3. Kosso	Hagenia abyssinica	• Broad-leaf tree • High resistance to termite • Turns to dark red when seasoned • g=630kg/m^3
4. Tid	Juniperus procera African Pencil Cedar	• Conifer • Almost immune to termite due to oil resins it contains • Turns to red-brown when seasoned • Difficult to treat or impregnate • Shrinks little • g=550kg/m3

5. Tukur Inchet	Pygeum africanum Iron wood Red Ivory	• Broad-leaf tree • Turns to pinkish brown on seasoning • Very hard(iron wood) • g=630kg/m3
6. Wanza	Cordia africanalam East Africa Yellow wood	• Broad-leaf tree • coarse grained • g=440kg/m3
7. Zegba	Podocarpus gracilior East African Yellow Wood	• Conifer • Easy to treat or impregnate • pale ivory to yellow in colour • g=440kg/m3

Besides its usage as structural member in buildings, timber can be used to prepare architectural or finishing materials such as veneers, plywood etc. Veneers are thin sheets of wood, from 0.5mm to 5mm. Since they have usually attractive appearance they are used as finishing materials or cover to timber surface of inferior quality.

FIRED CLAY PRODUCTS

General

The technique of firing clay to produce bricks and tiles for building construction is more than 4000 years old. It is based on the principle that clayey soils (containing 20 to 50 % clay) undergo irreversible reactions, when fired at 850 -1000^0 C, in which the particles are bonded together by a glassy ceramic material.

Advantages

- *Fired clay products can have high compressive strength* even when wet making them resistant to impact and abrasion. The excellent condition of many ancient brick constructions clearly demonstrates the durability of fired clay products.
- *Fired clay products provide excellent fire-resistance.*
- *The porosity of fired clay permits moisture movement, without significant dimensional changes.*
- Solid bricks have a high thermal resistance required for most climates, except for the predominantly humid zones; perforated bricks can be used (with perforations running vertically) for cavity walls, which provide thermal insulation, or (with perforations perpendicular to the wall face) for ventilation or screen walls.
- Bricks and tiles are weather resistant and can remain without any surface protection; thus saving costs. However, exposed brickwork is often considered unfinished and hence not always accepted.
- Poor quality and broken bricks are useable for other purposes, hence no wastage.
- The production process can be extremely labor-intensive and thus create many jobs, even for unskilled workers.

Bricks

Bricks are manufactured from clays generally found in abundance in many parts of the world. Clays are fine grained soils which have resulted from the decay of rocks. When brought to the required consistency by moistening and mixing with water, clays become plastic, easy to mold and are capable of retaining their shape on drying. On account of the different phases they might have gone through and their history of formation, clays are generally found mixed with other materials (impurities) which influence their proportion. A clay soil for brick making should be such that when prepared with water, it can be molded, dried and burnt without cracking or changing its shape or warping. Such material should preferably have the following composition:

a) Clay 20-40
b) sand 30-50
c) Other (lime, silt, loam--) 20-35

Each of these components and their constituents play different rolls in the manufacture of building bricks and influence the characteristics of the final product.

Functions of the Constituent Materials

Clays generally consist of the following chemical elements: alumina (Al_2O_3), silica ($Si0_2$), Ferric oxide (Fe_2O_3), lime (CaO), Magnesia (MgO), carbon dioxide, sulphur trioxide, alkalis and water. Each of these constituents of the raw material used in the manufacture of building bricks has a function which can be summarized as follows:

1. **Alumina- (AI_2O_3)**
    - When burnt alumina becomes stronger and harder.
    - Makes the major part of clay
    - Becomes plastic when mixed with water and is capable of being molded to the desired shape. (Responsible for plasticity of the mud).
    - On drying it loses its plasticity and become hard. This can be accompanied with shrinkage which might result in wrapping and cracking depending on the speed and magnitude of drying. If alumina content is excess, the brick will shrink on drying which leads to cracking and warping. If small than required, the brick will not be molded easily and nicely. Bricks of very high alumina content are likely to be refractory.
2. **Silica(SiO_2)**

Silica is available in two forms: Silica combined as a constituent of clay and free silica (sand or quartz). It is useful in reducing shrinkage and warping in burning. Its presence in brick produces hardness and durability however a large percentage of uncombined silica is undesirable because it leads to brittleness of the product

3. **Lime (CaO)**

When present in small quantity, lime acts as a flux and lowers the fusion point of silica. It also acts as a binder to the clay and silica particles leading to a greater strength. Excess of lime may cause the bricks to melt and lose their shape.

4. **Iron oxide (Fe_20_3)**

Acts as a flux i.e. it lowers down the softening temperature of silica. It is this element which imparts the colors of the clay and the burnt product. Depending on its percentage the color of the brick may vary from light yellow to red. If it present in the form of Pyrites (Sulfide of iron), it can get oxidized, crystallize and split the bricks to pieces.

5. **Magnesia -(MgO)**

Usually it is present in small quantity (1%) in clay and together with the iron oxide; it gives the brick darker or even black color. It also lessens warping of bricks in burning.

Manufacture of Bricks

The process of manufacture of bricks is carried out in a number of stages.

- ❖ Selection of suitable type of brick earth
- ❖ Preparations and tempering of mud
- ❖ Shaping and molding of brick units
- ❖ Drying of molded bricks
- ❖ Firing or burning of units
- ❖ Cooling of the units

The raw material for the manufacture of bricks is first excavated and crushed (clays usually convert to loose or powder form when excavated, hence, all that will be needed is to make them free from stones, bolder, coarse sand or lime. It is then mixed with water until it gets the desired consistency. Sand soil and or lime may be added to the dry raw material if it is found deficient in silica and lime. Mixing done until the whole mass becomes homogeneous and plastic.

The tempered clay is then fed into molds made of timber or metal and pressed (hand molding) or extruded through a rectangular hole the dimensions of which are equal to those of the transversal cross section of the brick (Mechanical molding). In the later case, the material thus formed is made to pass through a machine the function of which is to cut the long column into length equal to that of a brick which at this stage is called *green brick.* The green brick is then dried before burning.

Drying is essentia1 and usefu1 in giving the green bricks sufficient strength to be handled and staked in kilns without being damaged. It is done either in the open-air driers (open shades) provided with roofs or in the drying .Zone of a continuous kiln with sufficient care taken so as to avoid checking and warping resulting from quick drying. The dried bricks are then fed into kilns where they are burnt, at temperatures reaching, 900 to l200^{o} C. Besides imparting strength to the green brick and preventing cracking and warping; drying helps remove the moisture from the bricks which allows to save time and fuel during burning.

Burning, this is required in order to make the bricks stronger, harder, more durable and less absorbent, norma1ly takes couple of days to complete. Three irreversible reactions take place during the process of burning. These are:

Dehydration; which is generally completed before a temperature of 700^{0} C is reached. During the dehydration period the water left in the bricks after drying is driven off and some of the chemical elements such as the hydrate of alumina silicate ($A1_20_3.2SiO_2.2H_20$) are dehydrated.

Oxidation; which leads to the formation of an interconnected network made of new crystals (oxides). The rest of the carbon is also eliminated at this stage. Oxidation is completed at about 900^{o}c.

Sintering; the temperature is raised to l200^{0}C. At these temperatures hard-burnt bricks are produced which contain melted components acting as binder to the non-melted minerals. In addition to being stronger, hard-burnt bricks are more durable and absorb very much less water on wetting with water.

Types and Classification of Bricks

Two types of clay bricks are manufactured in Ethiopia at present. These are: solid clay bricks and hollow clay bricks and beam tiles.

A. Solid Clay Bricks

According to the Ethiopian Standard, the solid bricks are of the following three types.

a. Brick without holes or depression (type TS)
b. Brick with holes up to 20 mm in diameter each and having a total cross sectional area not exceeding 25 per-cent of the base area of the brick (type TH)
c. Brick with depression not exceeding 25 percent of the base area having a maximum depth of the depression not more than 10mm (type TD).

B. Hollow Clay Bricks

According to the Ethiopian Standard, the hollow and beam tiles bricks are of the following three types.

a. With two faces keyed for plastering or rendering (type kk)
b. With two faces smooth and suitable for use with out plastering or rendering on either side. Type (ss) and
c. With one face smooth and another face keyed for plastering (type sk)

Fire bricks or Refractory brick

These bricks are capable of withstanding very high temperatures

Firebricks are manufactured in exactly the same manner as the ordinary bricks. The clay is dug out, broken, weathered blended and tempered. It is then mixed in pug mill. Then it is molded, preferably with machines, to the shape and size needed. After drying these are then burnt in kilns at temperatures ranging from 1350^0c to 1900^oc.

Firebricks have white or yellowish white color and are used for lining the interiors of fireplaces, ovens, kilns, chimneys and furnaces.

Properties of Bricks

The essential properties of bricks may be conventionally discussed under four headings: physical properties, chemical characteristics, thermal characteristics and durability.

Physical properties

a. Shape- rectangular

b. Size -60 mmx120mmx240mm

c. Color -red d. Density

The density of bricks or weight per unit volume depends mostly on the type of clay used and the method of brick molding. In case of standard bricks, density varies from 1600 kg/m^3 to 1900 kg/m^3. A single bricks (60x120x240) will weigh between 3.2kg to 3.5kg depending upon its density.

Mechanical properties

Compressive strength is the most important property of bricks especially because they are to be used in load bearing walls. The compressive strength of a brick depends on the composition of the clay and degree of burning

Thermal properties

Besides being hard and strong, an ideal brick should also provide adequate insulation against heat, cold and noise.

The heat and sound conductivity of bricks varies greatly with their density and porosity. Very dense and heavy bricks conduct heat and sound at a great rate. They have therefore poor thermal and acoustic (sound) insulation qualities. For this reason, bricks should be so designed that they are light in weight, strong and give adequate insulation.

Durability

By durability of bricks is understood the-length of time for which they remain unaltered and strong when used in construction.

The durability of bricks depends on a number of factors such as: absorption value, frost resistance and efflorescence.

Efflorescence: is a whitish powder of crystallization on brick masonry walls caused by water-soluble salts deposited on the surface upon evaporation of water. Efflorescence will appear when salt is available within a brick and moisture to carry these salts to the surface .To overcome efflorescence, it is necessary to check types of brick, quality of water used, and type of mortar used.

Tests for Burnt Clay Bricks

Two types of tests are used to determine the quality of building bricks.

A. Field test

B. Laboratory test

Field tests: such as appearance, hummer test and hardness test can easily be made at a construction site:

- Appearance test is that: shape, plainness, color etc.
- When stroked with hummer, a properly burnt dry brick free from cracks emits a highly metallic ring.
- The hardness of a brick sample can be checked by scratching its surface or broken section with a knife or fingernail. A well burnt brick will be scratched with difficulty.
- A rough test for the strength of the brick is to let it fall freely from a height of about one meter on to a hard floor. It should not break

Laboratory tests:

1. Compressive strength test
2. Water absorption test
3. Efflorescence test and
4. Saturation coefficient test

Standard Specifications

Many countries have their own standard specifications for bricks, and reference should be made to these where available.

According to Ethiopian Standard solid clay bricks are classified according to the numerical values of their compressive strength, water absorption, saturation coefficient and efflorescence as follows:

1. <u>Minimum Compressive Strength</u>

<u>Table: 1 Minimum compressive strength</u>

Class	Minimum compressive strength	
	Average of 5 bricks*(N/mm2)*	Individual bricks *(N/mm2)*
<u>A</u>	20	17.5
<u>B</u>	15	12.5
<u>C</u>	10	7.5
<u>D</u>	7.5	5

2. Maximum water absorption. (%)

Table: 2 Maximum water absorption

Class	After 24hr.lmmersion		After 5hr.Boiling	
	Average of 5 bricks	Individual bricks	Average of 5 bricks	Individual bricks
A	21	23	22	24
B	22	24	23	24
C,D	No Limit	No Limit	No Limit	No Limit

3. Maximum Saturation Coefficient

Table: 3 Maximum Saturation coefficients

Class	Average of 5 bricks	Individual bricks
A,B	0.96	0.99
C,D	No Limit	No Limit

4. Efflorescence Rating

Table: 4 Efflorescence Rating

Class	Efflorescence
A,B	Nil to slight
C,D	Effloresced

In the case of hollow clay bricks and beam tiles the minimum compressive strength and maximum allowable value for water absorption are given in table 5 and 6 respectively.

1. Minimum compressive strength

Table: 5 Minimum compressive strength

Type	Minimum Compressive strength	
	Average of 5 bricks(N/mm2)	*Individual Bricks(N/mm2)*
kk	*7*	*5.5*
ss	*7*	*5.5*
sk	*7*	*5.5*

2. Maximum allowable water absorption, %

Table: 6 Maximum allowable water absorption

Type	After 1hr Submersion in boiling water	
	Average of 5 bricks(N/mm2)	*Individual Bricks(N/mm2)*
kk	21.5	23
ss	21.5	23
sk	21.5	23

Qualities of a good brick

1. It should have a rectangular shape, regular surface and red coloured appearance.
2. It should confirm in size to the specific dimensions (60mmx120mmx240mm)
3. It should be properly burnt. This can be ascertained by holding two bricks freely, one in each hand, and sticking them~ A sharp metallic sound indicates good burning where as a dull sound would indicate incomplete burning.
4. A good building bricks should not absorb more than 20% of its dry weight. Absorption should not exceed 25% in any case.
5. A good building brick should posses the required compressive strength, which in no case should be less than *35kg/cm^2*. A rough test for the strength of the brick is to let it fall down freely from a height of about one meter on to a hard floor. It should not break.
6. Bricks should be hard enough so that it is not scratched by fingernail.
7. A good brick has a uniform colour and structure through its body. This can be checked by taking a brick from the lot and breaking it into two parts. The broken surface in both the halves should have same appearance and structure.