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Fully Revised & Brought Updated Edition

A Text Book of
ENGINEERING
Materials

Dr. M.A. Aziz

University Campus
Publisher & Seller

A Text book
of
ENGINEERING
MATERIALS

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Dedicated to the sweet memory
of my beloved parents

PREFACE

This book is the outcome of my experience gained while dealing with the manifold aspects of the topics covered both in the teaching as well as in the practical fields. Its preparation was undertaken to meet the need in the engineering education and profession which was felt for a general textbook covering the manufacture. Properties and uses of the most common materials of engineering construction in a comparatively concise and thoroughly modern manner.

This book on engineering materials is designed for use as a textbook to the students pursuing engineering and technical education in the Engineering Universities. Engineering Colleges, Polytechnic Institutes and other Technical Institutions, Industrial as well as structural properties and application of various important locally available engineering materials are described and hence this book is a unique offer to the students of all branches of engineering. The practicing engineers, architects and to those preparing themselves for AM1E (Bangladesh) Examination. The treatment of various classes of materials follows a general systematic pattern which has been made uniform throughout so far as has been found practicable. The consideration of each material is prefaced by and introduction and general discussion of its applications in manufacture or natural occurrence and concluded by a discussion of physical and mechanical properties in relation to its uses.

This book aims at presenting in a simple, concise and lucid form the best of the most up to-date knowledge concerning materials use in all types of engineering construction in Bangladesh. Numerous illustrative diagrams, worked-out examples, tables, charts and graphs have been presented in this book to enable the requiring no previous knowledge in this field.

The author cannot make pretense of being a specialist in all of fields which are converted in various chapter of this book. This work is therefore to a large degree a compilation of data and opinion from a great many different sources. The author takes pleasure in acknowledging his great indebt Ness to the large number fo engineers, architects, government officials and manufacturers who have privately or by their writings contributes much to make up this volume. Care has been taken to give accurate information in this text book; however, in a subject so varied as engineering Materials, mistakes any occur. I will appreciate having errors called to my attention. Any suggestion for future improvement would be graciously welcomed.

The author is deeply grateful to Dr. A. Hasnat, Professor and Head, Civil Engineering, Department, Bangladesh University of Engineering and Technology, Dhaka, for his kind encouragement in writing this book. Thanks are due to Dr. S.H.K. Eusufzal, Dr. A. Hannan, Al-haj A.F.M. Abdur Rauf, Dr. M. Shajahan, Dr. J.R. Chowdhury, Dr. A. Salam. Dr. A Habib, Mr. Shamimuzzaman and Prof. Ali Akber of Civil Engineering Department for their interest, encouragement and valuable assistance in writing this book. I wish to express my gratitude to my wife, Saleha for her unfailing inspiration support and help during writing and in the final preparation of the book. Finally, sincere appreciation is extended to my family for allowing me to take so much of their time to write this book.

The author also thanks his publisher for kind co-operation and help in bringing out this book in time in spite of loss of difficulties.

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CHAPTER-ONE

INTRODUCTION

1.1 General Consideration: Any material which has got application in engineering constructions is termed engineering material. In all branches of engineering and understanding of the fundamental nature of engineering, materials is becoming increasingly vital. Not only are requirements for materials for engineering applications growing more complex, but there are more materials to choose from every day. The engineer can no longer be satisfied with a superficial knowledge of fees standard properties of a few commonly used materials. So many variations in properties are available that the engineer must have more basic understanding of the behavior of materials. This understanding can be developed only through knowledge of the properties of the materials.

A bridge or a dam or a building or a road is to be built and the choice of materials is up with the engineer. Shall steel or concrete being selected or are there newer materials that might prove superior? The choice must be based on several factors; availability of materials, economy, ease of handling and fabrication, strength, durability and workability.

A civil engineer engaged in the task of planning design and construction of building bridge, dams, roads, water purification plants, sewage treatment plants, airfields or any other structure, should be thoroughly familiar with the desired engineering materials and their properties. Every engineering construction (structure) must be sufficiently strong and durable to resist the action of external forces and Internal stresses due to various types of loads In order to achieve maximum economy. The engineer must know the strength characteristics of the materials and the permissible stresses in each case.

A structure must be a harmonious blend of beauty strength utility and economy. To achieve this, specification for engineering materials must be laid down. A specification for an engineering material supplies a set of statements of requirements which the material should conform to in order to be acceptable for use in structure. In all engineering constructions, it is Imperative in the interest of the safety and the durability of the structure that only materials of the acceptable quality and strength be used. Therefore, the engineer and other related personnel must have to acquaint themselves thoroughly with the functions and qualities of engineering materials, because upon the quality of engineering materials, depends the quality of structures. The quality control of all engineering materials is of prime importance to improve the quality of engineering Construction as a whole.

1.2 Properties of Engineering material: A duality that define a specific characteristic of a material is termed as a property. The properties of a material provide a basis for predicating its behavior under various conditions. They are the tools of the engineer uses to solve his material problems. Some of the most important properties of engineering material are:

1. **Physical properties:** Size, Shape, density, porosity, structure.
2. **Mechanical properties:** Strength, elasticity, plasticity, stiffness, ductility, malleability, hardness, brittleness, resilience, creep.
3. **Chemical properties:** Corrosion resistance, acidity, alkalinity, chemical composition.
4. **Thermal Properties:** Specific heat, thermal expansion, conductivity.
5. **Magnetic properties:** Permeability, cohesive force, hysteresis.
6. **Electrical Properties:** Conductivity, dielectric permittivity, dielectric strength.

Fundamentally, the properties of a material depend on the nature of that particular material alone. Nearly all those, properties listen, however, are also inseparably tied in with conditions of use environment and the state of the material. The actual evaluation of a property depends on all these factors. Mechanical strength, for example, differs for various forms of loading, and is commonly expressed by such terms as *tensile strength, compressive strength or fatigue strength.*

Most properties of engineering materials must be evaluated entirely by experiment: Certain specific conditions are applied and the corresponding properties are measured. Experiments for determining properties of engineering materials are usually called tests. Tests may provide properties for use in design or information on the quality of material. The procedures are usually standardized because if identical procedures are always followed, the results of a number of tests may be compared with some assurance Much of the standardization is done by then the national organization set up in each country to improve the use or materials in engineering constructions and also in industries Some of these organizations are (1) BSI (British Standard Institute); (2) ASTM American Society of Testing Materials;

(3) AASHO (American Association of State Highway Official), (4) ACI (American Concert Institute). Each organization gives standard test methods of all kinds in addition to standard specifications for materials and standard definitions of terms.

The following are the very important properties of engineering materials, o
o

(1) **Strength:** It is the property of material that represents its ability to resist internal forces or stresses. The three basic strengths of a material, the type of force to which the materials is to be subject, must be known. As for example the compressive and tensile strength of structural steel are nearly equal, whereas cast iron can take more compression and it is weak in tension. Similarly, concrete is very strong in compression but very week in tension.

Stress: Stress is the intensity of internal force developed when an external force is applied on -an engineering material.

It is denoted by the following expression.

$$S = \frac{P}{A} \qquad \mathbf{1.1}$$

Where S is the stress, P is the external force applied and A is the cross-sectional area of the surface on which the force P is applied. Stress is usually expressed is psi (pounds per square inch). There are three types of stresses (a) compressive stress, b) Tensile stress and (c) shear stress.

Tensile Stress: This type of stress is induced in an engineering material when it is subjected to a tensile force.

Compressive Stress: This type of stress is induced in an engineering material when it is subjected to a compressive force,

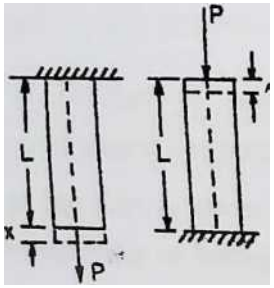
Shear Stress: When a part of an engineering material tends to slide over another portion at a given section, the fibers at the section are side to be shear.

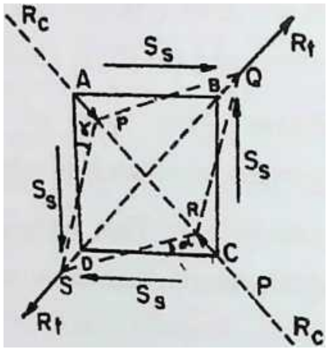
$$\text{Shear stress} = \frac{\textit{Shear Load}}{\textit{Are under shear}} \qquad 1.2$$

Strain: When load (external force) is applied to a material not only a stress is induced in the fibers, but the size or the shape of the material is also changed. Strains are the geometrical deformation of a material due to application of an external force. In other words, strain is a measure of the deformation produced by the application of external force. It should be noted that the value of the strain is not expressed in any dimensional unit. Strain is denoted by the following expression:

$$e = \frac{x}{L} \qquad 1.3$$

Where e is the strain, x is the extension or shortening of length and L is the original length.





Strains are again three types: (a) tensile strain, (b) compressive strain and (c) shear strain.

Extension of length
Tensile, strain, et =-------------------------- (Fig. 1.1) 1.4
Original length

Shortening of length
Compressive stain=-------------------------- (Fig. 1.2) 1.5
Original length

Shear Strain Shear strain is concerned with the change of shape or deformation resulting from the shear stress. The element ABCD shown in the Fig. 1.3 is subjected to shear stress. The rhombus PQRS is the deformed shape of the entire element ABCD caused by the shearing stress Ss. The value of shear strain is given by 2a.

(2) **Elasticity:** It is a property of a material which allows it to return to its original shape and size after the load to which it is subjected is released. This is a very important property of engineering materials. The strain for a given of load during the unloading process is equal to the strain for the same value of load during the loading process. A limiting value of load will be found at which the strain does completely disappear with the removal of the load. The value of stress corresponding to this load is called the Elastic Limit. It was discovered by Hooke that if a material loaded without exceeding the elastic limit, then the deformation produced is proportional to the load production it, from the expressions of stress and from Hooke's law it can be said that stress varies as strain. This expression will equally apply in tension and compression up to a stress value at the elastic limit.

Young's Modules of Elasticity: The physical constant obtained from the stress-strain ratio is given the name, Young's Modulus of Elasticity, and is denoted by the letter E as follows

Stress
E = --------------- 1.6
Strain

Hooke's elastic law holes also in the case of shear streams and shear strain but the value of this ratio differ from that obtained in tension and compression and is termed as the 'shear modules' of the given material. Since the value of strain is expressed as a number; the units of E will be as same as that of stress. It should be noted carefully that 'Young'? Modules has no significance beyond the elastic limit.

Modules of Rigidity: It can be defined as the ratio of the shearing stress to shearing strain; or

$$G= \frac{\text{Shearing stress}}{\text{Shearing strain}} \qquad 1.7$$

Where G is the modules of rigidity.

Bulk Modules: This elastic constant expresses the relationship between the volumetric strain caused by direct forces, it is denoted by the letter K.

$$K = \frac{\text{Direct stresses cussing a change in volumes}}{\text{Volumetric strain}} \qquad 1.8$$

Poisson's Ratio: If a direct force acts on a body, it produces direct strain in the direction of its action and an opposite kind of strain in every direction of action. This is known as lateral strain while the strain, in the direction of action of the force is known as longitudinal strain. The ratio of these two kinds of strain is a constant and is known as Poisson's Ratio It is generally denoted by μ .

μ =\f(Lateral strain, Longitudinal strain

1.9

(3) Plasticity: Plasticity is the opposite property of elasticity. A perfectly plastic material does not return to its original shape and size when the load causing deformation is removed. Lead is an example of plastic material.

(4) Malleability: This property, permits plastic deformation of a material when subjected to compression. Materials that can be hammered into thin sheets are malleable materials.

(5) Brittleness: The opposite property of malleability is brittleness. Cast iron is example of brittle material.

(6) Stiffness: The term stiffness designates the resistance of materials to deformation in the elastic range. Stiffness of ductile material is measured by the modules of elasticity.

(7) Ductility: Ductility indicates the ability of a material to deform in the plastic range without breaking. No accurate measure of ductility exists. For comparative purposes however, ductility is usually defined by the percentage elongation of a tensile specimen at fracture for a specified length.

(8) Toughness: This property matures the ability to absorb to release energy in the plastic range.

(9) Fatigue: Certain materials are very often subjected to repeat stress. The term fatigue (fatigue strength) of a material is used to indicate its strength in resisting repeated stress.

(10) Hardness: The term hardness, when used as a technological property of materials is primarily associated with the surface, an appropriate definition of hardness is the resistance of a material to permanent deformation of its surface. This deformation may be in the form of scratching, mechanical wear or cutting.

(11) Resilience: The resilience of a material is its ability to absorb energy in the elastic range. It is measured by the energy per unit volume required to stress a material in tension form zero stress to the proportional limit.

(12) Creep: In many applications engineering materials are required to sustain steady loads for long periods of time.

e.g. R.C.C (reinforced cement concrete) beams columns etc. Under such conditions the material may continue to deform until its usefulness is serially impaired. Such time- dependent deformations may be almost imperceptible, but over the life time of a material or structure they can grow large and even result in final fracture without any increase in load.

Under short-time loading, as in the conventional compression test, of a material there is an initial deformation that increases simultaneously with the load. As shown in the static stress-strain diagram. If under any conditions, deformation continues when the load is held constant, this additional deformation is termed as creep. In fact, creep is the time-dependent part of the strain relating from stress.

1.3 Selection of Engineering Materials: Selection of materials for engineering applications depends first upon their properties in relation to intended use. The engineer should he

alert for new materials that may be developed but he should also keep his mind receptive to possible new ways of using existing materials.

The next important considerations are economy and availability. Preference should always be given to the locally available materials. Sometimes a material must be selected even though inferior properties, because the right material is not locally available or too expensive.

1.4 Engineering Materials commonly use In Bangladesh:

The following are the important engineering materials that are commonly used in Bangladesh; Stones, brick and other structural clay products, lime, cement, surki and sand, concrete, iron, steel, ferrous alloys, non-ferrous metals and alloys, timber a timber product, bamboos, soils, bituminous materials, glass. Plastic, paints, and varnishes, rubber, etc.

The important features of all the engineering materials with respect to availability, manufacture, desirable properties standard specifications and uses in engineering constructions and in industries are discussed thoroughly in following chapters.

Questions

1 What is an engineering material? Critically examine the importance of engineering materials in engineering construction Do you think that paper, water, air and ink can be termed as engineering materials? Justify your answer

2. What do you mean by the term “Property of a material? Why it is very important? Enumerate various properties of engineering materials.

3 Define the following: Stress, Strain, Elastic limit. Young’s Modules of Elasticity, Modules of Rigidity Poisson's Ratio, Malleability, ductility, Fatigue, and Hardness.

4. What are the important considerations that are looked for selecting engineering materials? Name the engineering materials commonly used in our country Enumerate the specific uses of any ten of them.

CHAPTER-TWO

BUILDING STONES

2.1 Introduction. A building stone is obtained from the rocks in the earth-crust. It is a naturally occurring substance. Stone is considered to the king of engineering materials, and where durability and permanency of a structure are required. It continues to enjoy its superiority over all other rival materials of engineering construction. Stones were used in early days for structural works. Important historic examples of the uses of stones are the Taj Mahal, Buddhist Temples and Kutub Minar in India. The Pyramids of Egypt, the remains of Grecian and Roman structures and many other masses we and beautiful structures found practically throughout the world. The main censer of extensive use of stone is that when selected properly. It has less wear and tear and does not involve much maintenance cost. Therefore, engineers must have thorough understanding of the characteristic properties of different types of stones available in their own country to ensure their proper and most beneficial application leading to the successful design and construction of structures.

To understand the properties of stones very thoroughly one should study first the characteristics of stone forming minerals.

2.2 Minerals: The problems of civil engineering relate with foundation and again, foundation relates with rocks and soils. Since the rocks are nothing but the aggregates of minerals knowledge of minerals is essential first for civil engineers.

Minerals are naturally occurring substances, having characteristics internal structures, and of more or less definite chemical composition and displaying more or less definite physical properties. They can be easily identified by the following properties

1. **Streak and Color:** The color of a mineral is often of assistance in its identification. Streak is the color of mineral in powdered form.

2. **Cleavage and Fracture:** The cleavage of a mineral is its capacity to split more readily in certain directions than in others, due to the arrangement of the atoms. Fracture of a mineral is the haphazard way the mineral breaks.

3. **Hardness:** The hardness of a mineral is measured by its ability to resist scratching. If a mineral is scratched by a knife, it is softer than the knife. If a mineral cannot be scratched by a knife, the two are equal in hardness or the mineral is the harder. If the knife is scratched by a mineral, the mineral is harder.

4. **Luster:** Luster is the appearance of a mineral in ordinary light.

5. **Structure:** Some minerals are granular, for example: olivine, others are fibrous, crystalline etc.

6. **Specific gravity**: Specific gravity gives a very good basis tor identification of minerals.

7. **Magnetism: A** few minerals are attracted by magnet- of this mineral; magnetite is the most common example.

8. **Association:** The association of creation minerals with others is suggestive for identification of minerals.

Principal Stone forming Minerals: About 200 minerals have been recognized by the chemists and geologists but a

few of them have got engineering applications. The following- are the important rock forming minerals.

1. **Silica.** Quartz is pure Silica. It is unaffected by weathering. Its color may be white, grey, pink, purple or yellowish. Streak is white. No cleavage, luster is vitreous and the structure is granular. It is hard and specific gravity is 2.66. It is used in the manufacture of bricks, ceramics, glass, concrete, mortar, plaster etc.

2. **Feldspars:** Contains Silica, Alumina, Potassium, Sodium or Calcium. Generally, two types:

   (a) Potash Feldspars: Also known as orthoclase. It contains Potassium, Alumina and Silica. Its color is white, reddish, grey or grass. Streak is white 2 cleavages at 90°, luster is vitreous, granular in structure, very hard and specific gravity is 2.5 to 1.7. It is used in the manufacture of porcelain wares, glasses and also for glazing.

   (b) Lime-Soda Feldspars: Also known as plagioclase. It contains Sodium, Calcium Alumina and Silica. Its color is generally white, may be grey, blush or reddish, Streak is. white 2 cleavage at 90°. Luster is vitreous, structure is granular or fibrous, very hard, sp. gravity is 2.4 to 2.85. It is used for manufacturing glasses and ceramic products.

3. **Micas:** Complex Silicates of Potassium, Alumina, Silica, Magnesium and Iron. It is generally of two types

   (a) **Muscovite:** Complex silicates of Potash, and Alumina. Its color is generally white, yellowish or grey Steak is white, luster is vitreous, structure foliated very weak. One perfect cleavage has sp. Gravity of 3.0. It disintegrates very rapidly; hence a source of weakness is present in building stones.

(b) **Biotite:** It is a complex silicate of Potassium, Magnesium, Iron and Alumina. Its color is black, one perfect cleavage, luster is vitreous. Structure is foliated, moderately hard, sp.gr. =3.6

4. **Amphibole:** Also known as Hornblende. This is a complex silicate of Sodium, calcium, Magnesium, Iron and Aluminum, with a dark green to black color.

   Streak is pale black, two cleavages at 90°. Luster is vitreous. Structure is granular and very hard. sp. gr. =3.2

5. **Pyroxene:** Also known as Augite. It is a complex silicate of calcium, Magnesium. Iron and Aluminum, It is similar to hornblende, but slightly harder and heavier. Its color is green; streak is greenish cleavage 2 at 90°. Luster is vitreous, structure is granular.

6. **Olivine:** It is composed of Magnesium, Iron and silica.

   Yellowish green color, streak is pale green, cleavage is not distinct, Luster is vitreous, structure is granular, very hard. sp. gr. is. 3.5.

7. Calcite: It is calcium carbonate. It has a color varying from white to grey. Streak is white. 3 good cleavages, luster is vitreous, structure is granular. It is not very hard and sp. Gravity is 2.7. The chemical combination as calcite viz. CaO and $C0_2$ is liable to ready decomposition. A drop of dilute hydrochloric acid causes effervescence, liberating CO_2 from the mineral. But on exposure to atmosphere the anhydrous CaO absorbs moisture and becomes calcium hydroxide which further takes up CO_2 from the atmosphere and forms $CaCO_3$.

8. Dolomite: It is calcium magnesium carbonate. It is harder than calcite. Color varies from white to grey. Streak is white, 3 good cleavages, luster is vitreous, structure is crystalline, sp. gr. = 2.86.

9. **Magnetite.** It is magnesium carbonate Color is white or grey. Streak is white. Cleavage is not distinct, luster is vitreous. Structure is granular. It is a fine grained and compact mineral commonly used for making refractory materials.

10. **Garoet:** It is a complex lime-alumina or magnesia alumina silicate. It is strong, sp. gravity = 4.00. It also contains manganese and Iron. Its color is generally green. Streak is pale green: luster is vitreous. Structure is granular and cleavage is not clear. It is used as an abrasive for sawing and grinding stones.

11. **Asbestos:** This is a fibrous mineral and is composed of silicates of calcium and magnesium. This also contains iron oxide and alumina, its color varies from grey, brown to pale black Streak. Streak is pale grey. It is not very hard. It has a physical property of being separated into fiber; it is used to manufacture asbestos-sheets, fire resisting and insulating materials, and asbestos-cement.

12. **Iron Oxide:** Three common iron oxides are:

(a) Hematite: It is Fe_2O_3 its color varying from red to brown. Streak is reddish-brown, well-developed cleavages, luster is metallic, and structure is granular.

(b) Limonite: It is hydrous iron oxide. Its color is brown, black is yellow. Streak is yellowish, no cleavage, luster is earthy, structure is granular or fibrous.

(c) Magnetite: It is FeO, Fe_3, O_3. Its color is black. Streak is black, no cleavage, luster is metallic and structure is granular.

Iron oxides are used for the manufacture of wrought iron and cast iron.

2.3 Classification of Stones: Geologically stones classified as follows:

1. **Igneous Stones:** These are extracted from igneous rocks. These rocks are formed by cooling and solidifying of rock masses from their molten conditions on and within the earth crust. Building stones available from these types of rocks are very heavy strong and durable. Examples are granite, trap and basalt.

2. Sedimentary Stones: These stones are obtained from sedimentary rocks. These rocks form by hardening the sedimentation under lakes and seas. These are compacted by pressure and cemented together by deposition of materials carried by strains. Building stones, a from this veanety of rocks are not very heavy and strong, common examples are limestone and sandstone.

3. Metamorphic Stones: These stones are obtained from metamorphic rocks. Due to high pressure and temperature inside the earth crusts both igneous and sedimentary rocks are converted into metamorphic rocks with development of new characteristics. The stones: which are obtained from this variety of rocks are very strong and durable. Common examples are marble, quartzite and slate.

2.4. Properties of Building Stones: When stones are selected for use in structural and building constructions, the following properties are to be considered:

1. Structure: This relates to the manner in which the particles that go to form a stone are arranged. Igneous stones possess

unstratified structure which yields much strength and durability. Stratified structure is a characteristic feature of sedimentary stones. This is why sedimentary stones are not strong and durable and also, they split very easily. Metamorphic stones have foliated structure which yield much strength and durability like igneous stones

2. Texture: it is the arrangement, size and shape of the constituent minerals of a stone. Texture of a stone has a direct relation with its hardness. Stones with crystalline or homogenous texture are close grained and compact and better suited for resisting the weathering action of the atmospheric agencies. Good building stones should have uniformity in texture with compactness. Stones with fine grains are more durable and better suited for purposes of molding and receiving a finer polish.

3. Appearance and Color: Stones with uniform colors are found generally strong and durable. Better architectural aspects of structures are also produced by using highly colored stones Red and Brown shades indicate the presence of harmful matters such as oxide of Iron, loose-earth particles etc. Stones containing higher percentages of iron should never be used because they are liable to be disfigured from unsightly rusts and stains formed by the oxidation of Iron under atmospheric conditions.

4. Porosity: The porosity of a stone is defined as the percentage of total volume occupied by pore-spaces. Porous stones are always weak. So, they should never be used in the face-works of buildings because they get decomposed and disintegrated by rainwater which is chemically very active.

5. **Absorption:** When a stone is kept under water for a couple of hours, absorbs water. A porous stone will absorb more water when soaked. Absorption of water by marble stones is only 1% by volume; hence, it is a very strong stone. On the other hand, the absorption of water by sands tone is 20% by volume. This indicates that sandstone is porous and hence very weak. So, absorption is a good property of stone to see whether it is strong or weak.

6. **Strength:** Stones are subject to direct compressive loads in structures. So, their compressive or crushing strength is to be termined, stone are very strong in compression. Granite stone has a mpressive strength of 5,000 to 7,000 psi. The texture, specific gravity d porosity of a stone greatly affect its compressive strength. It is ture is even, specific gravity is high and porosity less, the stone is nsidered to be very strong under compressive forces.

7. **Density:** The density of a stone is determined by dividing the total weight of a stone by total volume. A denser stone will have higher specific gravity which yields higher strength. Densest stones are used in foundation works whereas light o stones are used in ornamental works.

8. **Toughness:** This is the resistance of a stone to impact. This property is particularly important where the stones are subjected to severe use in Impact. A good stone should be very tough.

9. **Abrasion Resistance:** This is the property of a stone to resist abrasion i.e., wears and tear. The stone that will be used in road Construction should have very good abrasive resistance.

10. **Permeability:** This is this capacity of a stone to transmit a fluid through it. A porous stone is more permeable and hence very weak. A good stone should be impermeable in nature.

11. **Heat Resistance:** Stone is a poor conductor of heat. Heat brings about rapid destruction of stone -structures by disintegration and decomposition. Limestones and marbles begin to calcite between a temperature of 600° to 800° C. and trap stones resist heat from fire very well, but granites disintegrate very quickly. Sandstones are very good in resisting heat in short, most of the stones are very good heat- resistant.

12. **Electrical Conductivity:** Stones are poor conductors of electricity. When dry, they offer a very high resistance but when wet their resistance becomes less. In an-electric installation, marbles and Slater are used because they are non-conductor of electricity. «

13. **Seasoning Qualities:** Stones contain a higher percentage of moisture (Quarry sap) when quarried. This makes the stones soft and easier to cut so, stones should be roughly dressed just immediate after the quarrying and final dressing and polishing should be done at the work site. Before use, the stones must be seasoned to remove moisture by leaving them in the sun for about six months; otherwise, the stones will disintegrate and destroy the durability and also the quality of the work.

14. **Facility of Working:** Economy in the cost of dressing stones plays a vital role in engineering constructions by stones. Hard stones are very difficult to dress and hence very costly, whereas soft stones can be dressed more economically.

Important Building Stones available in Bangladesh and Their Uses: The llowing are the important building stones available in Bangladesh: The llowing are the important building stones available in Bangladesh.

1. Granite: This is a crystalline variety of igneous rock. It is very heavy and strong. It weighs 170 lb. per cu. It. and the sp. gravity is about 2.7. The crushing strength of good granite is about 1,800 tons per sq. ft. Granite is used for works requiring great strength and durability and also for ornamental and monumental works and also for inscription purposes: It is also used when the stone is subjected to abrasion like paving blocks, road metals etc. It is comparatively a costly stone due to high cost involved in its cutting and dressing.

It is in small quantities In Sylhet and Chittagong.

2. Trap: It is an amorphous variety of igneous rock. It is very strong, hard and durable. It weighs about 175 lbs. per cu ft and its sp. gravity is 2.85 and possesses a crushing strength of about 1.000 tons per sq. ft. This is suitable for ordinary building works road construction.

Its deposits in Bangladesh are very rare, it is found in traces at Chhatak in Sylhet and Rangamati in Chittagong.

3. Basalt: It an igneous rock. It is very hard, compact, tough, and durable. Its sp. gravity is 2.85 and weighs 180 lbs. per cu • It is used as road metal and paving set to resist abrasion. It is extensively used in foundation of structures and as an aggregate in concrete works.

It is found in traces in Sylhet.

4. Sandstone: It is a sedimentary rock. It is a porous stone and exhibits different shade of colors. Sandstones are easier to work and dress, fts density is about 150 lbs. per cult and sp. gravity is 2.3 and its crushing strength is about 650 ton per sq. ft. It is extensively used as local building material.

Sandstones are abundantly found In Bangladesh. They are found at Cox’s bazar, Saint Martin Island, Sitakundu in Chandranath, and Hill Range in Chittagong Hill Tracts.

5. Limestone: It is a sedimentary rock. The chief constituent of limestone’s is calcite ($CaCO_3$). It is not very hard. It is easily affected by acids to cause effervescence. Lime stone is weak against abrasion. Its weight is about 165 lbs. per Cu. ft. and the sp. gravity is 260. Its crushing strength varies from 300 to 600 tons per sq. ft.

The following are the important varieties of limestone.

(a) Kanker or Argillaceous (Clayey) Limestone: These are found in nodular from. Their size varies from to 4 Inch and they are composed of pure compact carbonate of lime Kankar is invariably used as a source of lime. It serves as a cheap material for railway ballast and road metal. It is also used as building stones.

(b) Silicus Limestone: They contain higher percentage of silica and hence suitable for building stones.

(c) Magnesium Limestone or Dolomites: They contain calcium and magnesium carbonates practically in equal proportions. They are very heavy and compact. They are used to manufacture refractory bricks.

Limestone are abundantly found in our country. They are found at Chhatak in Sylhet, Saint Martin Island, Cox’s

Bazaar. Chittagong Hills Tract and also Khasia. Jaintia and Garu Hills area.

6. Shale: It is a sedimentary stone. Shale is a hardened mud, containing anhydrous aluminum silicate and small amount of mica and quartz. It is very strong and durable. Its weight is 1 80 lbs. per eft, and sp gravity 2.74. Its crushing strength varies from 600 to 900 tons per sq. ft. It is generally used for the manufacture of toys and ceramic products.

Shale is found In Sylhet. Mymensingh and Chittagong

7. Gneiss: It is a metamorphic stone and has same composition as granites but its structure differs due to metamorphic action. This yields good paving blocks and road-metals. It is a very durable type of stone. It weights 135 lbs. per Cu. ft. and its sp gravity is 2.42. Its crushing strength varies from 250 to 450 tons per sq. ft. It is found in Sylhet (small quantities).

8. Schist: it is a metamorphic stone. It splits very easily This Is due to greater quantity of mica present in it This is not very strong and durable. This is suitable for less important works.

Little traces are found to exist in Bangladesh.

9. Laterite: It is a sandy clay stone of metamorphic type It is comparatively a soft stone. It weighs about 140 lbs. per cu ft and the sp. gravity is 2.45. It's crushing strength vanes from 300 to 500 tons per sq ft. It is generally used in light constructions.

Laterite in fairly large quantities is available in various places of Sylhet district. These are suitable for use as soiling under metal e roads. The places where laterite is available In large

quantities in Sylhet are (a) Madhab Tilla and Bouji Tilla, a few miles from Jun off the Juri-Fultala Road and Juri- Karimgonj Road, (b) near Juni-Sheola Road (24 miles) between Dhalcherra and Quaya river and (c) Amura and Silghat villages about 3 miles from Gopalganj. The deposits are also found in the districts of Chittagong Hill Tract, Rajshahi, Dinajpur and Bogra.

10. Quartzite: Siliceous sandstone under the metamorphic action yields quartzite stones: It is fine grained, dense, strong and very durable. It is considered to be the strongest type of building stone. But it is very difficult to work with it because it breaks into irregular shapes and uneven surface. Its average wt is 185 lbs. per cu. ft. and sp. Gravity is 3.00. Its crushing strength varies from 1,000 to 1,450 tons per sq ft. Quartzite’s are quite suitable for retaining walls, revetments and aprons where dressing is of secondary importance.

It is found In Cox’s Bazaar in Chittagong district.

11. Slate: This is metamorphic product of clay, mudstone and shale’s. It absorbs less water and gives good abrasion resistance and also gives ringing sound when stuck with a hammer. It weighs 160 lbs. per Cu. ft. and sp. gravity is 2.48 and the crushing strength varies from 300 to 650 tons per sq. ft. It is best used as roofing materials, damp proof course, steps, and floor tiles and as road metal.

Slate is found in Sylhet and Chittagong.

12. Marbles: When Limestone becomes crystallized under the influence of high heat and pressure, it is called marble. So, Marble is a metamorphosed limestone. It is very compact and dense form of limestone and takes a very fine polish. It is generally white in color and used especially for decorative purposes. It can be easily sawn and resists weathering action very well. Taj Mahal of Agra in India is one of the famous examples of its use. Very small deposit in Sylhet and Chittagong.

2.6 Natural Water-Worn Stones: These are mainly five types. Boulder. Shingle. Pebble. Gravel, and Conglomerate.

Boulder: This is larger sized, roughly rounded water worn stone. This is crushed by a crushing machine to have building stones of required sizes.

Shingle: This is larger sized water-worn stone found near sea-shore. This is crushed to get required sizes of building stones.

Pebbles: These are small sized rounded water-worn stones found in river beds. They are used directly as building mater.

Gravel: This is a mixture of rounded water-worn pebbles of any stone with sand and is found in river beds and in alluvial tracts these are also used directly in road surfacing and as concrete aggregate.

Conglomerate: This is the stone formed when gravel and shingle get consolidate into stone. The pebbles being bound together by some cementing materials like clay lime etc. These stones are irregular in shape with porous granular texture. They are unsuitable for building purposes.

2.8 Uses of Different varieties of Stones for Various Engineering Constructions:

Concrete and Foundation: Granite. Quartzite, Trap and

Basalt

Paving of Roads: Granite, Gneiss, Trap and Slate.

Building floors: Sandstone, Granite and Marble.

Roofing: Slate.

Rubble Masonry: Granite, Trap, Basalt and Sandstone.

Superstructures: Granite, Trap, Laterite and Quartzite. **Arches and Carvings':** Granite and Marble.

Ballast: Granite, Trap and Quartzite.

Bed-Block: Granite and Quartzite.

Bridges: Granite and Slate.

Dams Construction: Granite and Trap.

Damp-Proof Course: Slate and Granite.

Lintels: Granite.

Marine Structures (Sea-Wall, Light-House, etc): Granite.

Mill Stones and Grinding Stones: Course grained sandstone,

Table-Tops. Steps, Columns and Ornamental Works: Marble.

2.7 Quarrying of Building Steps, in Bangladesh: The term "Quarrying" is generally applied to the art of extracting from the natural bed rocks the stones of various types as used in general engineering constructions. The exposed part of such bed-rock where all the works in connection with above is carried out, is termed as "quarry." The various operations involved in quarrying are open to the sky. The selection of site for a quarry often requires preliminary geologic Investigations about rock-deposit in the locality where a quarry has to be opened. The suitable location of a quarry depends upon the following considerations:

I. Availability of the desired building stones.

2. Nearness of the quarry to the existing communications systems such as roads, water-ways and railways.

3. Availability of suitable sites for the location of powder station, crushing and dressing machinery, labor sheds, etc.

4. In case of quarrying by explosives (Blasting method) the locality of the quarry should be at, a sufficient distance from the site of building works and other permanent structures.

5. The storage facilities of the quarried materials to the outside of the quarry of further conveyance.

2.9 Methods of Quarrying: The methods of quarrying are of two types depending upon then a true of the rock- deposit and the purpose for which the stones are required to be used. They are (1) Quarrying by hand tools like crowbars, axes, etc. and (2) Quarrying by blasting by the help of explosives such as blasting powder or gun powder, dynamite etc. In either case, quarrying may be carried out either by manual labor or by the help of machinery or by both.

2.10 Precaution in Quarrying: The following are the precautions that are to be adopted in quarrying:

(1) Layout Planning: When the selection of the site for quarry is made, the, engineer in charge should prepare a complete layout plan of the various stages of operation involved in quarrying so that with minimum cost, maximum amount of materials can be quarried.

(2) Stability of a Quarry: The quarrying should be done in such a way that the structural stability of the rock-side is not at all affected, otherwise, there is every possibility of dangerous rock-slide.

(3) Uses of Labor and Machinery: If the quarry is small; the work should be done manually to minimize cost of quarrying.

If the work is to be carried on a large scale and enough capital Is available, then mechanical equipment should be used, otherwise, the project might be a losing concern.

2.11 Various Quarries of Bangladesh: In Bangladesh most of the big quarries are in Sylhet district. All shingles occur as river wash in the bed of rivers and streams coming down from hills. The collection is made by boats. The collection is huge and it is estimated that about 2 to 3 cores cu. ft of materials can be collected in this district annually. The following are the names of different quarries in Sylhet district.

1. **Lubha Quarry:** This quarry is on the stream linking the Khasi Hills to Surma River. From this quarry, boulders and shingles of inferior quality are obtained.

2. **Plyan or Jafflong Quarry:** This very important quarry, both in respect of quality and quantity. The materials available are very hard and there is abundant supply of both shingles and boulders. The location is 35 miles away from Chhatak railway station. This is why the quarrying is very expensive.

3. **Bholagonj Quarry:** Largest collection is made nowadays from this quarry for its convenient location. This is situated on the Noa River and the site collection is 14 miles from this quarry are very hard, clean and fairly well-graded. Boulders available are also hard and fairly big sized. The supply is unlimited.

4. **Sheila and Bhowal Quarries:** These are comparatively small quarries located in the beds of streams originating from

Khasi hillisand falling on the Surma River. The sites of collection are 12 and 11 miles respectively from Chhatak and Sunamgonj. The materials are collected throughout the whole year. Though the materials are not of best class, but are quite hard, clean and well grades.

5. Sari River Quarry: This is about 6 miles away from Sari bridge In the 23rd mile of Sylhet-Shillong Road. This quarry is Important for its particularly well-graded hard pebbles of smaller size.

Chittagong District and Chittagong Hill Tracts: Small quantities of sandstone are quarried at Sitakundu in Chandranath Hill Range for local use. Considerable quantities of sandstone, shale laterite and limestone are quarried in Rangamati. Cox’s Bazaar and Sent Martin Island.

Jalpaiguri: Shingles of 1-to-3-inch size occur as river wash in the beds of rivers Chawal and karatoa. The supply is quite considerable.

Mymensingh District: Shingles are available as river wash in the beds of Mohadeb and other rivers coming from Garo Hills. The quantity collected is not abundant and cannot satisfy local needs.

2.12 Name of the quarries in Bangladesh where Important Building Stones are quarried:

Limestone: Sylhet, Cox’s Bazaar, and St. Martin Island.

Sandstone: Sitakundu, Chittagong Hill Tracts and Cox’s Bazaar.

Granite: Sylhet and Chittagong.

Trap and Basalt: Sylhet.

Laterite: Sylhet and Chittagong Hill Tracts.

Quartzite: Cox’s Bazaar.

late: Sylhet.

2.13 Chief Requirements of Good Building Stones: The following are the chief requirements of good building stones 1. Strength; 2. Density; 3. Durability; 4. Facility of working (Dressing and Polishing) 5. Cost.

2.14 Artificial Stones: Strong and durable stones are not always available easily, cheaply and locally. This is why artificial stones (cast stones or reconstruction stones) are manufactured now a day. Mirpur Ceramic Works in Dhaka is now manufacturing artificial stones of various sizes which are used in different types of engineering constructions. But they are costlier that natural stones. Artificial stones generally consist of crushes stones of small size mixed with cement. The usual proportions adopted are 1 pit of crushed stones o l Inch. The two sizes of stones are mixed together and added to one part of cement to three parts of mixed crushed stones with required quantity of water. The stones are cast by automatic machine or manually by moulds of wood or steel.

The main advantages of artificial stones are (1) It can be easily molded to suit ornamental works: (2) Its strength can be controlled by proportioning the ingredients and by using reinforcing steel; and (3) It can be cast to any desired size and shape.

2.15 Important Verities of Artificial Stones:

Mosaic Stones: These consist of grounded marbles (marble chips of any other suitable stone chips. 1 inch down size). They are used with cement in the usual ratio of 1.2 for making superior floor surfacing with usual variety of colors and patterns. This type of flooring is generally cast-in-situ but mosaic slabs or tiles (size 6” x 6”) are as quite commonly used.

Mosaic is also termed as terrazzo in some places. Mosaic flooring is very popular now- a- days. Mosaic work is also used for decorative and ornamental purposes.

Ransome Stones: These are prepared by mixing dry sand with a small quantity of finely grounded chalk or stones in a mortal mill or pug mill and forced into moulds. A cooled calcium chloride solution is poured over the blocks and then the blocks are immersed in the boiling solution of the same. So that, the pores get completely filled up with the solution which makes it hard. The calcium silicate is formed and the remaining of sodium chloride solution is washed off. Otherwise, it gives efflorescence. This type of artificial stone is hard, durable and can resist corrosion. This stone can be dressed and curved easily. But due to its cost, it no commonly used now a days.

Victoria Stone: These consist of finely powdered granite or any other suitable stones, and cement mixed with usual proportion (4:1). The molded blocks are hardened by the help of sodium silicate solution. This type of stone is very hard, and durable and generally used in pavements, landings etc.

Aggregate Stones: (Machine Made) these are manufactured mechanically from finely grounded stones (stone chips). '/^{4} inch down size mixing with cement and water in definite proportion. Their usual sizes are 1/2, 3/4, 1. *Vi* and 2”. They are used in making cement concrete. For special purposes when high strength and durability are desired.

Bricks: Theses are made of clay of special variety. The manufacturing processes, Characteristic and uses of bricks will be discussed elaborately in the following (chap. 3).

Questions

1. “Stone is considered to be the king of engineering materials”. Critically examine the statement.
2. What is a building stone? Give the classification of building stones with their characteristics.
3. Discuss the properties of a good building stone.
4. Name the common natural building stones that are available in Bangladesh and enumerate their uses.
5. Explain the term “Quarrying” How would you select the exact location of a quarry. Name the different quarries in Bangladesh and discuss about the types of stones that are found from these quarries.
7. **Give the specific uses of the following stones:**
   (1) Granite, (b) Marble, (c) Laterite, (dl Quartzite,
   (e) Limestone.
8. **Write explanatory notes on the following;**
   (a) Toughness of stone, (b) Artificial stones,
   (c) Boulders and conglomerates.
   (d) Kankar, (e) Trap,
   (a) Plain cement concrete (1: 2:4) and (b) Reinforced cement concrete (1: 2: 3) with 0.5 percent reinforcement.
   Ans. (a) Cement = 21.5 eft. = 17 bags (approx.)

Sand = 43.0 eft

Brick whoa = 85.5 cut

(b) Cement = 25 cut = 20 bags

Sand = 50 eft

Brick whoa = 75 eft

Steel = 0.5 eft = 245 lb (1 eft steel = 490)

CHAPTER-THREE

BRICKS

3. Definition: A brick is an artificial kind of stone made of clay whose chief characteristics are a plasticity when wet and stone like hardness after being heated to high temperature.

3.2 Factors that Affect the Quality of Bricks: The following are the factors on which the quality of bricks depends:

1. Chemical properties of the clay used.
2. Preparation of the clay.
3. Process of drying.
4. Different degrees of burning.

3.3 Constituents of Brick Clay and Their Functions:

A good brick-clay should be such a mixture of pure clay and sand that when prepared with water, it can easily be moulded and dried without cracking or warping. It should also contain alumina, (aluminum oxide) lime, iron oxide add magnesia (magnesium oxide). Chemical analysis of a good brick-clay should give the following chemical

Silica	55%
Alumina	30%
Iron oxide	8%
Magnesia	5%
Lime	1%
Organic matters	1%
	100%

Silica: Silica exists in all clays in a state of chemical combination with alumina forming silicate of alumina and sometimes exists in a free state when it is called flint or sand. The presence of sand prevents cracking, shrinking, and warping. The higher the proportion of sand, the more shapely and uniform in texture shall be the brick. But too much of sand makes the brick brittle and weak.

Alumina (Aluminum Oxide): The is the principal constituent of brick clay. It imparts plasticity to clay which is very essential for the purpose of moulding. It also imparts density. But the clay containing too much alumina should not be used decease bricks will crack and warp buring brying and becomes very hard under the influence of heat.

Iron Oxide: The presence of iron oxide in clay enhances the impermeable and durable qualities Iron and lime in small quantities give creamy colour to bricks the colour of bricks is very much dependent upon the contents of iron and the colour ranges from light yellow to orange and red. The colour gradually depend to red and then purple as the iron content goes up 8%. By adjusting the burning temperature, red colour due to iron oxide or back colour due to presence of manganese can be produced Magnesia in presence of iron makes the brick yellow.

Magnesia (Magnesium Oxide): Presence of magnesia in small quantity decreases shrinkage and gives yellow tint.

Lime. It reduces shrinkage of bricks during drying and enables the silica to melt in burning and thus binds the particles of brick together. In excess, however, it will cause the brick to fuse too readily and the shape will be lost. Lime should be present in a very finely divided state. Because, if present in the form of lumps it is very injurious to bricks,

because on buring it becomes quick lime and absorbs moisture causing disintegration.

Alkalies and Organic Matter: A small quantity of organic matter will assist burning bricks, Excess in bad, because if it is no completely burnt, the bricks will be porous. Small quantity of alkalies will lower the fusion point of clay.

3.4 Harmful constituents of Brick-Clay:

Iron Pyrites: Presence of pyrites cause crystallization and disintegration of bricks on burning.

Alkalies: They are mainly the chlorides and sulfates of calcium, magnesium, sodium and potassium. They produce a dark greenish hue on the surface of bricks on drying. They cause the bricks to fuse, twist, and warp during. Alkalies in bricks absorb moisture from and on drying cause efflorescence.

Stone Particles: Small particles of stones do not allow the clay to be mixed thoroughly and uniformly. These are harmful to the uniformity of brick-texture. These make bricks porous and weak.

Vegetation and Organic Matter: They make the bricks porous and weak because vegetations and organic matter get burnt during the burning of bricks leaving small pores in them.

Lime: Lime if present in excess causes the brick to fuse too readily and the shape is lost. Lime in the form of limestone and kankar nodules is very harmful and cause serious trouble to Bricks. Because due to high heating, limestone ($CaCO_3$), is converted into lime (Cao), and carbon-dioxide (CO_2). 0" contact with water, lime gets hydrated and swells and causes the bricks to split and crumble to pieces Limestone in the form of kankar nodules should not be present because it deteriorates the quality of a good brick.

3.5 Manufacturing of Bricks: The following are the different steps manufacturing bricks.

Selection of Brick- Clay: Brick-clay should be free from harmful constituents. The sedimentary deposits of clay are Bricks generally quite suitable for the manufacture of bricks. It is necessary that a few sample bricks should be made first and the suitability of the clay is judged from the product. The proportion of different constituents of clay could then be adjusted. To manufacture bricks on a large scale and analysis of the clay constituents is to be made to determine their best proportions.

Preparation of Brick-Clay: First selection is made where from the brick-clay is to be excavated and this earth is excavated before the rains and spread out or the ground for sometimes. This process is termed as weathering and has an important effect on the plasticity and strength of the clays. The clay should be kept moist during the period it is weathered. About 100 cu. ft of clay is required for manufacturing of 1000 nos. of standard bricks. The quality of brick-clay is to be improved (if there is any deficit of important constituent ingredients) by adding sand lime, alumina and magnesia. This process is known as blending.

The clay is then cut slashed and well worked with spade and is trodden which makes it soft. This process is known as tempering. Water is gradually added when tempering is in progress. The clay is well tempered by kneading it under feet of men and cattle into a stiff condition and thereby the clay is

made homogeneous having uniform consistency, so that it may possess the required plasticity for moulding for large scale manufacturing of bricks. A pug mill is generally used to temper the clay shown in fig. 8.1. This consists of a conical vessel of wrought iron. 5 ft. 6 inch, high, partially (2 ft. 6 inch.) buried underground. It is provided with a central revolving shaft to which are attached horizontal blades. To these horizontal blades, small vertical wedge-shaped steel knives are fixed. Feeding of clay and water is done through the top. The shaft is rotated either by bullocks or by mechanical power. When Tempering is complete, the clay is forced out of an aperture at the base of the mill.

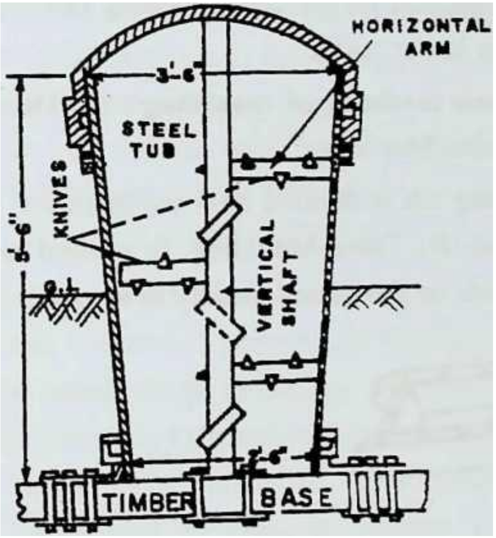


FIG. 3.1 PUG MILL

Brick Moulding: Having prepared the brick-clay as described above the next step is brick moulding. Moulds are rectangular boxes with top or bottom made of any variety of hard wood, sometimes lined with iron or brass where accurate mouling is needed. The edges are protected with thin strip of iron to prevent wearing of the mould. Moulds are sometime made of iron or brass. The mould is generally made for one brick its size being determined by the dimensions of brick required after buring. It is an usual practice to make the internal-dimensions of the mould about 1/10 larger than the size of the burnt bricks to allow for shrinkage on buring. Typical brick-moulds are shown in Fig. 3.2. Generally, identification marks (Frogs and Impression) are left on the face of the brick drying the process of moulding to indicate the name of the manufacture of bricks. This is done by fitting a fillet or projection on the corresponding face of the mould, usually on the lower surface.

There are two methods, of moulding: (1) Hand Moulding and (2) Machine Moulding.

Hand Mouling: It is divided into two methods: (A) Ground Moulding and (B) Table Moulding. In ground moulding the bricks are made on the ground usually in wooden moulds while in case of table moulding, they are made on a table usually with metal moulds. Table moulded bricks are superior to ground moulded bricks because of the regularity of the level and shape and also because sharp corners are obtained in table moulded bricks.

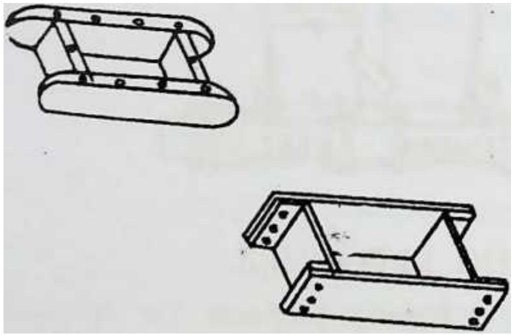


Fig. 3.2

The mould is placed either on the ground made smooth and even or on a table, the tempered brick-clay is rolled up into shape slightly longer and thicket than the required brick. The rolled-up clay is lifted over head with both hands and dashed with force into the mould and pressed by hand very carefully and thoroughly so as to fill the mould completely. The excess earth on the top of the mould is removed by a straight edge of wood or steel, known as strike. The usual dimension of a wood or strike is "12 x 2" x $^1/_8$" and that of a steel strike "12 x 2"x $^1/_8$" " A thin piece of wood known as pallet board, little larger than the size of the mould, is placed on the top of the mould and the mould with the brick inside is lifted up and put upside down. The mould is then lifted leaving the wet brick on the pallet.

Before the mould is filled with clay above, it is frequently dipped during use in water to prevent the clay sticking to the mould. This is called sloup moulding. Another method to secure some object is to sprinkle fine sand or ashes over and into the mould. This is called sand mouding. Sand mouldling is considered to produce cleaner and sharper bricks.

Machine Moulding: Generally, two types of machines are used namely: (1) The Plastic Clay Machine; and (2) The Dry Clay Machine. The plastic clay machine combines the process of crushing, tempering and moulding. The raw-clay is tipped into a hopper at the top of the machine.

The clay passes between crushing rollers and the crushed clay then passes through a horizontal pugmill. The tempered clay moves on to a mouding box and is forced from the box by reciprocating piston moved by a rack and pinion movement, alternately from either end of the box through two roller dies on to a smooth and greased platform in a continues rectangular bar. The bar as comes over the platform is cut into bricks by wires stretched across a frame shown in Fig. 3.3. The distance between the consecutive wires corresponds to the length of the bricks. The bricks are called wire-cut bricks as they are cut by wires. In this method, uniform size and density of bricks are secured.

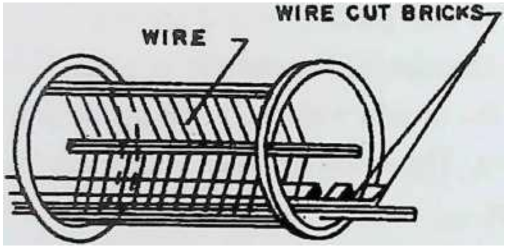


fig. 3.3

In the dry clay machine, stony clay is first ground to powder and mixed with a small proportion of water so as to form stiff plastic paste. This paste is fed through a power-driven press where it is first formed into a rough clot and then shaped accurately. The bricks made by this process are very hard and compact.

Brick Drying; Before burning it is necessary to dry the bricks so that they are sufficiently hard to be. handled and stocked in the burning kiln without any injury. The moulded

bricks are dried by being placed on their, edges for sometimes and then piled in open order in long row and stacks. The length and breadth of the stacks are generally kept equal. This should be carried on a slightly raised platform and the surroundings should be carried on a slightly raised platform and the surroundings should be sanded to keep it dry in wet weather. To protect the bricks from the rain, they should be covered with some sort of thatched roof. In Bangladesh brick-moulding is generally suspended during the monsoons. Brick- drying generally takes 5 to 12 days depending upon the local climatic conditions. In case of machine-made bricks, drying is performed by circulating hot air or gases around the bricks. Great care should be taken in this system of drying because rapid drying may develop cracks in the bricks.

Brick Brurning: When drying is complete, the bricks are burnt for the following purposes:

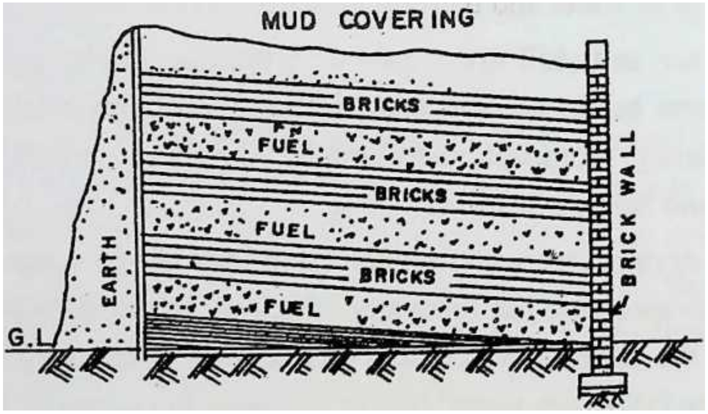
1. To impart hardness and strength to bricks.

2. To increase the density of bricks to make them less absorbent to water and thereby increasing durability.

Great care and skill are required in burning bricks because under burnt bricks are soft and useless. Well burnt bricks are hard, strong, compact and durable. Overburnt bricks will vitrify and hence not sound.

During drying, free water contained in the clay gets removed due to evaporation but the water which incorporated with the clay in the form of water of crystallization is removed only when the bricks are burnt. Bricks are burnt in clamps or kilns where the temperature is raised to about 2100 F. At a temperature of about 1200°F, the organic master present in the bricks is oxidized and disappears. When the temperature raised to about 2100°F, certain chemical changes take place in its constituent minerals, giving new properties to the bricks. Particles of alumina and sand bind themselves together and that increases the density and strength of the bricks. Fusible glass in small quantity is produced by burning of alumina and sand grains. But when heated beyond 2100°F, the fusible glass is formed in a much greater quantity and the bricks are said to be vitrified. Vitrification softens the bricks are said to be vitrified. Vitrification softens the bricks and they begin to lose their shape. Therefore, vitrification must be controlled so as to be just sufficient to impart the required density' and strength. Bricks are burnt in clamps (Pazawha) or in kilns.

Clamp or Pazawah Burning: In clamps, bricks and fuels (grass, cow dung, wood-chips, rice-husks, jute-sticks etc.) are placed in alternate layers, shown in Fig. 3.4 and the whole male mass is plastered over with mud on the external surface.



SLOPING FLOOR OVER ONE BRICK FLAT

Fig. 3.4

The clamps are formed on the sloping ground measuring about 30' x 40'. "The height is generally 8' to 12". In the first course, a layer of fuel is laid about 2".6" thick. Bricks are laid in alternate layers. The upper surface is kept sloping at an angle of about 30° in the direction of its length. The clamp is fired from below. During burning the violent outburst of flames is noticed and earth is thrown on to suppress it. When fireing is completed, the clamp is left to bum itself out thoroughly and completely. The burning of bricks by this method is very slow. In a large of bricks can be burnt in about month. In this method, bricks are not uniformly burnt. Nowadays, this method, has become obsolete and is used in rural areas where the quantity required is small and the quality also not of a high standard.

Kiln Burning: Kiln burning is preferred when bricks are required to be manufactured in large quantities. The kiln consists of a regular walled structure with proper arrangements for healing and the bricks are arranged in regular stacks. A good kiln should supply the maximum number of well burnt high class brick with less consumption of fuels (powdered coals). There are various types of kilns, the most common ones that are generally used in our country' have been shown in Fig 3.5 and Fig 3.6.

Hoffman's Kiln: It is circular in plan and consists of an annular chamber by brick partitions with small opening into twelve or more compartment each of which is connected by a flue to a central chimney. Each compartment is also provided with a door-opening outward for loading and unloading bricks. When the compartments are in use, the doorway is closed by dry bricks and sand, and the joints are closed by mud filling. Holes are provided on the top of each compartment, and through these holes, fuel (powdered coal) is dropped.

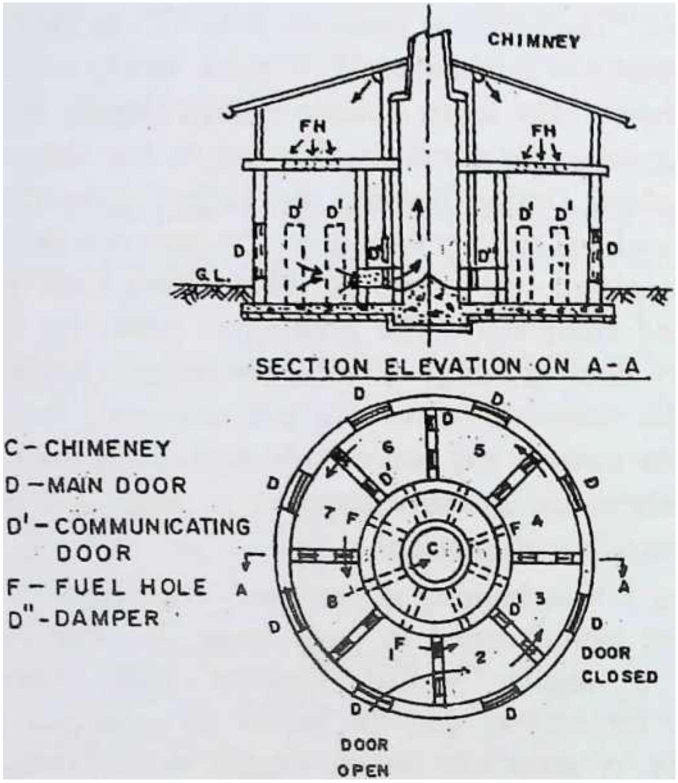


Fig. 3.5

At any particular time, each compartment of the kiln has a specific function to perform. In Fig. 3.5, compartment no. 1 is being filled up with unburnt bricks, compartment no. 2 contains burnt bricks which have cooled and are being unloaded, compartments nos. 3 and 4 contain bricks already burnt that are being cooled down, compartment nos. 5 and 6 contain bricks which are being supplied with, fuels and compartment no’s 7 and 8 contain bricks which are being dried and preheated. Due to continuity in operation form the loading of the new bricks, this type of kiln is also termed as continuous kiln. The kiln, shown in Fig. 3.5 has got 8

compartments. Depending upon the output desired, continues kiln may have 12, 16 or 20 compartments’

Generally cool air enters through the open door of the compartment nos. 1 and 2, passes through the cooling compartment nos. 3 and 4 them enters into a heated condition in the burning compartment nos. 5 and 6 and finally the hot flue gases enter compartment no’s, 7 to 8.

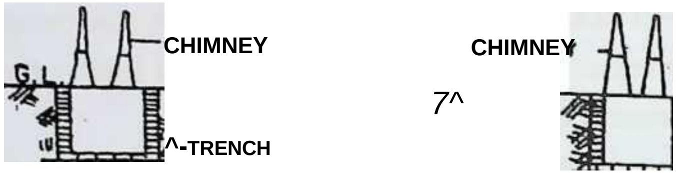
In a moderately sized kiln, each compartment, if made about 36 ft. long, 15 ft. mean width an 8 ft. high, will hold 25,000 bricks and 8x25.000=2,00,000 bricks may, therefore, be burnt in 12 days. Such a kiln will, therefore, bum approximately 60 lakhs of bricks annually.

ADVANTAGES AND DISADVANTAGES OF HOFFMAN'S KILN:

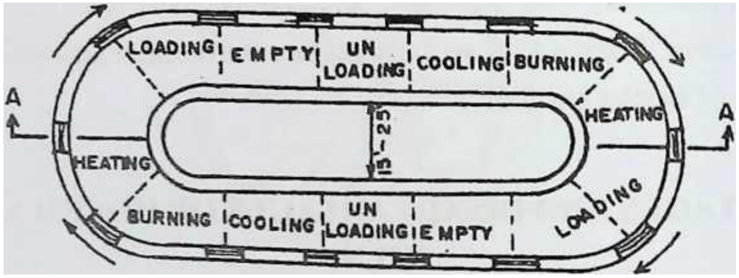
Advantages: (1) Economy of fuel; (2) Uniform burning of bricks, (3) Regulation of heat, (4) Preheating of unburnt bricks (5) Higher percentage of good bricks (6) Regularity of supply (7) No smoke as the combustion of the fuel is.

Disadvantages: Only one that is the high initial cost of - construction.

Trench or Tunnel Kiln: This type of kiln is continuous in operation, consists of a tunnel of generally 200 ft. long 18 to 24 ft. wide and 6 to 8 ft. deep, rectangular, circular or oval in plan. Of course, the length of the kiln depends upon the site available and the number of bricks to be manufactured. The most common shape of the kiln is an oval one with semicircular ends to save space, but in this case irregularity of boring bricks result as firing approaches or leaves the semicircular ends. A typical oval shaped kiln with semicircular ends is shown in Fig. 3.6. Uniformity in burning o is generally results in a circular section and the second best in the rectangular section.



SECTIONAL ELEVATION ON A-A



PLAN

Fig: 3.6

It is made in a trench excavated below ground and lined with masonry walls. A number of openings are built around the outer walls. A number of openings are built around the outer wall of the kiln and movable iron chimneys are placed over the opening (generally 2’ 6” x 1 x 7”) at about 12 ft. apart and the coal pits lie between them. These chimney openings are connected to the trench by two arched opening for draught. Sometimes, permanent, chimneys are built over these openings but for economy, movable chimneys on four wheels can be used by easily moving them along the kiln. In some cases, chimney, openings are provided in the inner wall as well but in others, chimneys are placed over the arranged bricks in the kiln and in the case no hole is to be provided in the walls. Dampers or iron plates are placed by the side of these openings. The space between two dampers in the trench is called a section. Each section of a trench 18 ft. wide contains 10.000 bricks which require 58 cu ft. of coal of burn. Roughly. 6 mounds (692 lbs.) of coal are required per 1000 bricks. The fig. 3.6 shows an oval trench kiln in which loading drying, burning, cooling and unloading take place in two stages. Two chimneys and two batches of workers are required for its operation. The arrows on the plan indicated the direction of movement of chimneys. One section is loaded first, and then covered with earth on top to prevent the escape of heat. When one section is being burnt, its hot gases pass on to the next section to warm up the bricks already slacked in the second section before passing out through the chimneys. When first section is burnt and the fire has advanced to the next, all the flue holes of the first are closed and it is allowed to cool down gradually. When fire has advanced through a number of sections from one side, the first section cools sufficiently and is unloaded and reloaded with dry raw bricks which in their turn are warmed up first with the hot gases of the last section and then burnt up by the advancing fire going round the kiln. Thus, the kiln works continuously admitting loading, drying, burning, cooling and unloading to go on simultaneously in different sections. The average output of this type of kiln is as follows;

1st class bricks 60%

2nsd class bricks 15 %

3rd class bricks 10%

Picked Jhama *5%*

Jhama bats *5%*

Bricks bat 5%

The smallest size kiln of 20 chambers of sections 18' x j? with one chimney will turn out about. 10,000 bricks daily large size kiln of 24 to 40 chambers worked by two chimneys will be much economical to operate and also cheaper in construction.

A trench kiln generally takes 36 to 40 hours for burning and 10 to 12 days for cooling.

In Bangladesh, most of the brick manufactures prefer this type of brick burning because of the following reasons: (1) Economy in construction; (2) Net affected by wind and moderate rain as it is constructed below ground level and covered with earth on top: (3) Short period of burning: (4) Better quality of bricks.

3.6 Characteristics of Good Bricks:

1. Bricks should be uniform in colour, size and shape.
2. They should be sound and compact.
3. They should be free from cracks and other flaws such as air bubbles; stone nodules etc.
4. They should not absorb more than 1/5 of their own wt. of water when immerged in water for 24hours (15 to 20% dry wt.,).
5. The compressive strength of bricks should be in the range of 5,000 to 8,000 psi.
6. The percentage of soluble salts (sulphates of calcium, magnesium, sodium and potassium) should not exceed 2.5% in burnt bricks, because the presence of excess soluble salts causes efflorescence.

7. They should be neither overburnt or under burnt.
8. They weight should be generally 6 lbs. per brick and the weight per cu ft should not be less than 125 lbs.
9. They should have low thermal conductivity as it is desirable than the buildings built of them should be cool in summer and warm in winter.
10. They should be non-inflammable and incombustible.
11. Bricks should not change in volume when wetted.

3.7 Field Tests of Bricks: The following are the test that are generally performed in the field to determine the quality of good bricks:

1. Take a brick and try to make mark on the surface by nil. If you can make it. it is not, a good brick, if not. it is very hard and compact.
2. Take a brick and strike it with a hammer. If it gives clear ringing or metallic sound, it is a good brick, if not a bad one.
3. Take two bricks and form a tee (T) and drop from a height ■ of 6 ft on a more or less solid surface. If they break, they are not good bricks. If they remain unbroken, they are good bricks.

3.8 Size of Bricks: In Bangladesh, according to P.W.D. specification, each brick should measure **9$^{1}/_{4}$" x 9 $^{1}/_{2}$" x 2$^{3}/_{4}$"** This is the standard size of bricks in our country. There are other sized bricks also. But this size is most economical. Because when bricks are put in any construction with the size becomes 10 "x 5" x 3" (approximately). The size of walls which are constructed by bricks in our country 3", 5", 10", 15", 20". 25” and 30" So 'his size of bricks 21 used safely Without any breakage. Hence, this standard size is most economical in engineering constructions in our **$9^{1}/_{4}$" x 9 $^{1}/_{2}$" x $2^{3}/_{4}$"** country.

3.9 Classification of Bricks: The following is the classification of bricks by PWD in our country.

1. First Class Bricks: They should be of uniform size; and colour, thoroughly and evenly burnt. They should ring clearly when struck. With a hammer or another brick. They should be well shaped with even surfaces and without cracks, rain spots or flaws of any kind. They should not absorb more than one sixth of their weight of water when wet in water for 24 hours.
2. **Second Class Bricks:** These bricks must possess the hardness and colour of first-class bricks but are slightly irregular in shape: size or rough on the surface.
3. **Third Class Bricks:** These are bricks which are not sufficiently well-burnt sufficiently and of uniform shape and size for use in unimportant constructions.
4. **First Class Bats:** These are broken bricks of the same quality as first and second-class bricks.
5. **Second Class Bats:** These are broken bricks of the same quality as third-class bricks.

«• **Picked Jhama Bricks:** These bricks are uniformly vitrified throughout, but must be of good shape heavy and of selected quality. They must not be spongy.

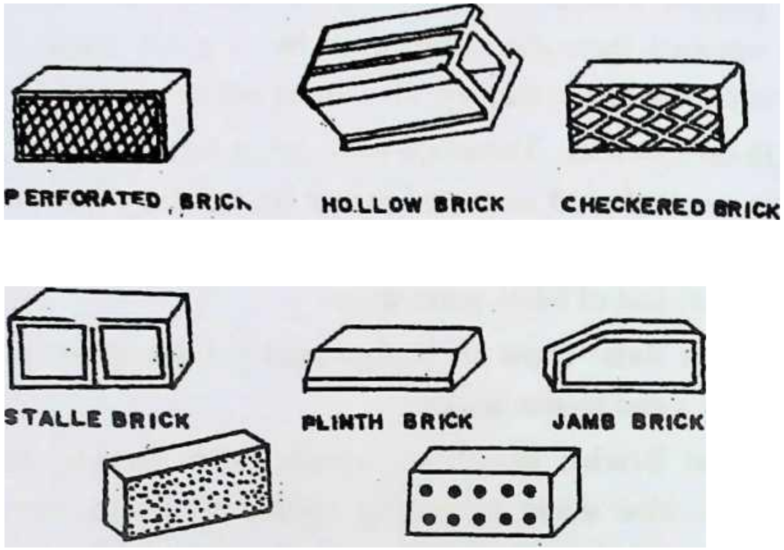
7. **Jhama Bricks:** These are well- burnt bricks but not quite so well-shaped as picked jhama bricks. They must not be spongy and must be free from cinders and projecting lumes and of fairly good shape.
8. **Jhama Bats:** These are broken bricks of the classes picked jhama and jhama bricks.

3.10 Special Bricks: Bricks are usually made rectangular but they are also made in various special forms to meet the different situation where they are used also to suit to the taste of the users. Such bricks are called purpose-made bricks and are more costly than ordinary bricks. These are:

(1) Perforated bricks used in building walls: (2) Hollow bricks used in hollow walls in building; (3) Checkered bricks, used in bricks masonry; (4) Stable bricks (with grooved Pannels); (5) Plinth bricks, (6) Jam bricks-bricks chamfered and rounded to the desired shape at one corner; (7) Klinker (paving brick) for internal flooring. In addition to these, there are other varieties of special bricks. They are mainly used for decorative and ornamental purposes.

The Mirpur Ceramic works in Dhaka manufactures various types of special bricks. A few special bricks are shown in Fig.

3.7



KLINKER (PAVING)BRICK HOLED BRICK

Fig- 3.7

3.11 Uses of Bricks:

1. Construction of walls of any size.
2. Construction of floors.
3. Construction of arches and cornices.
4. Making khoa (broken bricks of required size) to use as an aggregate in concrete.
5. Manufacture of surki (powdered bricks) to be used in lime piaster and lime concrete.

3.13 Brick Works: The following are the different types of brick works:

1. First Class Brick-work: This consists of first-class bricks in lime or cement mortar. All the material required should be of first-class quality.
2. Second Class Brick-work: This consist of second-class bricks laid in lime or cement mortar.
3. Third Class Brick-work: This consists of third-class bricks in mud mortar.

For 100 cft, of brickworks 1200 no’s, bricks and 45 cft, of mortar are required 830 bricks will make 100 eft, of khoa for concrete.

Questions

1. Discuss the factors that are to be considered in selecting raw materials for manufacturing good bricks.
2. Name the factors that affect the quality of good bricks. Give the constituents of a good brick clay and state their functions.
3. What are the harmful constituents of brick clay?

   Explain why they are termed harmful?
4. Name the different steps in the manufacturing process of bricks.
5. Discuss the principal aspects of burning bricks.

   (a) Draw the plan in oval and elevation of a teach kiln.

   Explain also its working principle.

   (b) If a daily production of 3 lacs of bricks is required, what should be size of the kiln? What will be the amount of c dust that will be required per day?

7. What is the standard size of bricks in our country? Do you think that the existing size is economical? Justify your answer.
8. Give the characteristics of good bricks. What is the test that are carried out in the field to determine the quality of good bricks?
9. Supply the classification of bricks with proper specification.
10. Write explanatory notes on the following:
    (a) Pug Mill, (b) Machine moulding (c) Brick drying
    (d) Pazawah (e) Hoffman's kiln (f) Brick works.
11. What is the function of special bricks? Give neat (sketches of the different types of special bricks that are commonly used in Bangladesh.

CHAPTER-FOUR

TILES

Tiles

4.1Introductory: Tiles are than slabs made of clay burnt in kiln. They are used for flooring, walling and drainage purposes. Tiles require more care in manufacture than bricks, as from their greater delicacy they are more liable to deformation. The clay should be much stronger than that used for bricks. The manufacturing process is same as that of bricks.

4.2 Classification: The following are the various types of tiles according to the purpose they serve:

1. Roofing Tiles: There are various types of roofing tiles of which plain tiles, pot tiles and pan tiles are most common in use.

Plain Tiles: They are handmade tiles from clay. They are glazed to prevent the absorption of water. They are provided with two small projections beneath the top edge to facilitate fixing against roof battens (Fig. 4. 1).

Pot tiles: They are made by hand on a potter's wheel. They are hollow, half round and tapering in shape. The length varies from 10" to 12" on and the diameter is generally kept 6" on one side and 5" on the other side. The thickness is generally **^{3}/8"**. On the wheel, the tile is first made into a tapering tube just before taking the tile off the wheel the potter makes two vertical cuts, one at each end of the diameter. These cuts are intended to assist in easily the tube into two pot tiles after the tube has been burnt (Fig.4.2).

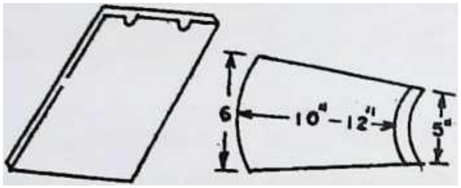


Fig. 4.1 PLAIN TILE FIC. 4.2 POT TILE

Pan Tiles: Pan tile is similar to the pot tile. In shape and differs from it only in being shorter, heavier and less curved and having equal width at both ends. They are first moulded flat, then curved and are provided with a small projection beneath their top edge which rests against horizontal battens and prevents the tile from sliding down the slope of the roof (Fig. 4. 0).

Flat Tiles: They vary in size from 6"X6"X $^{1}/_{2}$" to 8"X8" X $^{1}/_{2}$" • The larger variety called paving tile is used on floors while tiles. Fig. 4.4 shows a typical flat tile.

Ridge Tiles: This is meant to serve a specific purpose in roofing shown in fig. 4. 5.

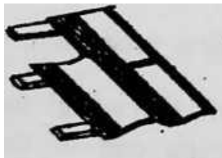


Fig: 4.3 PAN TILES

Fig: 4.4 FLAT TILE

Fig: 4.5 RIDGE TILE

Concrete Tiles: They are made in various shapes and shades from L3 (1 part cement and 3 parts sand) cement mortar with powdered coloring ingredient. They are used very commonly in the form of precast thin slabs.

3. **Flooring Tiles:** The size of the flooring tiles varies from 6" square up to 12" square and the thickness ranges from $^{1}/_{2}$" to 3" they are made exactly like flat tiles. They may be of concrete or mosaic.

4. **Wall Tiles:** The size is generally 6"X6"X$^{1}/_{2}$". They are mainly used in bathrooms and latrines.

5. **Drain Tiles:** They are used for drainage purposes. They are manufactured circular. V or (U shaped and in lengths of 2 to 4 ft each. The clay should be of best variety, perfectly homogeneous and of uniform semi-stiff consistency to admit of hollow moulding.

6. **Sewer or Water Pipes:** They are made from highly silicious clays contain about 75% of silica and 22% alumina.

4.3 Characteristics Of Good Tiles: The tiles should be of regular desired shape and size, free from twist, cracks, flaws and bends. They should be of well burnt and of uniform colour. They should be compact, hard and sound.

4.4 Glazing of tiles And Its Purposes: The surface of tiles is sometimes glazed for the protection of the surface from the action of the atmospheric destroying agents and sometimes for beautiful appearance.

A glaze is a mixture of glass forming materials of special compositions like lead silicate, titanium, zirconium oxides etc. They are ground to a very fine powder and give colorless glazes, other metallic oxides such as iron oxide for red and brown, iron oxide with tittle time for cream and yellow, copper oxide for green, cobalt oxide for blue colour etc. The process of applying the glaze on tiles is known as glazing.

The glazing is applied to the surface of clay-wares for improving the appearance, for producing decorative effect of 'the desired colors and design, for making them nonabsorbent, for imparting durability, for protecting them from the destroying effects of atmospheric agents. In case of sewers, glazing is applied to save them from the corrosive action of sewage and sewage gases and also to provide smooth surface.

Questions:

1. What is a tile? Discuss the different types of tiles with neat sketches wherever possible.
2. Give the characteristics of good tiles. Name the different uses of tiles.
3. What is glazing? Explain its functions over tiles.

CHAPTER-FIVE

REFRACTORIES_AND_OTHER_CERAMICS

5.1 Definition: Refractories are constructional materials which must perform their duties at high temperature. Hence, they must have a high fusion point. The clay which is used for manufacturing refractories and refractory linings is called fire clay. This type of clay can resist high temperature without melting or becoming soft.

5.2 Uses of Refractories: They are used in building works for setting stones in ovens and fire places. They are used for the manufacture of fire bricks and chimney posts. They are also used as lining of sand melting furnace of glass factor}' and iron-ores melting furnaces in steel plant. Fire bricks are used for the construction of boilers, combustion chambers and chimney flues.

5.3 Composition of Fire Clays: Fire clay should contain a higher percentage of silica and alumina and very small quantity of lime and magnesia, iron oxide and alkalies. Silica (SiO_2) becomes soft at about 2800°F and finally fuses and becomes a glassy substance at about 3200°F. It melts around 3300°F. Due to this high softening and melting point, it is, therefore, used as a principal material in the manufacture of refractories and fire bricks. Alumina ($A1_2O_3$) has still higher softening and fusion temperature. It melts at about J800°F. It is, therefore, used in Combination with silica to manufacture refractories to resist high heat and temperature. But the presence of time magnesia, iron oxide and alkalies act like fluxes to lower the softening and fusion point and temperature. So, silica and alumina are nondetrimental and

Lime, magnesia, iron oxide and alkalies are termed as detrimental in fire clay. The following chart show the approximate compositions of fire clays depending upon the special use.

Silica	60 to 96 percent
Alumina	2 to 36
Lime, magnesia, iron oxide and alkalies	2 to 5

4.5 Manufacture of Refractory Bricks: Fire bricks are manufactured from fire-clay and the different steps in the manufacturing process such as digging, weathering, tempering and moulding of fire bricks are same as those of ordinary bricks but the burning is generally carried out in a superior type of kiln under carefully graduated temperature control.

Varieties of Refractory Bricks: There are mainly three varieties of refractory bricks, namely: (1) Acid Refractories; (2) Basic Refractories and (3) Neutral Refractories.

(1) Acid Refractories: Following are the different types of acid refractories:

(a) Ordinary Fine Bricks: These are made of ordinary natural fire clay with a mixture of crushed flin clay and sand. They provide very good type of acid refractory lining to furnaces. They can resist a high temperature of 1600°C.

(b) Silica Bricks: They contain 95% of silica and are manufactured from sandstones or quartzite with an addition O to 0 of lime to act as a binding material and flux. Silica bricks are quite suitable for acid lining of furnaces such as manufacture of glass and also for the walls and arches of

basic open-hearth steel furnaces and copper melting furnaces. They can resist a high temperature of 2000°C.

(c) Ganister Bricks: They manufactured from the silicious variety of ganister rock containing 85% of silica and 10% clay with an addition of 2% of lime. They are very hard, compact and rigid at a high temperature of 2100°C.

(2) Basic Refractories: The following are the different varieties of basic refractory bricks.

(a) Magnesia Bricks: They are manufactured from fire clay containing 85% of magnesium oxide, 3 to 5% iron oxide and the balance lime and alumina. They can resist a higher temperature of 1800 to 2100°C. They are used for basic lining of furnaces.

(b) Dolomite Bricks: They are manufactured from fire clay containing higher percentage of dolomite. They are cheap substitutes for magnesia bricks in furnace lining. They are weaker refractories but can be made stronger by the use of serpentine. They can resist a temperature of 1400° to 160o°C.

(c) Bauxite Bricks: They are manufactured from fire clay containing 86% of bauxite. They can resist a higher temperature of 1600°C.

(3) Neutral Refractories: They are used for separating the acid and basic linings of furnaces to prevent them reacting together. The following are the different varieties:

Chromite Bricks: They are made from fire clay containing 50% of chrome iron ore, 30% iron oxide (Ferrous oxide) and 20% bauxite with little silica. They can resist a higher temperature 2000°C.

Carborundum: This is a special type of natural refractory bricks. It is made from fire clay containing higher percentage of silicon carbide. It is used in electric furnace. It can resist a high temperature of 1900°C.

5.6 Properties of Good Refractories:

1. They must resist stress developed at high temperature in furnace walls and arches.
2. They must preserve their rigidity at high temperature.
3. Irreversible volume change should not occur at furnace temperature, because shrinkage leads to opening of joints and results in a leaky furnace.
4. They must resist the tendency to crack and spit off fragments when exposed to sudden change of temperature.
5. They must not easily form fusible products with slags.
6. They must not be acted upon by furnace gases.
7. They should weigh about 150 lbs. per cu. ft.
8. They should take a compressive strength of about 20.000 to 30,000 lbs. per sq. inch.
9. They should not absorb more than 6% of water by wt. when kept in water for 24 hrs.

5.7 Laying of Fire Bricks: Fire bricks are laid by a mortar of fire clay but not in lime or cement mortal. Generally, 1.5 to 2 eft of fire clay mortar is required for laying 100 nos of fire • bricks of the standard ordinary bricks size.

8 Terracotta. This is a special type of earthen-ware. **It** is used as a substitute for stone in the ornamental parts of buildings

such as cornices bases and capital of pillars and other ornamental works.

A good terracotta clay should contain 73% of silica, 10% alumina. 3% iron oxides 1% lime. 7% organic matter. 0.3% alkalies. 0.2% magnesia and 5.5% water.

Terracotta is manufactured in the same way as ordinary bricks are made. It should not show any sign of shrinkage and should be hard, compact and impervious to water. Usually, terracotta blocks are 12' to 20' long. 6 to 15’ high and 4.5 to 9” thick on the bed. They can be given any desired colour by the help of some coloring ingredients. The main advantages of terracotta are that it is very strong, hard and durable.

Terracotta which is burnt twice in the kiln is called ’Faince', It is stronger and harder ordinary terracotta and hence, durable.

5.9 Earthenware’s: They are made from ordinary clay, similar to that used for bricks, and is burnt at a comparatively low temperature. Earthenware’s are very weak and porous. They comprise the bulk of most pottery and table wares like toys, ash toys, flower vases etc. They are always given a glaze to look beautiful.

5.10 Stoneware: This is employed when chemical resistance and impermeability are required. It is largely used in sanitary wares (Basins, sewer pipes, glazed tiles for bath and latrines) and is chemical engineering. This is manufactured from the clay containing 76% of silica, 214% alumina and very small quantity of other ingredients. It is always glazed.

O)

5.11 Porcelain: This is a whiteware which is so highly vitrified that it is translucent in sections. This is manufactured from kaolin, a special variety of clay containing high percentage of silica and alumina. It is used for variety of purposes such as tableware, insulators, electric furnaces, resistor tubes, reactor chambers, crockeries.

5.12 Porous Ware: This is a light-weight cellular clay product used for sound proofing and thermal insulations.

Exercise

1. What are refractories? Enumerate their engineering application.

2. What is fire clay? Explain its constituents and point the importance of each.

3. Give the properties of good refractories.

CHAPTER-SIX
LIME

6.1 Introductory: Lime is a more or less impure calcium oxide (CaO) and obtained by the alcination (heating of shells corals, limestones, kankar and other substances. Composed of almost pure or impure calcium carbonate ($CaCO_3$). Lime acts as a binding or cementing material in engineering constructions.

6.2 Uses of Limes: Lime is used for the following purposes.

1. White washing.
2. Lime punning.
3. Making mortar (Lime mortar and surki mortar).
4. Making concrete (lime concrete).
5. Manufacturing cement.

6.3 Technical Terms: To understand the manufacturing process of lime, the following technical terms are to be understood thoroughly.

Calcination: This is the heating of limestone to redness (1500°C) in air.

Quick Lime or Caustic lime: This is the lime immediately, after calcination of limestone.

Slaking: When water is poured on quick lime it gives rise to heat due to certain chemical reactions and this process is termed as slacked or hydration.

Slaked Lime: The substance left slaking of quick lime is called slaked lime or hydrate of lime.

Setting (Hardening): When lime is mixed with water to form a paste it hardens and this process is called setting or hardening of lime.

Hydraulicity: This is the property of the lime for setting under water.

6.4 Constituents of Limestones: Limestones exist in nature either as pure or impure calcium carbonate. The following are the main constituents:

Calcium oxide: This is the principal constituent of limestone. It acts as a binder.

Clay: Clay in small quantity retards slaking and in large proportion arrests slaking. It causes setting of lime and renders it insoluble in water. It should, therefore, be proportioned properly with the remaining constituents. Generally, 5 to 10% of clay presence in limestone is recommended because with this the lime will make excellent mortar.

Silica and Alumina: They impart hydraulicity in lime.

Magnesium Carbonate: It slakes lime more slowly, evolves less heat, expands less, set more slowly but finally gains greater strength.

Alkalies and Metallic oxides: They impart hydraulicity in lime. Sulphates: Small quantity of sulphates retards the slaking action and increases the rapidity of setting.

Iron Pyrites: Presence of iron pyrites is highly objectionable as they reduce the strength of lime.

6.5 Classification of Limes: These are mainly three types of limes. They are:

(1) Fat lime. (2) Hydraulic lime and (3) Natural cement.

(1) Fat Lime: This also known as High Calcium Lime. This is a purer type of lime and is so called because it swells two to three times it volume when slakes. Fat lime is obtained by calcination of nearly pure limestone, chalk and sea shells. It is nearly white and free from other substance to produce any major effect upon either the staking or setting action. It does not set under water but dissolves.

Fat lime is generally used for finishing coat in plastering, white washing and lime punning.

(2)Hydraulic Lime: It possesses the property of setting and hardening under water. This is obtained from kankar or clayer limestone. It is hot white because It contains impurities of clay and magnesium carbonate.

This is used for masonry in foundations and for thick walls. It is also used for mortar for masonry work in superstructure of buildings and plastering.

(3) Natural Cements: These are hydraulic binding material almost similar to hydraulic limestone but containing a higher percentage of clayey matter (40%). These natural stones are the complication the products exhibit a high value of hydraulicity.

The following table (TABLES 6.1) shows the composite ions of limestones for producing different varies of limes.

Table 6/1 Composition of Limestone for Different Type of Limes

Principal Ingredient:	Percentage composition Quality of Limestone		
	Fat Lime	Hydraulic Lime	Natural Cement
Calcium oxide	96	45 to 65	30 to 35
Magnesium oxide	1 to 2	30 to 40	10 to 15
Aluminum oxide	Little or Nil	2 to 5	5 to 10
Silica	2	20 to 30	20 to 35
Iron oxide	Little or Nil	2 to 5	about 5
Others Impurities	Little or Nil	1 105	upto 2

6.6 Tests on Limestones: For the manufacture of lime and cement, engineers are to carry out some tests on limestones, the tests are discussed below:

1. **Physical Tests:** The sample of limestone showing a slightly earthy surface indicates the presence of clay and will be x suitable for producing hydraulic lime. White colour indicates a pure limestone.
2. **Chemical Test:** The following are the different chemical tests that are generally performed on limestone.

   (a) **Heat Test:** Weigh a piece to dry limestone. Heat it to redness in an open fire for about six hours. Since the bond

between calcium oxide and carbon dioxide in limestone is very weak the following reaction will take place:

Limestone + Heat = Lime + Carbon-dioxide

$(CaCO_3)$ (CaO) (CO_2).

Allow the product to cool and weight again. From the loss of weight, the amount of calcium carbonate in the specimen can be determine. For every loss in weight of 44 parts, there is 56 parts of lime by weight. This is adopted if the sample does not contain magnesium carbonate. Clayey and silicious impurities required higher temperature to drive out carbon dioxide and this indicates the extent to which the lime is hydraulic.

Example: An one pound sample of limestone was heated in a lime-kiln at a temperature of 1500°C. After heating the sample weighed 0.325 lbs. Calculate percentage of quick lime that will be available from this sample.

Solution:

Loss of wt due, to heating = 1,00 - 0.825 = 0.675 lbs.

Percentage of quick lime = ((0.675x 56) / 44)) x 100= 86%

Slaking Test: Quick lime is an anhydrous product of calcination or heating. When water is added to it, the following reaction takes place.

Quick Lime + Water = Hydrated Lime (6.2)

(CaO) (H_2O) $[Ca(OH_2l)]$

During the process of hydration, heat is given out the energy thus liberated is often enough to split it and to make it crumble to powder. A vigorous slacking indicates high calcium content in the sample i.e., fat lime, while with hydraulic limes, the slacking action is very slow.

Again, sufficient water is added and if the sample sets under water, it is hydraulic lime, if not, fat lime.

From this test, it is possible to determine whether or not a particular sample of limestone will yield ft lime or hydraulic lime.

(b) **Acid Test:** This test is carried out for two purposes which are discussed below:

(i) To determine the presence of calcium carbonate in a given sample of limestone: Dilute hydrochloric acid is added to the specimen. This will cause effervescence with the liberation of carbon dioxide and formation of calcium chloride. The reaction is as follows:

Hydrochloric Calcium

Limestone x Acid= Chloride + Carbon - dioxide + H2O

$(CaCO_3)$ $(2HC1)$ $(CaCl_2) + CO_2 + H_2O)$

Effervescence will be vigor if the presence of calcium carbonate Content of the sample is very high and thereby the residue will be less. If the effervescence is not vigorous, calcium carbonate content is less and the residue will be more.

(ii) To determine the rough composition of limestones: Powder a sample of limestone and dry it gently to remove moisture, weight its Let the weight be W gms put the powdered sample in a number and add dilute hydrochloric

acid gradually. Stir and sand hydrochloric acid until effervescence ceases. Strain the content through filter paper. Carefully dry the residue on the filter paper and weight it. Let the wt. be Wigms. Then (W-W,) will be the weight of calcium carbonate in the sample. To separate the clay from sand in the residue, stir up the residue with water, the sand being heavier will settle at the bottom, while the clay particles will be in suspension. Decant the water.

Dry the sand and weigh it. Let the wt. be W_2 gms. Then $(W_1 - W_2)$ will be the wt. of the clay.

Example: The initial wt. of a sample of powder limestone is 445.45 gms and the wt. of the dried resiue on filter paper is 120.23 gms. The residue after decantation and drying weighed 68.42 grams. Calculate the percentage of carbonate sand and clay present in the sample of limestone.

Solution: Here W = 445.45 gms. W1 = 120.23 gms. W_2 = 68.42 gms. Wt. of calcium carbonate=W-Wj=445.45-120.23=325.22 gms. Percentage of calcium carbonate

$$\frac{325.22}{445.45} \times 100 = 73\%$$

Clay = 120.23 - 68.42 = 5 1.81. gms

Percentage of clay = (325.22/445.45) x 100= 73%

Percentage of sand = 100 -(73+12) = 15%

hemical Analysis: of **Limestones:** It is very rare that the engineers are called upon to carry our detailed chemical that the engineers are called upon to carry out detailed chemical test on limestones but the selection of limestones will not be proper if the following important things are not known to the engineers. By detailed and routine chemical tests, the correct values of five principal components of limestone (calcium oxide, magnesia, alumina, silica, and iron oxides) must be known to determine the following:

Hydraulic Index or Ratio =

$$\frac{\text{Silica + Alumina + Oxides of Iron}}{\text{Lime + Magnesia}}$$

It may be noted from the above equation that there is a possibility of getting the same ratio though the percentage of the ingredients change in themselves. This indicates that two different samples will have the same value of the ratio.

Cementation Index =

$$\frac{\text{2.8 Silica +1.1 Alumina + 0.7 Oxides of Iron}}{\text{Lime +1.4 Magnesia.}}$$

The hydraulicity of limestone is always expressed on the basis of hydraulic index and cementation index. The following table 6.2 shows the hydraulic values of different types.,

Table 6.2

Hydraulic Values of Different Type of Hydraulic Limes

Quality of Lime	Hydraulic Index	Cementation
Feebly Hydraulic Lime	0. 1 to 0.2	0.2 to 0.4
Moderately Hydraulic Lime	0.2 to 0.3	0.4 to 0.6
Eminently Hydraulic Lime	0.3 to 0.4	0.6 to 1

Example: The chemical analysis of a sample of limestone gave the following results.

Calcium oxide	= 70%
Silica	= .20%
Alumina	= 6%
Magnesia	= 1.5%
Iron Oxides	= 2.5%

Determine the hydraulic index and cementation index and also write what type of hydraulic lime it is?

Solution: Hydraulic Index = $\frac{20-6 + 2.5}{70 + 1.5} = \frac{28\ 5}{71.5}$ 0.399

Cementation Index = $\frac{2.8 \text{ X } 20 + 1.1 \text{ x } 6 + 0.7 \text{ x } 2.5}{70 + 1.4 \text{ x } 1.5}$

$$= \frac{64.35}{72.10} = 0.892$$

This is eminently hydraulic lime.

Manufacture of limes: The principal stages involved in the manufacture of lime are: (1) Pre-heating (2) Calcination or Burning and (3) Hydration or Slaking.

Pre-Heating: Limestones are heated in a closed container to remove moisture present in them. This is generally done at temperature of about 600° F.

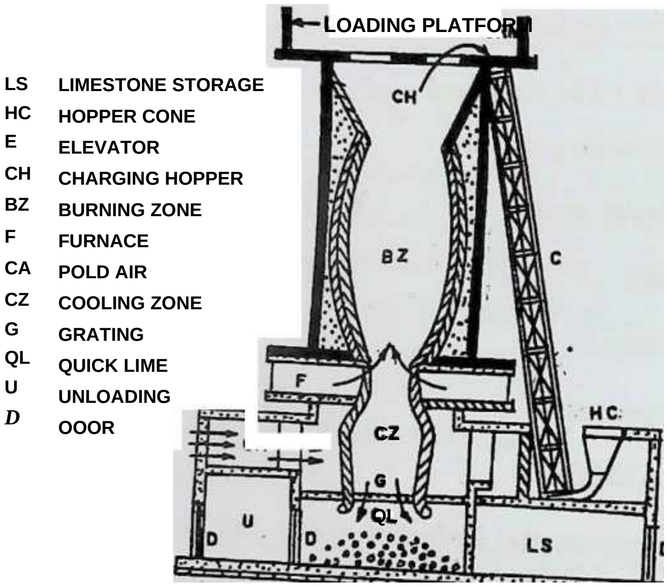


Fig: 6.1 MODERN CONTINUOUS LIME KILN

Calcination or Burning: Limestone is burnt in clamps or in kiln and the process of burning is called the calcination of lime. Kiln burning is generally adopted in every country because it economies the fuel. Fuel used for calcination is generally coal, coal ashes or firewood. There are various types

of lime kilns, the most widely used one has been shown in Fig 6.1. Due to its continuity in operation, this is known *as continues kiln Fig 6.1* shows that the central section of the kiln is widened out to form the zone of calcination so as to accommodate the hot gases of combustion and to establish a continuous draught. The kiln is provided with a lining of fire clay plaster. This is built partly below the ground level and a loading plant form is provided at the mouth of the kiln to facilitate the dropping of feed. As the level of the material at the top of the kiln sinks, the feed consisting of limestones or kankar with coal is put at the mouth. An iron grating is provided at the bottom with holes to draw the calcined particles. The top of the grating could be racked to admit and easy fall of calcined particles. The burnt limestones (Quick lime) are collected for further treatment of slaking or hydration.

At the temperature of about 1500°F, limestone dissociates into calcium oxide (lime) and carbon-dioxide. Limestone should not be heated more that 1600°F, because at higher temperature of about 2200°F. a series of complicated reaction will take place and these reactions are not desirable to have a good variety of time.

Hydration or Slaking: After calcination, the next step is hydration or slaking. After hydration, lime powder is obtained. Hydration of lime is accompanied hy (1) chemical combination of calcium oxide with water to form calcium hydroxide or hydrated lime (2) evolution of heat energy and (3) increase in volume.

ualities of good lime:

1. It should be free from ashes, under burnt particles and other impurities.
2. It must pass through Sieve No. 64.

esting of lime. The following are the tests that are generally carried out to determine the strength of lime.

Adhesive Strength Test: Prepare a past of freshly burnt lime and standard and in the proportion 1:3 with requisite amount of water. Two standard sized bricks are placed flat in a cross fashion one over the other with a joint of '/$_2$ thick by the prepared mortar. The two jointed bricks should be kept wet with the help of gunny bag for 24 hours and then they are kept immersed in water for 7 days. The two cemented bricks are then testes. The force (pull) required to separated them at the joint should not be less than 30 psi.

2. Tensile Strength Test: A lime mortar of ratio 1 :3 is prepared and a briquette of the shape shown in Fig.7.7 is made and kept under water for 7 days. The section central neck of the briquette is $^1/_2$-inch square. This is in the machine for tensile strength of lime. This should less than 45 psi after 7 days and 90 psi after 28 days.

Compressive Strength Test: With the help of same mortar of 1'3 ratio. 2"cubes are made shown in Fig. 7:8 and are kept for 7 days in water. The cubes are then tested for compressive strength by machines. The compressive strength should not be less than 200 psi after 7 and 450 psi after 28 days.

4. Soundness Test: The- lime is mixed with the necessary quantity of water to form a paste. The paste is made into a small ball, I" diameter by hand, and then allowed to set under a wet cloth for 24 hours. Thereafter, it is exposed to steam for 6 hours. At the end of this period the ball should not show any sign of cracking or warping.

Questions

1. Discuss the different Constients of limestones.
2. What are the different types of limes? Give their properties.
3. Name and discuss the tests are generally carried out to determine the quality of limestones.
4. A sample of limestone weighing 1 lb was heated in a lime kiln at a temperature of 1500°C. After heating, the sample weighed 0.254 lbs. Calculate the percentage of quick lime that will be available from the sample. Ans. 95%
5. The initial wt. of a sample of powdered limestone is 330.50 gms and the wt. of the dried residue on the filter paper is 100, 25 gms. The residue after decantation and drying weighed 60.50 gms. Calculate the percentage of calcium carbonate, sand and clay present in the sample of limestone.

   Ans. calcium carbonate = 69.6%

   clay 12% sand = 18.4%
6. Explain hydraulic index and cementation index. The chemical analysis of a sample limestone gave the following results.

Calcium oxide	72 %
Silica	18%

Lime		
Alumina	5	%
Magnesia	1 -5	%
Iron oxides	3.5	%

Determine the hydraulic index and cementation index and speak what type to hydraulic lime it is.

Ans. Hydraulic index = 0,36

Cementation index = 0.787

Hydraulic lime.

7. Explain the importance of lime as a material of construction.
8. What are the characteristics of good lime? Name the tests that are generally performed to determine the strength of lime.
9. Write explanatory[7] notes on the following:

   (a) Hydration, (b) Calcination, (c) Natural cements

   (c) Quick lime, (e) Setting of lime, (f) Hydraulicity.
10. Draw the section of a limes kiln for manufacturing lime and explain its working principle. [11]

11. Give the specification of good limes.

CHAPTER-SEVEN

CEMENT

7.1 Introductory: Cement is a cementing or binding material used in engineering construction. It is manufactured from calcareous substance (compounds of calcium and magnesium) and is similar in many respects to the strongly hydraulic limes but possessing far greater hydraulic properties. Cement differs from lime in many respects. Cement is very useful and superior to lime under the following conditions and requirements.

1. For construction of structures in wet places and under water.
2. Where great strength and durability of structures are required.
3. Where mortar or plaster has to set quick and attain its strength.
4. Where hard surface is required for the protection of exposed surfaces of structures against the destructive agents of the weather and certain organic or inorganic chemicals.
5. For water tightness of structures.
6. For decorative ornamental and pointing works.

There are two classes of cements: Natural Cement and Artificial Cement.

Natural Cement: This is manufactural by boring and crushing to powder natural stones containing 25 to 40 percent of clay, the remainder being the carbonate of lime, sometimes mixed with carbonate of magnesia. It is brown in colour and sets very quickly when mixed with water. It is not so strong as the artificial cement. The best vanity of natural cement is known as 'Roman cement' in England. Romans first used powdered calcined limestone as binding materials in construction works. Roman cement is not used in Bangladesh. This type of cement was first obtained by Joseph Parker in England by calcining nodules of argillaceous limestone in 1824.

Artificial Cement: The best variety of artificial cement is known as ordinary Portland due to its resemblance in colour and quality to Portland stone, which was first found and quarried in Dorset in Europe. This is also known as 'Normal Setting Cement'. In most of the engineering works Portland cement is used. In this chapter, composition, properties and the manufacturing processes of Portland cement will be dealt with. Also, the different varieties of cement and their properties and uses will be discussed briefly.

7.2 Composition of Portland Cement: Raw materials used for manufacturing of Portland Cement are:

(1) Calcareous materials which are the compounds of calcium and magnesium and (2) Argillaceous materials which are mainly silica, alumina and oxides of iron.

Limestones are the common calcareous materials and clay and shale are the common calcareous materials and clay and shale are the common argillaceous materials.

Constituents of Portland cement are mainly two types (1) Mineral constituents and (2) Acid and Alkaline constituents.

Table 7.1 Mineral Constituents of Portland Cement

Constituents	Oxide Composition	Abbre-Range of viation percent composition	
1. Tricalcium silicate	SCaO. SIO	C_2S	45-55
2. Dicalcium silicate	$2CaO,SiO_2$	C_2S	20-30
3. Ti calcium Aluminate	$3CaO.A]_2O_3$	C_3A	9-13
4. Tetra calcium Aluminoferrite	$4CaO, Al_2O_3$	C4AF	8-20
5. Calcium sulphate	Fe203' $CaSO_4$		2-6
6. Other compounds	-		2-8

Table: 7.2 Acid and Alkaline Constituents

Constituents	Range of percentage	Composition
1. Calcium Oxide	CaO	60-67
2. Magnesium Oxide	MgO	0.1-4.0
3. Silica	SiO_2	17-25
4. Alumina	Al_20_3	3-8
5. Iron Oxide	Fe_2°3	0.5-6
6. Sulphur Trioxide	SO3	1-3
7. Potassium Oxide	K_20	0.3-1
8. Sodium Oxide	Na2O	0.4-1.3

10.	Loss on ignition	1.8-2
11.	Insoluble residue	0.3-0.5

Two terms used in Table 7.2 require explanation. The insoluble residue, determined by treating with hydrochronic aid is a measure of adulteration of cement, largely arising from impurities in gypsum (calcium sulphate, GaSO 4 H2O). The insoluble residue should not exceed 1.5 percent of the weight of cement.

The loss on ignition shows the extent of carbonation and hydration free lime and free magnesia due to the exposure of cement to the atmosphere. The maximum permissible loss on ignition (at l,000°C) is 3 percent

7.3 Functions of Various Ingredients of Cement:

1. **Lime (Calcium Oxide, CaO):** Lime plays a very important role on the quality of cement because it forms about 63 percent of cement. To form the required silicates and a luminated of calcium, a sufficient quantity of lime must be present. A deficiency in lime reduces the strength of cement and causes it to set quickly. On the other hand, and excess will make cement unsound and cause it to expand and disintegrate.

2. **Silica (SiO_2):** Sufficient quantity of silica should be present in cement to dicalcium and tricalcium silicate. Silica imparts strength to cement and usually present to the extent of about 30 percent cement.

3. **Alumina (Aluminum Oxide, $A1_2O_3$):** It imparts quick setting property to cement, Clinkering temperature is lowered by the presence of requisite quantity of a alumina. But an excess of alumina weakens the cement.

4. **Magnesia (Magnesium Oxide, MgO):** Magnesia should not be present more than 2 percent in cement. An excess is harmful and will reduce the strength of the cement.

5. **Iron oxide (Fe_2O_3):** It imparts colour to cement. It acts as a flux. At a very high temperature it enters into chemical reaction with calcium and aluminum to form tricalcium aluminoferrite. This new compound imparts hardness and strength to cement.

6. **Calcium sulphate ($CaSO_4$):** This is present in cement in the form of gypsum (CaSO4 $2H_2O$). It shows down or retards the setting action of cement.

7. **Sulphur Trioxide (SO_3):** It should not be present more than 2 percent in cement. An excess causes cement to become unsound.

8. **Alkalies:** These should not be present more than I percent in cement, because excess alkaline matter causes efflorescence.

7.4 Manufacture of Cement: There are generally two processes adopted for manufacturing cement in Bangladesh namely, (1) Wet process and (2) Dry process.

Wet process: The manufacture of cement by this process is divided into three stages: (1) Preparation of cement slurry, (2) To obtain cement clinkers, and (3) To prepare cement.

In the first stage, the raw materials (calcareous materials - limestone kankar, marl, chalk, etc. can argillaceous material clay containing requisite among of silica, alumina, magnesia and oxides of iron) are mixed together. Generally, 3 volumes of calcareous materials are mixed with 1 volume of argillaceous materials. After mixing the materials arc crushed in a crushing machine.

The crushed materials are put into a wash will where they are finely grounded with addition of requisite quantity of water. The quantity of water used in the wet process is round about 45 percent. The grinding of the materials in the wash mill should be such that about 80 to 85 percent should pass through No. 200 sieve. The mixture now exists a complete homogeneous condition of suspension in water. Such an intimate mixture is termed as slurry. This slurry is sufficiently liquid to pass through pipes and to admit of being handled by pumps. 'The slurry is then pumped into correcting silos where it is corrected for its composition.

In the second stage 2 the slurry is fed into a rotary kiln (See Fig-7.1) at the top. A rotary kiln is a long-inclined steel cylinder lined with refractories. It is inclined about 1/2" to a foot and is about 8 to 12 ft in diameter and 200 to 400 ft in length. The fuel to be used for the purpose may be either coal, oil or gas. If coal is to be used, it should be in thoroughly grounded form. The coal dust is blown in the rotary kiln under pressure from the lower end together with sufficient among of air to be utilized during the progress of combustion. The kiln revolves at a speed of about 2-3 revolution per minute (RPM), depending upon the nature of the material and the time taken by the material to reach the lower end of kiln In the first few feet length of the kiln, a system of

thick iron handing chains is provided. The slurry dries and peels off in the form of fakes and drops down at the bottom of the kiln. This section of the kiln is termed as *drying zone and* has a temperature of about 400 to 600°F to remove water from the slurry.

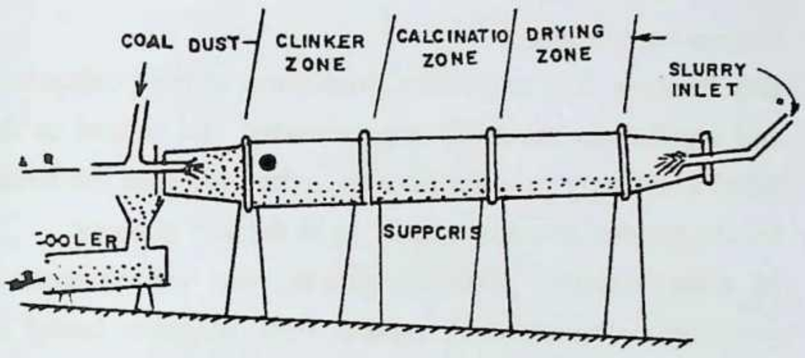


Fig. 7.1 Rotary kiln

In the next section, termed as *calcination zone*, takes place at a temperature range of 1200 to 1600 °F and the entire moisture from the flakes are removed. The flakes gradually slide down to the third and last section, termed as *clinkering zone.*

In the clinkering zone. The temperature ranges from 1600 to 3000°F. In this zone, the calcareous and argillaceous materials enter into chemical real actions to from the cement compounds of silicates, aluminates and ferrites. These compounds come out as vitrified glassy nodules of varying sizes from 3/8 to 1/4" down wards. These re-termed as clinkers. The hot clinkers have to be cooled and stored before grinding them into cement. Cooling cylinders are mounted on the lower end of the rotary kiln into which the hot clinkers fall and are cooled. The cooled clinkers drop down from the lower end of the cooling cylinders and collects into a pit from which they are conveyed by means of a belt conveyor to the clinker storage compartment.

Dry Process: The calculated proportion of both calcareous and argillaceous materials are grounded and mixed in dry state. The finely ground mixture is then fed into the rotary kiln to prepare cement clinker, as in the wet process.

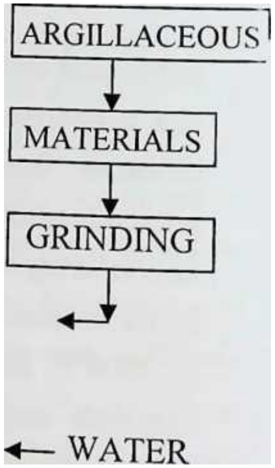
In manufacturing Portland cement, the wet process is commonly employee. A typical flow diagram based on wet process of Manu faction cement is shown in Fig. 7.2.

CALCAREOUS

MATERIALS

r

GRINDING



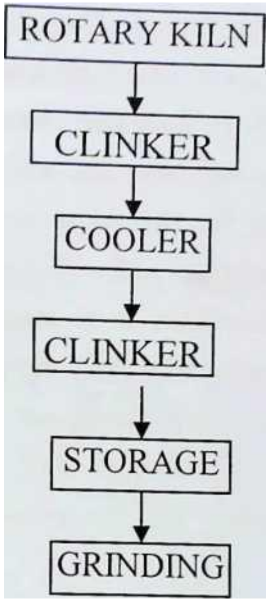
MIXING

--------- 1 ______

WET GRINDING

I ------- —

SLURRY



◄—FUEL

(COAL DUST)

◄—GYPSUM

CEMENT

Fig. 7.2

7.5 Storing of cement: Cement should be stored in a dry place and on a raised platform and should be protected against wind and rain. Because cement has better affinity for water and will readily absorb moisture from the atmosphere or from damp contact surfaces. As far as possible, long period of storage should be avoided because long storage reduces the strength of cement.

7.6 Properties of Cement: The most important properties of cement are: (1) Hydration. (2) Setting; (3) Fineness, (4) Soundness, and (5) Strength.

Hydration of Cement: The term 'Hydration' is applied to all reactions of cement to water. All the cement constituent compounds are in an hydrous (dry) state. As soon as water is added to Portland cement, chemical reactions start simultaneously between them. The different constituent compounds have different rates of hydration. Tricalcium aluminate (C_3A) and tetra calcium alumina ferrite (C_4AF) react instantaneously with water and are the first to hydrate. Tricalcium silicate (C_3S), the most important constituent compound is next to hydrate and within a week a substantial part of it reacts with water. It is mainly responsible for imparting strength to cement in early days. Dicalcium silicate (C_2S) is the slowest constituent compound to hydrate and the process continuous for several days. This constituent compound is responsible for the progressive strength of cement.

The process of hydration is essentially the formation of minute crystals of calcium and gels from the solution of cement and water and continues for a long period. The hydration of different constituent compounds (Pure compounds) of Portland cement is illustrated as follows: For tricalcium silicate (C_3S):

$2C_3S+6H_2O \text{-------->} C_3S_2\ H_2O+3Ca\ (OH)_2$ (7,1)

(Calcium silicate (lime)

(hydrate)

For dicalcium silicate (C_2S):

$2C_3S+6H_2O) \text{.....-»} c_3S_2\ H_2O+Ca\ (OH)_2$

(Calcium silicate (lime) hydrate)
(7.2)

The reaction of true C_2A with water is very violent and leads to immediate stiffening of the paste, known as flash setting. To prevent this form happening, gypsum ($CaSO_4\ 2H_2O$) is

added to cement clinker during grinding. Gypsum and *C3A* react to form insoluble calcium sulpho-aluminate (which does not hydrate) but eventually a tricalcium aluminate hydrate is formed

$C_3A+6H_2O \longrightarrow 3CA.\ 3C_3aSO_4.\ 3H_4.O > C_3A.H_2O$ (7.3)

(Tricalcium sulph-(Tricalcium aluminate hydrate) aluminate hydrate)

This has in general a retarding action on the starting of initial setting of the cement after the water is added and gypsum also retards the hydration of tricalcium silicate. For tricalcium a alumino-territe (C_4AF). Gypsum reacts not only with C_3A; with C_4AF it forms calcium sulpho-ferrite as well as calcium sulpho-aluminate and its ressnee may accelerate the hydration of the silicates. The amount of gypsum added to the cement clinker has to be very carefully watched; in particular an excess of gypsum leads to an expansion and consequent disruption of the set cement paste and also the initial setting time is much delayed. The amount of gypsum added to cement clinker is usually expressed as the weight of SO_3 present; this is limited to a maximum of 2.5 per cent when the C_3A content is not more than 7 per cent and to 3 per cent when the amount of C_3A exceeds 7 per cent but not more than 10 per cent.

The progress of hydration of cement can be determined by different means, such as the measurement of: (a) the amount of $Ca\ (OH)_2$ in the paste; (b) the heat evolved by hydration; (c) the specific gravity of the paste; (d) the amount of chemically combined water; (e) the amount of chemically combined water; (f) the amount of unhydrated cement present (using x-ray quantitive analysis); (g) also indirectly from the strength of the hydrated paste. Unfortunately, the application of these methods to commercial cements is by no means simple.

The rates of hydration of various cement constituent compounds are graphically represented in Fig. 7.3.

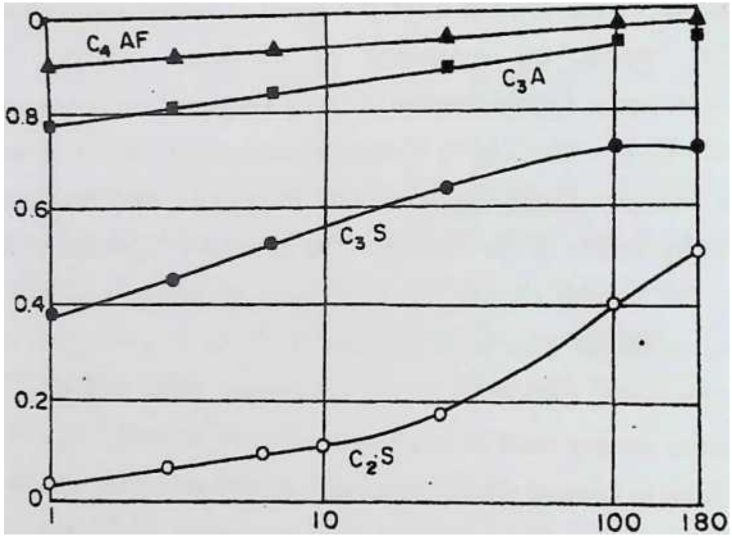


Fig. 7.3

Setting of Cement: The term 'setting' is used to describe the stiffening of the cement paste. Broadly speaking setting refers to change of cement paste from a fluid to a rigid state. Setting differs from hardening of cement. The term hardening' refers to the gain a fluid to a rigid state. Setting

differs from hardening of cement. The term 'hardening' refers to the gain of strength of a set cement paste, although during setting the paste acquires some strength.

In practice, the terms 'initial setting’ and 'final setting’ are used to describe arbitrarily chosen stages of setting. The setting process is accompanied by temperature changes in the cement paste: initial setting corresponds to a rapid rise in temperature and final setting to the peak temperature. The setting of cement paste decreases with a rise in temperature but above about 85°F a revers effect may be observed. At low temperatures, setting is retarded.

False Setting: False setting is the name given the abnormal premature stiffening of cement within a few minutes of mixing with water. It differs from flash setting in that no appreciable heat is evolved, and the remixing the cement paste without addition of further amount of water restores plasticity of the paste until it sets in the normal manner and without a loss of strength.

Some causes of false setting are: (a) dehydration of gypsum when Interground with too hot a clinker; semi-hydrate

($CaSO_4\ 0.5H_2O$) or anhydrite ($CaSO_4$) are formed and when 2

the cement is mixed with water this hydrate to form gypsum again, thus setting takes place with a resulting stiffening of the paste: (b) Another cause of false setting may be associated with the excess alkalies present in cement. During storage, they may carbonate, and alkali carbonates react with calcium hydroxide [$Ca\ (OH)_2$] liberated by the hydrolysis of C_3S to form calcium carbonate ($CaCO_3$). ns precipitates and induces a rigidity of the paste; (c) It has also been suggested by many researchers that false setting may be due to activation of C_3S by aeration at moderately high humiaities. Water is adsorbed on the grains of the very rapidly with more water during mixing. This rapid hydration would produce false setting.

However, a good cement should be free from false setting.

Fineness Cement: It may be recalled that one of the last steps in the manufacture of cement is the grinding of clinkers mixed with gypsum. Since the hydration starts at the surface of the cement particles, it is the total surface area of cement that represents the material available for hydration. Thus, the rate of hydration depends on the fineness of the cement particles, and for a rapid development of strength, high fineness is necessary'. On the other hand, the cost of grinding to a higher fineness is considerable and also the finer the cement the more rapidly it deteriorates on exposure to the atmosphere if proper protective measures are not taken. Finer cement leads to stronger reaction and hence greater strength. An increase in fineness increases the amount of gypsum required for proper retardation as in a finer cement more C3A is available for early hydration. The water content of a paste of standard (normal) consistency (to be described in the following section) is greater the finer the cement, but conversely an increase in fineness of cement slightly improves the workability of a cement concrete mix.

Soundness of cement: It is essential that a cement paste, once it has set does not undergo a large change in volume. Such changes in volume may take place due to the delayed in the hardened cement, namely free lime, magnesia, and calcium sulphate.

If the raw materials fed into the kiln contain more lime (CaO) than that can combine with the acidic, oxides, the excess will remain in a free condition. The free lime will hydrate very slowly in a subsequent stage and the mortar and concrete prepared with such cement is therefore liable to expand and crack after a few months or a year. Cements which exhibit has expansion are known as unsound.

A cement can be unsound due to the presence of magnesia (MgO), Which reacts with water in a manner similar to quick lime (CaO). However, only crystalline variety of magnesia (Periclasue MgO) is deleterious, but magnesia present in glass form is of course, harmless.

Calcium sulphate is the third compound liable to cause expansion; in this case calcium sulpho-aluminate is formed. It may recalled that a hydrate of calcium sulphate-gypsum is added to cement clinker in order to prevent flash setting, but if gypsum is resent in epcess of the amount that can react with C2A during setting, unsoundness in the form of a low expansion will result. For this reason, it is essential to limit- very strictly the amount of gypsum that can be added to clinker, but the limits are well on the safe side as far as the danger of unsoundness is concerned.

Strength of cement: The mechanical strength of hardened cement is perhaps most obviously required for structural uses. It is not surprising, therefore, that strength tests are prescribed by all specifications for cement.

The strength of mortar, plaster or concrete depends on the cohesion of the cement paste on its adhesion to the aggregate particles, and lastly on the strength of aggregate itself.

Strength tests are not made on a neat cement paste because of difficulties moulding and testing with a consequent large variability of test results. Cement-sand mortar and, in some cases, concrete of prescribed proportions and made with specified materials under strictly controlled conditions are used for the purpose of determining the strength of cement.

There are several forms of strength: (a) Tensile strength, (b) Compressive strength and (c) Flexural strength. The latter determines in reality the tensile strength in bending. Since the flexural strength of cement is not used in Bangladesh and little used elsewhere, it will not be further discussed.

Generally, compressive strength is used in Bangladesh and elsewhere. Since structural techniques are designed mainly to exploit the good- strength of mortar, paster and concrete in compression, the tensile strength of cement is often of tesser interest than its compressive strength. Moreover, cement is very weak in tension but very strong in compression.

7.7 **Testing of cement**: The manufacture of cement requires stringent control and a number of tests are performed in the laboratory to ensure that the cement is of the desire quality and that it conforms to the requirement of the relevant standards. The following standard tests are conducted for ordinary Portland cement.

1. Test for Fineness
2. Test for Setting time: Initial and final
3. Test for Soundness
4. Test for Chemical Composition
5. Test for Strength: Compressive and Tensile

Test for fineness: Fineness is a vital, property of cement and has to be carefully controlled. The fraction of a cement retained on No. .170 B, S. (British standard) test sieve is determined, and the maximum residue is limited to 10 percent by weight for ordinary and 5 percent for rapid hardening Portland cement.

Test for Setting Time: Initial and final: For the determination of the initial and final setting times and for soundness test, neat cement paste of a standard consistency has to be used. It is, therefore, necessary to determine first for any given cement the water content of the paste which will produce the desired consistency.

The consistency is measured by the Vicat apparatus shown in Fig 7.4 using a 10 mm diameter plunger fitted into the needle holder. A trial Paste of cement and water is

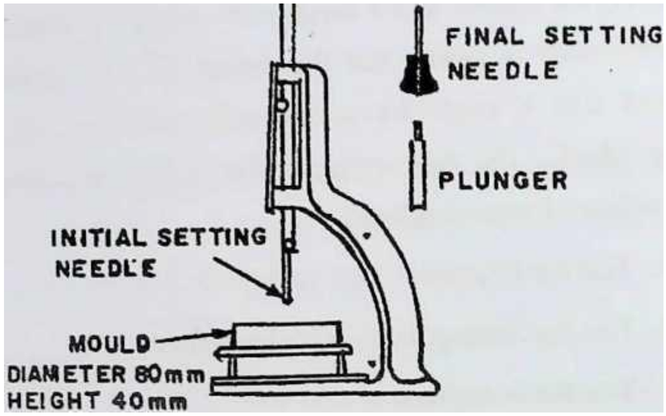


Fig. 7.4 Vicat Apparatus

mixed in a prescribed manner and placed in the cylindrical mould (80 mm diameter and 40 mm deep) of the Vicat apparatus. The plunger is then brought into contact with the top surface of the paste and releases. Under the action of its weight the plunger will penetrate the paste, the depth of penetration of the plunger into the paste is observed on the vertical scale. This is considered to be the standard when the plunger penetrates the paste to a point 5 to 7 mm from the bottom of the mould. Several trial pastes are made each time with different percentages of water for the plunger to penetrate to a depth of 33 to 35 mm from top. The water content of the standard pasts is expressed as a percentage of the weight of cement. The cement paste which allows the above penetration of the plunger is termed as standard *cement paste or cement paste of normal (standard) consistency.*

The quantity of water required for a standard cement paste is used to determine the quantities of water required for preparing (a) the cement paste for setting test (b) the cement paste for soundness and (c) the standard mortar to test compressive and tensile strengths.

The technique of mixing cement with water or cement. Water and any other inert materials (sand, stone, brick, khoa, etc.) in a specified manner for testing its properties is termed as *Gauging.*

Initial Setting Time: The setting times (initial and final) of standard cement pastes are determined by the Vicat apparatus. For the determination of the initial setting time. A round or square needle, with a cross sectional area of 1 sq. mm is used. This needle, acting under a prescribed weight is used to penetrate a paste of standard consistency placed in- the Vicat mould. When the paste stiffens sufficiently for the needle to penetrate only to a point about 5 mm from the bottom (35 mm from the top) initial setting is said to have taken place. Initial setting is expressed as the time elapsed since the mixing water (clean water, fit for drinking) added to the cement.

The following are the prescribed timing for the initial setting for different variety of Portland cement.

Ordinary Portland Cement Not less than 45 minutes

Rapid Hardening Portland Cement

Low Heat Portland Cement- Not less than 60 minutes

Aluminous Cement- Not less than 2 hours.

Final Setting Time: Final setting is determined by 1 mm squire needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter and set 0.5 mm behind the tip of the needle. The final setting is said to have taken place within the needle, gently lowered to the surface of the paste, makes and impression on it but the circular cutting edge fails to do so. This final setting time is reckoned from the moment when mixing water was added to the cement. The following are the standards of the final setting time (British standards):

Ordinary, Rapid hardening. Low Heat, and Blast Furnace Portland Cement- Not more than 10 hours.

Aluminous Cement- Not more than 2 hours after the initials setting.

Since the setting of cement is affected by the temperature and the humidity of the surrounding medium these are specified as follows: (a) temperature between 58 to 64°F and (b) relative humidity of air not less than 90 per cent.

It should be remembered that the speed of setting and the rapidity of hardening (gaining of strength) are entirely independent of one another. For instance, the prescribed setting times of rapid hardening cement are of no different from those for ordinary Portland cement, although the two cements harden at different rates.

Soundness Test: The soundness of cement is tested by the Le Chatellier apparatus. This apparatus (shown in Fig. 7.5) consists of a small brass cylinder split along it generates (axially).

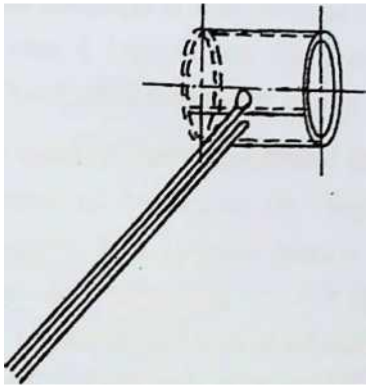


Fig- 7.5 Le Chatler Apparatus

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 cement is greatly magnified and can be easily measured. The cylinder is placed on a glass plate filled with cement past of standard consistency and covered with another glass plate. The whole assembly is them immersed in water at 64 to 68°F for 24 hours. At the end of that period, the distance between the indicators is measured. Let it be denoted as d|. The mould is them immersed in water again and brought to boil in 30 minutes. After boiling for one hour; the mould is removed and after cooling, the distance between the indicators is again measured. Let it be denoted by d_2. The increases in this distance (d_2-dj) represent the expansion is limited to 10 mm. It the expansion exceeds this value a further test is made after the cement has been spread and aerated for 7 days during this time some of the lime may hydrate or even carbonate and a physical breakdown in size may also take place. At the end of 7 days the Le Chateller test is repeated and the expansion of aerated cement must not exceed 5 mm. A cement not satisfying at least one of these two tests should not be used.

The Le Chatellieer test detects unsoundness due to free lime only. But sometimes an access of magnesia is present in cement. For this reason, another test, named as. Autoclave test (devised in U.S.A) is performed on cement to test its soundness. Both free lime and magnesia are very sensitive to ’Autoclaving’. In this test, a neat cement bar (prescribed by ASTM standard) 2-inch square in cross section and 10 inches long is cured in humid air for 24 hours. The bar is than placed in an autoclave (a high-pressure steam boiler), which is raised to a temperature of 420°F (steam pressure of 300 psi) in one hour and maintained at this temperature for 3 hours. The high steam pressure accelerates the hydration of both magnesia and lime. The expansion of the bar due to autoclaving must not exceed 0.5 percent for Portland cement.

No test is so far devised for the detection of unsoundness due to and excess of calcium sulphate but its content can be easily determined by chemical analysis.

Chemical Composition Test: This test is generally carried out to determine whether or not certain cement constituents are present in quantities exceeding those specified to be safe (see Table: 7.2) Both for ordinary and rapid hardening Portland Chemical composition is the same. On chemical analysis, both ordinary and rapid hardening cement should give the following results:

(a) Net proportion of lime to silica, alumina and iron oxides, shown below.

$$\frac{CaO}{2.8'(SiO_2) + 1.2(A''1_2O_3) + 0.065\,(Fe_2O_2)}$$

(b) Magnesia should not exceed 2 percent by wt.

(c) Loss on ignition should not exceed 2 per cent by wt.

(d) Insoluble residues should not exceed 0.5 percent by wt.

(e) Total Sulphur content as Sulphur trioxide should not exceed 2% by wt.

Test for Strength: For carrying out both the tensile and compressive strengths for cement, briquettes and cubes (shown in Figs. 7.6 and 7.7) of specific shapes are made of standard mortar of cement, sand and water.

Standard Sand: The sand used for making mortar should be pure natural silica and should be well grades. All sand particles should be smaller than No 18 (BS.) sieve and at least 90% is retained on No. 25 (BS.) sieve. Sand should be completely dry when weighing for proportioning. The ratio of cement to sand for making standard mortar is taken as 1: 3.

Water: Clean water, fit for drinking should be used for making standard mortar. The quantity of water for *gauging* to make standard mortar for briquettes can be determined roughly following empirical equation.

$$w= \frac{1}{4}(0.78p) + 2.5$$

in which W is the percentage of water by weight of solids and p is the percentage of water required to prepare the cement paste of normal consistency.

Usually, a water content of 8 per cent of the weight of solids is used.

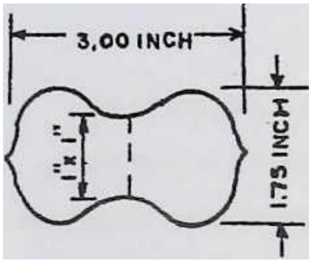


Fig. 7.6

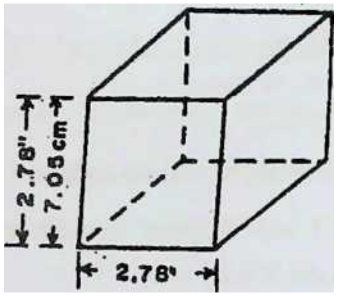


Fig. 7.7

Test of Tensile Strength: The briquette, shown in Fig, 7.6. are moulded with standard mortar in a specific manner cured for 24 hours at a temperature between 64 to 61 °F in an atmosphere of at least 90 percent relative humidity. The briquettes are demolded after 24 hours and further cured for 3 and 7 days and tested in direct tension the pull being applied through special jaws engaging the wide ends of the briquettes. The following should be the results (average of six briquettes) for tensile strength of different varieties of Portland cement.

Ordinary Portland Cement: Not less than 300 psi after 3 days and not less than 375 psi after 7 days.

Rapid Hardening Portland Cement: Not less than 300 psi alter 24 hours and not less than 450 psi after 3 days.

Test for compressive Strength: There are two standard methods of testing the compressive strength of cement. One uses the mortar and the other concrete.

In the mortar test 1: 3 cement-sand mortar is used. The sand is again the standard sand and the weight of water in the mix is 10 percent of the dry materials. Expressed a water, cement ratio, this corresponds to 0.40 by weight. A standard procedure is followed in making 6 nos. 2.78-inch cubes (Fig. 7.7) with standard mortar. The cubes are demolded after 24 hours and cured further for 3 and 7 days. After curing, they are tested under direct compression. They average strength of six cubes after 3 and 7 days should not be less than those shown in Table 7. 3.

In the concrete test, fixed weights of cement and water (corresponding to water/cement ratio of 0.6) are mixed with such amount of course (stones, brick khoa, etc.) and fine (sand) aggregates (inert materials) as will produce a v workable concrete with a slump (to be discussed in chapter 10) of between $^{1}/_{2}$ and ich. Three 4-inch cubes are made by hand in mould with standard concreate, one at a time in a prescribed manner. The cubes are demolded after 24 hours and cured for 3 and 7 days. They are tested under direct compression. The average strengths of 3 cubes after J and 7 days should not be less than those values shown in Table 7.3.

TABLE 7.3 Requirement for compressive Strength of Cement

Age in days	Minimum Compressive Strength in psi			
	Mortar Test		Concrete test	
	Ordinary Portland Cement	Rapid Portland Cement	Ordinary Portland Cement	Rapid Portland Cement
3	2,200	3,000	1,200	1,700
7	3.400	4,000	2.000	2,500

7.8 Types ’of Portland Cement: In order to facilitate discussion, a list of varieties of Portland cements, together with American description (by ASTM) where available, is given in the following Table - 7.4

TABLE 7.4 Main Types of Portland Cement

English Description (B.S.I)	American (ASTM) Description
1. Ordinary Portland	Type I
2. Modified Portland	Type 11
(a) Air Entraining Portland	
(b) Expanding Portland	
3. Rapid Hardening Portland	Type III
4. Quick Setting Portland	
5. Low Heat Portland	Type IV
6. Surphate Resisting Portland	Type V
7. Blast Furnace	Type IS
8. Pozzolana Portland	Type IP
9. White Portland	

Ordinary Portland Cement: This is by far the most common cement is Bangladesh and elsewhere: nearly 95 percent of all cement used in Bangladesh is of, the ordinary Portland type. The chemical composition, manufacturing properties of ordinary Portland cement have already been discussed in the preceding sections of this chapter and need not therefore be repeated.

Modified Portland Cement: (a) Air Entraining Portland Cement: It is seen that entrainment of air or formation of gas bubbles while applying cement increase resistance to frost action fire, scaling and other similar defects. Air entraining cement is produced by grinding minute air entraining materials with clinker of by adding some resinous materials, e.g-vinsol resin to ordinary Portland cement. Entrainment of air improves workability' and durability' of cement but reduces the strength by about 10 percent Air entrainment from 3 to 6% by volume gives satisfactory results.

(b) Expanding Portland Cement: In this type of cement, certain chemicals-are added which causes its expansion by predetermined amount during setting and this expansion is more than the shrinkage of ordinary cement concrete. This property is utilized for preventing cracks caused by shrinkage. It is very useful in works like underpinning were the increase in volume fills up the spaces which are not otherwise easily accessible, this cement is never recommended for use in contact with sea water because salinity reduces the strength and durability of this cement.

Rapid Hardening Portland Cement: This cement is very similar to ordinary Portland cement. Rapid hardening cement, as its name implies, develops, strength more rapidly and therefore, it is also termed as high early strength cement. It has been shown it Table 7.3 that the strength developed at the age of 3 days is of the same order as the 7-day strength of ordinary' properties like hydration fineness, soundness and setting have already been discussed and therefore, need not be repeated.

The used of rapid hardening cement is indicated where rapid strength development is desired e.g., when form work (shuttering) is to be removed early for re-use of where sufficient for further construction is wanted as quickly as practicable. This cement is comparatively costly than ordinary Portland cement.

A special type of rapid hardening Portland cement is speed cement'. It is extremely fine ground with a 0.5 percent residue on No. 170 (B.S.) sieve and a specific surface area of 4500 cm2/gm. No. accelerators or admixtures are added. The standard mortar cube test gives strengths of about 4,000 psi after 1 day, 7,000 psi after 3 days and 9,800 psi after 28 days. This very rapid gains of strength make ‘speed cement' suitable for winter concreting or urgent jobs such as road repair, well sealing, *grouting* etc. It was first

manufactured by double burnings in the kiln in Belgium but it is now introduced in England, Italy, France and Sweden.

I here am another variety of rapid hardening Portland cement, named as *Extra Rapid Hardening Portland cement.* This cement is obtained by intergrading calcium chloride with rapid hardening cement. The quantity of calcium chloride should not exceed 2 percent. Because calcium chloride is deliquesced not (capable of absorbing moisture from the atmosphere), it is vital to store this cement under dry conditions, and it should generally be used within one month of dispatch from the manufacturing plant.

This cement is suitable for cold weather concreating or when a very high early strength is required but when it is not advisable to use aluminous cement. The strength of this cement is about 25 percent higher than that of rapid hardening cement after 1 or 2 days and 10 to 20 percent higher after 7 days. The initial setting time is short.

Depending upon temperature, this can be 5 to 30 minutes so that early placing is essential Shrinkage is rather higher than when rapid hardening Portland cement is used.

Quick setting cement: This cement has the property of setting initially after about 7 minutes and final setting is only 30 minutes. The quick setting action of this cement is achieved by fineness and adding small percentage of aluminum sulphate and also by adding very little or no percentage of retarder (Gypsum) to the clinker during grinding. This cement has got disadvantage in normal working because the time is too short to ensure proper-missing and laying of concrete. But where concrete is to be laid under water or in running water. This cement is very advantageous.

Low Heat Portland cement: The rise in temperature in the interior of a large concreate mass (such as dams, etc.) due to the heat evolved by the hydration of cement can lead to serious cracking. For this reason, it is necessary to limit the rate of heat evolution of the cement used in this type of structure; a greater proportion of the heat can then be dissipated and a lower rise in temperature results. This type of cement with low rate of heat evolution was first produced for use in large gravity dams in the U.S.A. The following are the specification (B.S.) for low heat Portland cement:

(a) The heat of hydration should not be more than 60 calories per gm after 24 days.

(b) The limits of lime content should be as follows:

$$\frac{\mathrm{CaO}}{2.4(\mathrm{SiO_2}) + 1.2(\mathrm{Al_2O_3}) + 0.65(\mathrm{Fe_2O_3})\ \mathrm{zl}}$$

and

$$\frac{\mathrm{CaO}}{1\ .9(\mathrm{SJO_2}) + 1.2(\mathrm{Al_2O_3}) + 0.65(\mathrm{Fe_2O_3})\ \mathrm{zl}}$$

(c) Specific surface area to ensure a sufficient rate of gain of strength must not be less than 3,200 $\mathrm{cm_2}$*1* gm.

Sulphate Resisting Portland Cement: This type of cement is specially manufactured for uses in situation where resistance to disintegration under the action of sulphate is required. In certain regions water may have high content of sulphates of various minerals and ordinary Portland cement is liable to disintegrate because of the unfavorable chemical reaction between the water and cement.

In manufacturing this type of cement, the following are the limits of the principal constituent: (a) C_2A content not exceed 5 percent (b) Total contents of C_2AF plus twice the C_3A content should not exceed 20 percent (c) Magnesia content should not exceed 4 percent.

1 his cement is recommended to be used for hydraulic structures in alkaline water and for canal lining culverts etc.

Blast Furnace Portland Cement: This type of cement is made by intergrading Portland cement cylinder and granulated blast furnace slag the proportion of the latter not exceeding 65 percent of the weight of the mixture.

Slag is a waste product in the manufacture of pig iron and is a mixture of lime, Silica and alumina, that is the same oxides that make up Portland cement, but not in the same proportions. Quickly cooled glassy slags which are used for this purpose possess the property of hardening under water in presence of lime. This cement is rather similar to ordinary Portland cement and requirements for fineness, setting times, soundness and strength are the same for both cements. It is fairly high sulphate resistant and is frequently used in seawater constructions. It has got various special names, in Germany it is under the name of *Eisen Portland* (up to 30% slag) and *Hochofen cements*,(31 to 35% slag), in France, most common names are *cement metallurgies mixture* (50% slag) and *cement hant Journea* (65% to 75% slag).

Pozzolana Portland Cement: This is the name given to intergrown or blended mixture of Portland cement and pozzolana.

Pozzolana is a natural or artificial materials containing silica in a reactive form. It is essential that pozzolana be in a finely divided state as it is only then that silica can combine with lime in presence of water from stable calcium silicates which have cementing properties. Pozzolana materials most commonly used are volcanish ash (original natural Pozzolana), pumicited, shales, calcined earth, burnt clay, fly ash etc. The percentage of pozzolana should be between 15 to 50 of the weight of the cement.

Pozzolana Portland cements gain strength very slowly and require, therefore, curing over a comparatively long period, but their ultimate strength is approximately the same as that of ordinary Portland cement.

White Portland Cement: This cement is made from raw materials containing very little iron oxide and manginess oxide, China clay is generally used together with chalk or limestone free from specified impurities. Oil used as fuel for the kiln in order to avoid contamination by cool ash. Since iron acts as a flux in clinkering its absence necessitates higher kiln temperatures but sometimes cryolite (solidum aluminum-fluoride) is added as a flux. A typical compound composition of white Portland cement is given in Table 7.5.

Table 7.5 Typical Compound Composition of White Portland Cement

Constituent compound	Content, percent
C_3S	51
C_2S	26
C_3A	11
C_4AF	1
SO_3	2.6
Alkalis	0.95

The strength of this cement is lower than that of ordinary Portland cement. It is not liable to cause staining because it has low content of soluble alkalis. It is 4 to 6 times costlier than ordinary Portland cement.

snow Crete is the commercial name given to white Portland cement. It is mainly used for architectural and ornamental purposes, especially in tropical countries.

7.9 Special Portland Cement: These are: (1) Colored Cement (color Crete) (2) Aluminous Cement and (3) Antibacterial Cement.

Coloured Cement: Color Crete is a trade name given to coloured cement. The basis of coloured cement is the white Portland Cement. A better way to obtain a uniform and durable colour concrete is to use colour cement. The colour cement consists of white cement interground with 2 to 10 percent of pigment (a colouring ingredient). A through distribution of pigments is essential for satisfactory results.

The common pigments are: (a) Iron oxides-red yellow black and brown (b) Manginess dioxide-black and brown (c) Chromium oxide-green (d) Cobalt blue-blue and (e) Carbon pigments black. Specification of this type of cement are given by the individual manufacturer of this rather specialized product. This cement is mainly used for architectural and ornamental works, external and internal decorations of building, mosaic (terrazzo) floorings, swimming pools, fountains, bathrooms and ornamental plastering.

Aluminous Cement: This is also known as high alumina cement. Its French name is ’Cement Fondu' which is now used in England as a trade name. Its other names are Lightning cement, (in England) and Luminate (in the U.S.A.).

From the very name of the cement-aluminous or high alumina it can be inferred that it contains a large proportion of alumina. This cement consists in fact of approximately equal parts' about 40 percent each of alumina and time with some ferrous and ferric oxides and upto about 5 percent of silica.

This cement is manufactured by calcining limestone *Bauxite.* Bauxite is a residual deposit with high alumina content! This cement is very resistant to sulphates. It is not affected by the CO_2 dissolved in pure water and is therefore suitable for the manufactured of pipes. High alumina cement is also unaffected by corrosive action of acids (unaffected upto PH value 4). Another outstanding feature of this cement is its very high rate of strength development. About 80 percent of its ultimate strength is achieved after 24 hours and

even at 6 to 8 hours the concrete is strong enough for the side formwork to be struck off and for the preparation of further concreting to take place. Concrete made of aluminous cement and aluminous cement clinker as aggregate with water cement ratio of 0.5 can reach strength about 1.4000 psi in 24 hours and 18,000 psi in 28 days.

Aluminous cement is slow setting but the final setting follows the initial setting more rapidly than is the case in Portland cement. Typical values are: (1) Initial setting time 4 hours 40 mins to 5 hrs. 35 mins.

The cement is used for manufacturing pipes and for lining in chemical plants

Antibacterial Cement: It is a Portland cement interground with an antibacterial agent which prevents microbial growth. This cement is used in floors of food processing plants, in slaughter houses swimming pool, public baths and other similar places where bacteria and fungi might grow.

Questions

1. What is cement? Compare the suitability of cement over lime when used in engineering constructions.
2. Discuss the importance of cement in engineering constructions.
3. What do you mean by 'Portland cement'? Give both chemical and mineral constituents of ordinary Portland cement and discuss briefly the function of each in cement.

4. What are the different methods of manufacturing ordinary Portland cement? Draw neat diagram of a rotary kiln and explain the different steps in the wet process of manufacturing Portland cement with a neat flow diagram.

5. Discuss the following properties of ordinary Portland cement and give their specification:

   (a) Setting times, (b) Soundness, (c) Fineness, and

   (d) Strengths.

6. Name the different standard tests that are carried out on ordinary Portland cement and enumerate their purposes.

7. Write short notes on:

   (a) Hydration, (b) Natural Cement, (c) Rapid Hardening Portland Cement (d) Pozzolana, (e) Coloured Cement.

8. Give the specifications of the ordinary Portland cement with respect to the follows: (a) Setting times (b) Fineness (c) Soundness and (d) Strengths.

CHAPTER-EIGHT

SAND_AND_SURKI

8.1: Sand: Sand, as an engineering material, plays and important part in engineering constructions. In concrete work, it is usually termed as fine aggregate, Sand is a form of silica (quarts) and may be of argillaceous, silicious or calcareous according to its composition. Natural sands are the weathered and worn-out particles of rocks (mainly quartzite) and are of various grades or sizes depending upon the intensity of weathering. The sand grains may be of sharp, angular or rounded.

8.2 Classification of Sand According to Source: Sand is usually obtained from pits, shores, river beds and seas. There are mainly three kinds of sands in use: (1) Pit sand (2) River sand and (3) Sea sand.

Pit Sand: The type of sand is sharp angular, porous and free from salts. It might contain clay and other impurities which should be screened and washed before use. It is light brown or yellowish colour. It is most suitable for mortar work.

River Sand: This variety of sand is fine, round and polished. It generally contains earthy impurities like gravels, pebbles etc. These impurities should be screened and washed before the sand is used. It is whiter in colour, globule and smaller in size than pit sanid and hence most suited for plastering works.

Sea Sand: This type of sand is also fine, round and polished. But it is the worst of the three varieties because it contains sea salts which absorb moisture from the atmosphere (hygroscopic) causing permanent dampness and efflorescence and thereby the work gradually disintegrates. It also contains shells and organic matter which decompose in the body of mortar: plaster and concrete also reduce their life and strength.

8.3 **Classification of Sand According to Size:** According to size, sand is **Classified into three major groups:** (1) Fine Sand: All the sand particles should pass through No. 16 (ASTM sieve (size, *1/16* inch). This is usually used in plastering works: (2) Moderately coarse sand: All the sand particles should pass through No. 8 (ASTM) sieve (size 1/8 inch). This type of sand is generally used for mortar in masonry works and (3) Coarse sand: All the particles should pass through No. 4 (ASTM) sieve (size 3/16 inch). This type of sand is very suited for concrete work.

8.4 **Properties of Good Sand:** Sand should be of pure silica ($SiCO_2$). It should be free from clay, silt, organic matter, shells, and salts. It is preferable that sand should be washed before use in all engineering construction.

8.5 **Test on Sands:** Sand is usually tested for silt and clay and organic matters.

Test for Silt and Clay: The presence of silt and clay in sand is determined by the percentage loss in weight of a sample after washing the same with clean water.

Test for Organic Matter: The presence of organic matter is determined by stirring a sample of sand with 3% solution of sodium hydroxide or caustic soda in a closed bottle. The sample is left for 24 hours. The colour of the solution turns brown if any organic matter is present. The amount of organic matter is determined from the intensity of darkness of the solution.

85. Tests on Sand: Sand is usually tested for silt and clay, and organic matter.

lest for Silt and clay: The presence of silt and clay in sand is determined by the percentage loss in weight of a sample after washing the same with clean water.

8.5 **Availability of Sand in Bangladesh:** It Is abundantly available all over Bangladesh. Very *good* variety of river sand is available in the districts of Dhaka, Mymensingh and Sylhet (Savar, Kaliakair, Durgapur, Sunamganj). Both sea sand and river sand of good quality are found in coastal districts like Khulna, Noakhali and Chittagong.

A good variety of coarse sand is abundantly found in Cox’s Bazar. Sand is also available in northern districts of Bangladesh but not good quality.

8.6 **Uses of sand:** Sand is mainly used in making mortar plaster. Sand and concrete. It is also used for manufacturing. How and sheet glasses. Sand is also used to fill up gaps in between bricks in road construction.

8.7 **Bulking of Sand:** This is the increase in the volume of a given weight of sand due to the presence of moisture. For upto about 5 to 8 percent of moisture by weight of sand there is a steady increase in volume to about 20 to 30 percent. The bulking of sand for small moisture content is to the formation of thin film of water around the sand grains and interlocking the air in between the sand grains and the film of water.

The bulking phenomenon of sand due to the presence of moisture can be experimentally demonstrate as follows. Take a known volume of dry sand in a graduated cylinder and small quantities of water successively. It will be observed that each time there is an increase in volume upto 8 percent of moisture. Upon further addition of water, the moves into the voids between the particles so that the total volume of sand decrease until when fully saturated (Flooded) its volume is approximately the same as the volume of dry sand originally take. This is apparent from, 8.1 which also shows that finer sand bulks. considerably more and reaches maximum bulking at a higher water content than does coarse sand. Extremely fine sand has been known to bulk as 40 percent at a moisture content of 10 percent but such a sand is in any case very unsuitable for making of good quality concretes.

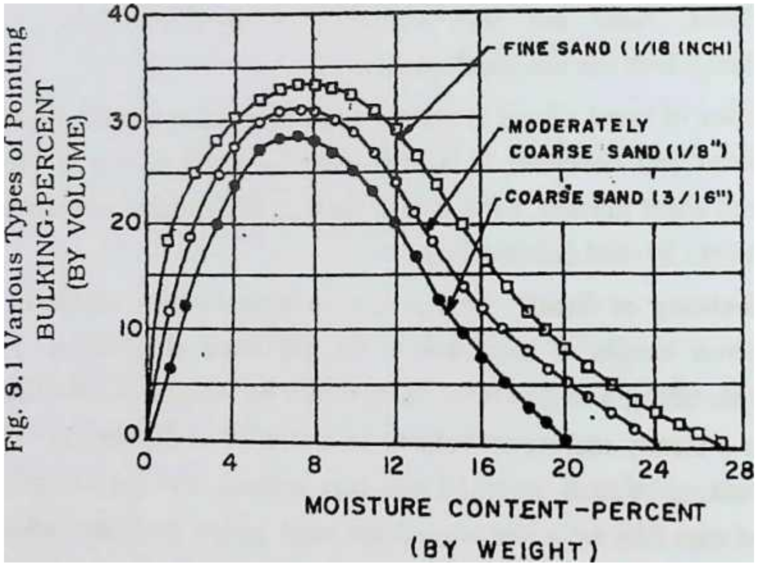


Fig. 8.1

Fig. 81 Bulking of sands with different moisture content.

Since the volume of saturated sand is the same as that of dry sand, the most convenient way of determining bulking is by measuring the volume of the given sand when moistened.

The bulking of moist sand is determined by the following expression:

$$b = \frac{Vm}{Vs} \times 100 \qquad \textbf{(8.1)}$$

in which b is the bulking in percentage, Vs is the volume of dry or fully saturated sand and Vm is the moist sand.

Since it has been a common practice to measure sand by volume in preparing mortar and making concrete, due allowance should be made in its volumetric measurements for its apparent increase in bulk.

8.3 Grading of Sand: All sand particles should pass No. 4 to No 16 sieves (3/16 to 1/16 inch). But at the same time, sand should not contain very fine particles. In between these two extreme sizes, (3/16 to 1/16 inch), sand should contain particles of uniformly varying sizes or it should be grades in order to get dense mortars. The grading of these various sizes, of sand particles is determined by the help of ’Sieved Analysis'. A known quantity of dry sand (generally 100 to 200 gms.) is taken and sieved through a consecutive order of standard sieves **8", $1^{1}/_{2}$", $^{3}/_{4}$"**, **$^{3}/_{8}$"** No. 8, No 16. No. 30, No. 50 and No. 100. The percentages of the respective retained quantities are added and divided the sum by 100 to obtain *a* figure termed as 'Fineness Modulus' of the sample.

Fineness Modulus is an empirical formula obtained by taking the sum of the cumulative percentages of sand retain on the following standard sieves, 3". **$1^{1}/_{2}$", $^{3}/_{4}$"**, **$^{3}/_{8}$",** No. 8, No 16. No. 30, No. 50 and No. 100m and dividing the sum by 100. It is generally denoted by 'F'. The fineness modulus of and should be between 2 to 3. A smaller value of fineness modulus indicates the presence of larger proportions of finer particles and vice-versa.

It two or more different variety of sand are mixed together the combined fineness modulus of the mixed.

Sample can be determined as follows:

$$\text{From} = \frac{m.\,F + m,\,F\text{-}, + \ldots\ldots\ldots + Fn}{M_x + M_2 + \ldots\ldots\ldots\ldots + \quad mn} \qquad (8.2)$$

In which F com = combined fineness modulus.

Fi and F_2 = Fineness modulus of sample 1 and 2 respectively, mi and m2 = Amount of samples 1 and 2 respectively.

If R is the ratio of one variety of sand to be mixed with 1 of the other variety[7], then

$$R = \frac{Fi\text{-}Fcom}{Fcom\text{-}F_2} \quad (8.3)$$

The Eq. 8.3 can also be written as

$$R = \frac{Fi\text{-}Fcom}{F1\text{-}F2} \qquad (8.4)$$

Where Ri is the ratio of one variety in the combined mix. **Example:** 100 gms of Sunamganj sand was sieved through standard sieves and the following result were obtained:

Sieve	Cumulative percentage retained
3"	0.00
$1^1/_2$"	0.00
$^3/_4$"	0.00
$^3/_8$"	0.00
No. 4	0.00
No. 8	0.00
No 16	10.00
No. 30	30.00
No. 50	100.00
No. 100	100.00

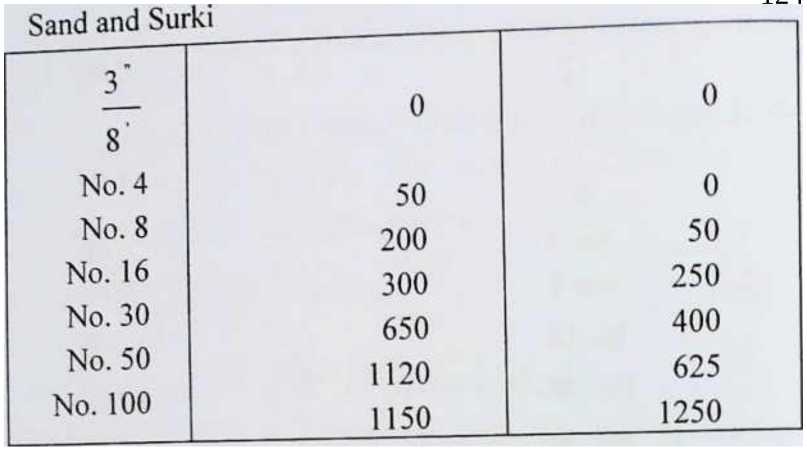
Compute the fineness modulus of the sample of sand. 240

Solution:

$$F = \frac{10+30+100+100}{100} = \frac{240}{100} = 21.40$$

Example: The following is the result of the sieve analysis of two samples of sand (1250 gms each), one from Savar and another from Durgapur. Calculate the combined fineness modulus.

Sieve	Savar sand Cumulative amount retained, gms.	Durgapur sand Cumulative amount retained, gms
3"	0	0
$1^1/_2$"	0	0
$^3/_4$"	0	0



Sand and Surki

$\frac{3"}{8'}$	0	0
No. 4	50	0
No. 8	200	50
No. 16	300	250
No. 30	650	400
No. 50	1120	625
No. 100	1150	1250

Sieve	Savar sand Cumulative amount retained, gms.	Durgapur sand Cumulative amount retained, gms
No. 4	4	0
No. 8	16	4
No. 16	24	20
No. 30	52	32
No. 50	90	50
No. 100	100	100
	286	206

Fs = 286/ 100=2.86 Fd= 206 / 200=2.06

$$Fcom = \frac{1250x2.86+ 1250x2.06}{1250+ 1250}$$

$$\frac{1250(2.86 + 2.06)}{2 \times 1250}$$

$$= \frac{4.92}{2} = 2.46$$

Example: Two samples of sand, one from Kaliakari (Fineness modulus = 2.24) were mixed together to get a combined fineness modulus of 2.54. Determine the ratio in which they were mixed.

Solution:

Fcom = 2.54, Fk = Fs = 2.24

$$R= \frac{2.84 -2.54}{2.54-2.24}$$

$$= \frac{0-30}{0.30} = 1$$

Samples were mixed in the ratio 1: 1

8.9 **Surki:** Surki is made by grinding freshly burnt and well burnt bricks. It should be perfectly clean free from foreign matter and sufficiently fine to pass through No. 8 sieve (US). Surki is largely used in making lime mortar, lime plaster and lime concrete.

Questions

Discuss the importance of sand in Engineering Construction.

Give the classification of sand passed on the following;

(a) source and (b) size.

Give the specification of good sand. Why sea sand is not recommended for making cement concrete?

4. What do you mean by bulking of sand? Do you think this phenomenon is important in designing a concrete mix? Justify your answer.
5. What is the purpose of grading sand? How is it done? What *is* "Fineness modulus”? Explain its significance in sand grading.
6. A mixed sample of 1200 gms. of two different variety of sands, on from Savar (Fineness modulus = 2.28) and the other from Durgapur (Fineness modulus = 2.74 were sieved and the combined fineness modulus was found to be 2.1: Calculate the amount of each variety of sand in the mix.

Ans. 600 gms each

7. Three different variety of sand A, B and C were mixed in the ratio 1. 2, 3 and their fineness modulus were 2.62. 2.32 and 2.80 respectively. Compute the combined fineness modulus.

Ans. 2.61

8. What is surki? Enumerate its uses. Give specifications for a good surki.

CHAPTER-NINE

MORTAR AND PLASTER

9.1 Mortar: Mortar is a paste generally made by mixing cementing or binding material (Lime or Cement) and an inter material (Sand or Surki) with water. There are different types of morter:

(1) Lime mortar: Lime + Sand + Water

(2) Surki Mortar: Lime + Surki + Water

(3) Lime Surki Mortar: Lime + Sand + Surki + Water

(4) Cement Mortar: Cement + Sand + Water

(5) Mud Mortar: Mud + Saw dust + Water

or Rice husk

or

Cow-dung

Sand should be sharp, angular, porous and free from salts and other impurities. Surki should be perfectly clear free from foreign matter and sufficiently fine to pass through No 8 (US) sieve. Lime must be well slaked and cement must be fresh and free from adulteration. Water should be clean, free from salts and other impurities and should be of drinking water standard. Mud should be free from foreign matter.

9.2 Function of Sand in Mortar: (1) Sand in mortar does not generally and to its strength but is used mainly as an intern material to give volume for economy (2) It subdivides the Paste of the cementing materials into a uiin film, which is the basic principle involved in using all cementing materials (3)

It offers the requisite surface areas lor the film of cementing materials to adhere and to spread (4) It prevents shrinkage and cracking of mortar in setting (5) A well grades sand adds to the density of the mortar (6) It allows carbon dioxide from the atmosphere to reach to some depth in case of fat lime mortars and thereby improves their setting power (7) It is also claimed that some chemical reactions take place between silica (SiO_2) of sand grains and the constituents of the cementing materials to form a hardened mass.

9.3 Functions of Surki in Mortars: In mortar, surki is used as an adulterant (a material which provides volume). Surki imparts strength and hydraulic property to mortars.

9.4 Uses of Mortar: Mortar is used (1) to bind together the bricks or stones in brick or stone masonry (2) to give a soft even bed between different layers of brick or stone masonry for equal distribution of pressure ever the bed (3) to fill up the spaces between bricks or stones for making walls tight (4) in concrete as a matrix (5) in plasting works to hide the joints and to improve appearance and (7) for moulding and ornamental purposes.

9.5 Preparation of Lime Mortar, Surki Mortar and Lime Surki Mortar:

These mortars are prepared by grinding the ingredients in a specific manner. Grinding is purely a mechanical process. It helps in preparing and intimate mixture of sand and lime, sand and surki, or sand, surki and lime with water and in slaking the unslaked lime particles if any.

Grinding is done either by ponding the ingredients in small mortal pits and mixing by human labor or by a bullock driven mortar mill, known as ’Ghani’ or 'Chakki’ or by power driven mortar mill.

The first method is used when mortar is required in small quantities. Bur for a steady and continuous supply of mortar as in the case of large construction, power driven mortar mills are employed.

Mortars are ground in two stages. In the first stage, the cementing material is ground with water to the consistency of a thin and lean mix. In the second stage, sand or surki or both is added in the require proportion and grinding is done. During the process of grinning, the mixture is properly turned by a scraper and a requisite quantity of water is again added to impart the proper consistency.

Mortar should consist of one part lime to two or more parts of sand, or sand and surki together. The proportion may vary depending upon the nature of works. The lime, sand and surki, are to be measured dry by volume and not by weight. They are to be thoroughly mixed by grinding with a sufficient quantity of water to bring the mortar up to the proper consistency to give very workability. The mortar should always be used as stiff as it can be spread and should be used as soon as possible after being mixed. The mortar which has once set or which has been left for more than 24 hours after it has been mixed, should not be used. These mortars are used in temporary and important types of construction works.

9.6 Preparation of Cement Mortar: Cement and sand in definite proportion are measured by volume (cement is generality measured by weight, 93 lbs. being taken as equivalent to 1 eft or 1 bag cement = 1.25 eft = 112 lbs.). Sand is first spread to uniform thickness on a non-porous plant form and then the cement is spread over sand. The cement and sand are mixed together thoroughly till the colour is uniform to get a dry mix. The quantity of water to be added is calculated and only half of that quantity is sprinkled on the dry mix. The remaining quantity of water to be added is calculated an only half of that quantity is sprinkled on the dry mix. The remaining quantity of water is now added and the whole mixture is turned over twice or thrice to form cement mortar should be mixed in small quantities which can be used up on the work before the initial setting of the cement commences. Mortar which has set already should not be used Cement mortar is used in all important types of constructions.

9.7 Mud Mortar: Sticky clay and saw dust or cow-dung or rice husk are puddled or pugged with water until it comes to the required consistency. It is frequently used for economy in temporary works not exposed to the action of water and other unimportant works like ’kancha’ walls etc. Brick masonry in good mud mortar can stand a safe pressure of 1 ton per sq ft.

9.8 Curing of works in lime and Cement Mortars: All works done in lime and cement mortar should be kept wet for about 15 days for the purpose of curing. During this period important chemical reactions take place and the whole mass gains strength through the process of hardening. Occasional sprinkling with water is necessary until the works set and become hardened.

9.9 Special Varieties of Mortar: The following are the special varieties of mortars that are used in special types of engineering constructions:

(1) **Grout:** Very thin lean or liquid mortars are termed as grout and are specially prepared to fill in the cracks, faults or narrow joints. The process is term as "grouting.

(2) **Cement-Lime Mortar:** This is prepared by adding 15 to 20 per cent of hydrated lime in cement mortar. This mortar is more plastic, spreads readily and easily and produces greater uniformity and better workability.

(3) **Gauged Mortar:** Lime mortar is not very strong. There-fore to achieve more strength, 1 part of cement is used with 6 to 8 parts of lime mortar. This process of adding cement to lime mortar for better strength is termed as ’gouging'.

(4) **Pumice Mortar:** This is prepared by adding finely ground pumice with lime mortar. Finely ground pumice is added in the proportion of half or one part to one part of lime. This imparts better strength to lime mortar.

(5) **Pozzolana Mortar:** It is prepared by adding required proportion of pozzolana to lime mortar in order to impart more strength.

(6) **Cinder Mortar:** This type of mortar is prepared by mixing 1 part of slaked lime, 1 $^1/_2$ part of crushed cinder (obtained from railway engines and boiler ashes) and 1 $^1/_2$ part of sand with required quantity of water. This mortar is light in weight and is mainly used for cheap and unimportant constructions.

(7) **Light-weight Mortars:** These mortars are prepared by mixing saw dust, rice husks, jute fibers, coir’s, asbestos fibers

etc. along with sand and lime or cement. Cinder mortar is also another variety of light-weight mortals. For developing adhesion, small quantities of glue or other adhesive materials are added to mortars.

9.10 Precautions in Using Mortars: The following precautions are to be adopted carefully to get good works from mortars:

(1) Mortar should be mixed in small quantities so that it can used conveniently before the mortar starts setting. The mortar which has already should never be used.

(2) In using mortars, bricks or stones to be jointed together should be soaked in water very thoroughly at least for 12 hours before they are put into work with mortar so as to prevent the absorption of moisture from the mortar before it sets.

(3) Mortar should be as stiff as it can be used without inconvenience and the joints should be well filled.

(4) Works made of mortar should be kept wetted for a week or two after it has been laid so as to prevent the rapid drying of mortar especially in hot weather like in Bangladesh.

9.11Plaster: Plaster is a thin coat of mortar of different composition which is applied on both external and internal faces of walls ceilings, columns, staircases etc. The process of applying plaster is termed as plastering. Plastering, work must be cured properly and carefully, otherwise, cracks may develop.

9.12 Uses of Plaster: Plaster is used go give a smooth and finished surface to the works (2) to cover joints and defective workmanship, (3) to preserve surface from the action of weathering (4) to provide a ground for decoration or white or

colour washing and for moulding, ornamental and architectural works.

9.13 Specification of Good Plaster:

1. It should adhere firrnaly to the surface on which it is applied.
2. It should not strink or contract in volume on drying and setting, otherwise it cracks and gives an unsightly appearance
3. In case of lime plaster, it should not contain unslaked particles of lime which absorb moisture from the atmosphere and spoils the plastered surface.

9.14Classification of Plaster: Plaster is divided into the following classes:

1. **Lime Plaster:** Lime plaster consists of lime and sand (usually 1 part lime, 2 to 3 parts sand) mixed with water to form a paste of required consistency/. The mixture should be kept in a vat for about 24 hours and then to be laid on the soaked surface 3/8 to $^1/_2$ inch thick in one coat and thoroughly smoothed. The plastered surface should be kept moist for at least two weeks afterwards.
2. **Surki Plaster:** Surki plaster consists of lime and surki (I part lime: 1 $^1/_2$ to 2 parts surki): mixed with water to form a paste of required consistency and is mainly used in plinths and walls. It is suitable for surface exposed to sun and air. Surki shrinks on drying and so plaster white selling is beaten well for hours with wooden mallets. It is laid on soaked surface 3/8 to $^1/_2$ inch thick in one coat.
3. **Lime-Surki Plaster:** To prevent shrinkage, sand is added to surki plaster in the proportion of 1 part lime: 1-part surki and

1 part sand. It is laid in thickness 3/8 to $^{1/}{}_{2}$ inch in one coat on soaked surface.

4. **Neeru or lime Putty:** This is prepared from the best variety of quick lime. The quick lime is slaked first with fresh water and then screned through a fine screen. It is them kept immersed in water for about 7 days and the excess water is then decanted. The paste thus obtained is termed as neeru or lime putty. This putty when used in making plasters imparts high degree of plasticity and workability. This type of plaster is mainly used for the finishing coat of plastering of walls of various types.

5. **Moghal Plaster:** This is composed of stone lime, sand and surki in the proportion 1:2:3 or 1:3:4. The ingredients are ground very thoroughly and mixed with some adhesive (glue) substances. The Moghal plaster is usually applied in two coats, 3/8 to V_2 inch thick each on wet surface and properly rubbed and smoothed. After laying, the surface should be kept moist for about 15 days.

6. **Mud Plaster:** This is composed of selected mud and cow dung or saw dust in equal proportion and sometimes one pound of straw is added to every two eft of plaster. The materials are mixed very thoroughly and the plaster is applied on the surface in two coats of total thickness of 3/4 inch. The first coat is applied by hand to fill up all the interstices of the surface and is left with rough surface. When the first coat is nearly dry, the second coat is applied with trowel and worked to a smooth even surface. The straw or saw dust need not to be used in the second coat. When the surface will dry up there will be development of cracks on the surface which

must be filled up again with plaster finally the mud plastered surface is given sometimes a thin coat of pure lime plaster.

7. **Cement Plaster:** This is composed of Portland cement and standard sand in the proportion 1:2, unless otherwise specified. The ingredients are mixed with water to form a paste of required consistency. The wall or the surface to be plastered is carefully scraped off and thoroughly cleaned and soaked with water before laying the plaster. It is always laid in single coats from 1/4 to 1 inch thick. The plastered surface is cured for about two weeks. Cement plaster is used in most important engineering constructions like dams, reservoirs irrigation canals and other structures in contact with water and also for wall, floors, ceilings etc.

8. **Stucco Plaster:** The term ’stucco' is generally applied to an ornamental coat of plaster on walls. This made of either cleans white shell lime and powdered marble (1: 2) or cement plaster (1:2$^{1}/_{2}$) or (1: 3). This type of plastering consists of three coats, each about 1 $^{1}/_{2}$ inch thick. These coats are scratch coat brawn coat and finished coat. Scratch coat is generally 3/8 to $^{1}/_{4}$ inch thick. This coat is troweled hard and tight and deeply cross-scratched just before setting in order to provide bond for the nest coat. Brown coat is applied to thickness of $^{3}/_{8}$ to $^{1}/_{2}$ to 3 days and then allowed to dry completely. Finished coat is applied when all other works in the structure are completed, otherwise it is spoiled or damaged by the workmen. The thickness of the finished coat is generally Vs to V_2 inch.

9. **Gypsum Plaster:** First natural gypsum is crushed and ground to fine powder and heated to a high temperature of 125 to

140°F. The product thus obtained is termed as plaster of Paris. Gypsum plaster is prepared by mixing *plaster of Paris* and sand (1:3 or 1:4) with sufficient quantity of water to produce required consistency. To avoid quick setting, retarder in the form of coir, saw dust. Jute cutting etc. is used with gypsum plaster.

Gypsum plaster is very strong and fire resistant. There is no abnormal change in volume when dry. It is generally used for decorative face works, internal walls and ceiling, decorations and for architectural structures. It is also used for soundproofing. But it is very costly.

10. **Mosaic Plaster or Terrazzo Plaster:** This consist of marble chips or stone chips /2- inch down size and white or colored cement in the ratio 2:1 unless otherwise specified. Sometimes a coloring ingredient is used with white cement in place of colored cement. The thickness of this type of plaster ranges from V2 to $^{1}/_{4}$ inch. The ingredient is mixed thoroughly by adding water gradually. Minimum amount of water is to be used otherwise the colour will be spoiled by efflorescence which takes place if too much water is added. The mixture is then laid over a prepared sub-base poked properly and levelled. The plastered surface should not be disturbed for 24 hours. After that, the surface should be kept moist for about 2 weeks. Then polishing is done by stone like carborundum in plenty of water. Finally, the surface should be finished up with soft powdered slate and oxalic acid and a through wash with clean water is given. After washing, the surface is allowed to dry and finished with *way-polish.*

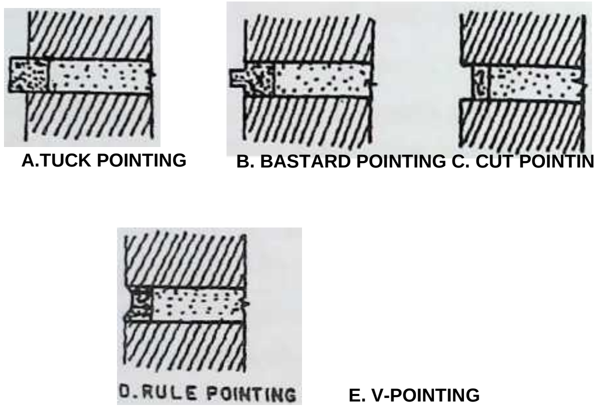
It may be of precast tiles, normally 1" thick and 6" x 6" in size. It can have many variations in colour, shades patterns and designs.

The external and internal surface of structure finished with mosaic or terrazzo plaster enhance beauty of the structured. It is mainly used in room-floors, floors and walls of toilets and bathrooms. It is also used for decorative and ornamental purpose.

9.15 Sand Rubbing: The external plastered surface of buildings is sometimes finished with sand rubbing which is a plaster composed of cement, lime and clean sand in the proportion, 1:2:6 unless otherwise specified. It is laid on plastered surface in thickness of $^{1}/_{16}$ to $^{1}/8$ inch. The surface is thoroughly rubbed, smoothed and finished. The surface is to be kept moist for at least 2 days.

9.16 Pointing: Pointing is the finishing off (with the trowel) of the mortar in the rough brick joints of walls to give the surface a beautiful appearance. For cement pointing the plaster should consist of cement and clean sand in the proportion 1:2. In lime and surki pointing, the plaster consists of lime and surki in the proportion 1:1. All joints on walls are raked out to a depth not less than 7 inch and all dusts are brushed off. The surface of walls kept moist for at least 24 hours before pointing is started. If specified coloring ingredient is added to the plaster. There are various types of pointing such as tuck pointing, bastard (half tuck) pointing, cut pointing, rule pointing, V-pointing (Fig, 9.1) and the choice of a particular type depends upon the owner.

Pointing gives attractive appearance of walls. I he Curzon Hall in Dhaka city is a typical example of good pointing. Pointing protects joints from dampness and makes then water proof. Pointing is also applied on old walls when the joints become loose and defective.


A.TUCK POINTING B. BASTARD POINTING C. CUT POINTING

D.RULE POINTING E. V-POINTING

Fig. 9.1 Various Types of pointing

9.17 Lime Punning: This is a very thin coat of lime plaster. This is usuals applied to the ceilings and walls. This plaster consists of fresh slaked lime and good sand in equal volumes. The lime and sand are first to mixed dry thoroughly and then water is added just enough to make it a workable mixture. The lime punning is laid in thickness not more than 1/16 inch and the surface is made smooth.

9.18 White Wash: This is applied to give better appearance to the surface and also for sanitary reasons, because lime is said to have antiseptic and disinfectant properties. The process of application of white wash is termed as white washing.

I he white was is prepared in vats by mixing and stirring slaked lime a water in a proportion which will produce a mixture of the consistency of thin film. Some, adhesive substance like gum or paste of boiled rice are used in the white wash. To prevent glamour and to give pleasing effect, a small quantity of copper sulphated is sometimes added to it.

The white wash is laid on plastered clean surface in 2 to 3 coats vertically and horizontally alternately. Each coat is to be dried perfectly before the succeeding one is laid on it. The final coat is laid by hair brushes.

9.19 Colour Wash: This nothing but white wash with some, desirable coloring ingredients added to it. The process of laying is exactly similar to that of white wash except a sufficient quantity of colour wash is to be prepared at a time to complete a certain portion of the surface so that colour is uniform. This is mainly used for decorative purposes.

9.20 Distemper: Distemper is a coloring substance in solutions. The process of colouring surfaces of walls with distempers is termed as *distempering.* Distempers are readily available in the market with manufactures instruction for mixing and applying.

Questions

1. What is mortar? Name the different types of mortars used in engineering constructions. State their composition, pointing out clearly the importance of each ingredient and the functions played by it.

9 State the functions of sand and surki in mortars. Enumerate the uses of mortars.

3. Explain the objectives of (a) grinding of lime-surki mortars in mills (b) spacing bricks or stones before use and (c) curing of mortar works.
4. What is cement mortar? How it is prepared? Supply the specification of a good cement mortar.
5. Write short notes on:

   (a) Groutins (b) Gauging (c) Pozzolana mortar (d) Lightweight mortars (e) Precautions in using mortars.
6. Distinguish between mortar and plaster. What is the different type of plasters. Give specification of a good plaster.
7. Write explanatory notes on the following:

   (a) Plaster of paris (b) Stucco plaster (c) Terrazzo plaster, (d) Lime punning (e) Sand rubbing.
8. What is pointing? Explain various types of pointing with near sketches.
9. Distinguish between white washing and lime punning. What is a distemper? Distinguish between distempering and colour washing.

CHAPTER-TEN

CONCRETE

10.1 Introduction: Concrete is an artificial stone manufactured from a mixture of binding materials and inert materials with water.

Concrete = Binding materials + Inert materials + water.

Concrete is ’considered as a chemically combined mass where the inert material acts as a filler and the binding material acts as a binder. The most important binding material are cement and lime. The inert materials used in concrete are termed as aggregates. The aggregates are of two types namely. (1) fine aggregate and (2) coarse aggregate.

Fine aggregate: Sand and Surki are commonly used as fine aggregate in Bangladesh., Stone screenings, burnt clays, cinders and fly-ash are sometimes used as a substitute for sand in making concrete. The fine aggregate should not be larger than 3/16 inch (4.76mm) in diameter.

Coarse Aggregate: Brick Khoa (broken bricks) broken stones, gravels, pebbles, clinkers, cinders etc. of the size of 3/16 to 2 inch are commonly used as coarse aggregate in Bangladesh. It may be remembered that 3/16 inch is the dividing lime between fine and coarse aggregates.

Functions of Aggregates in Concrete: The aggregate give volume to the concrete, around the surface of which the binding material adheres in the form of a thin film. In theory the voids in the coarse aggregate is filled up with fine aggregate and again the voids in the fine aggregate is filled up with the binding materials. Finally, the binding materials as the name implies, binds the individual units of aggregates into a solid mass with the help of water.

Qualities of Aggregates: Since at least three quarters *of* the volume of concrete is occupied by aggregate, it is not surprising that its quality is of considerable importance. Not only the aggregate limit the strength of the concrete, as weak aggregates cannot produce a strong concrete, but also the properties of aggregates greatly affect the durability and structural performance of the concrete.

Aggregate was though, originally viewed as an inert material dispersed throughout the cement paste largely for economic reason, yet it is possible, however, to take an opposite view and to look on aggregate, as a building material connected into a cohesive whole by means of cement paste in a manner similar to masonry constructions. In fact, aggregates are not truly inert and their physical chemical and sometimes thermal properties influence the structural performance of a concrete.

Aggregates are cheaper than cement and it is therefor, economical to put into the mix as much as of the former and as little of the latter. But economy is not the only reason for using aggregate, it confers considerable technical advantage on concrete, which has a higher volume stability and better durability than the cement past alone.

The qualities of fine aggregate (sand) have already been discussed in chapter 8.

Thee coarse aggregates should be clean, strong, durable and well grades and should be free from impurities and deleterious materials, such as salts, coal residue etc.

Functions of Water in Concrete : 3 Water serves the following purposes : (1) to wet the surface of aggregates to develop adhesion because the cement paste adheres quickly and satisfactory to the wet surface of the aggregates than to a dry surface (2) To prepare a plastic mixture of the various ingredients and to impart workability to concrete to facilitate placing in the desired position and 3 Water is also needed for the hydration of the cementing materials to set and harden during the period of curing.

10.2. Classification of Concrete: There are mainly two types of concrete namely, (1) lime concrete and (2) cement concrete.

Lime Concrete = Lime + Surki + Khoa + Water.

Cement Concrete = Cement + Sand + Khoa + Water or Stones.

Lime Concrete: Lime concrete consists of lime surki and khoa or stones in the proportion 1:2:5 unless otherwise specified. The khoa or stones should be soaked thoroughly in water before mixing. The lime and surki in required proportion are to be first mixed dry by volume on a clean watertight platform till the colour is uniform. The requisite quantity of thoroughly soaked khoa or stones is then added and the whole again mixed very thoroughly. Water is then added gradually and mixing is continued till a workable mixture is obtain. Concrete should be mixed in such a quantity that it can be utilized during the day it is mixed and the concrete which has been left overnight should not be used. The concrete thus mixed should be laid evenly in the position in which it is desired to be used. The common practice of throwing concrete in the desired position by the workers should be avoided. Concrete is to be laid in layers not exceeding 3 inch in thickness. Each layer is to be thoroughly compacted before the next layer is laid. Concrete is to be kept well wetted while setting and at least 7 days after the final layer is completed.

Limes concrete is used mainly in foundation and in terrace roofing.

Cement concrete: Cement concrete is widely used in all important engineering constructions. It consists of cement, sand and brick khoa or stones of required size in the proportion 1: 2: 4 or 1: 3: 6 unless otherwise specified.

The ingredients are measured dry separately by volume according to required proportion. In measuring cement generally 90 lbs. will be taken as I cu ft and hence I bag of cement. (112 lbs.) equals 1.25 cu ft. The khoa or stones are soaked thoroughly in water before use. The fine and coarse aggregates are mixed dry first on a clean watertight platform. The cement is then added and mixed thoroughly once again till the colour is uniform. The required quantity water is then gradually added and the whole is mixed thoroughly. When the coarse aggregate has been soakes thoroughly the approximate quantity of water is 4.5 gallons for one cut it of cement in a concrete of 1:2:4. The quantity of water should be such that the mixture would give a good workability. The concrete is to be prepared in small quantities which can be used within 45 minutes and any unused concrete after that time should not be used. In foundation works, the concrete is to be rammed properly the water appears on top and on khoa or stone is left uncovered by mortar. In reinforced concrete work the

concrete is to be poked very thoroughly with steel rods of recommended size to get rid of voids and to ensure a good between concrete and the reinforcing steel sometimes a mechanical vibrator is used to minimize voids as soon as the concrete has set the surface should be sprayed with water. The process of curing is to be applied 28 days to attain its proper strength. Mixing concrete by hand does not generally produce a good concrete. Where large quantity of concrete is required and also a very good quality concrete is desired the mixing is done in a mechanical mixer.

10.3Advantage of Concrete Over other Materials of Construction: The following are main advantages of concrete construction:

1. Concrete is free from defects and flaws which natural stones are associated.
2. It can be manufactured to desired strength and durability[7] with economy.
3. It can be cost to any desired shape.
4. Maintenance cost of concrete structures is almost negligible.
5. Concrete does not deteriorate appreciably with age.

10.4Special Terms: To understand thoroughly the proper ties of concrete the following terms need classification first.

1. **Segregation:** Segregation can be defined as separation of the constituents of a heterogenous mixture so that their distribution is on longer uniform. In case of concrete, it is the difference in the size of particles and in the specific gravity of the mix constituents that are the *primary* cause of

segregation but its extent can be controlled by the choice of suitable grading and water-cement ratio and by care i_n handling transporting and placing of concrete.

In concrete, there are two forms of segregation. First the coarse particles tend to travel further along a slope or settle more than finer particles. The second form of segregation, occurring particular in wet mixes is manifested by the separation of grout (cement plus water) from the mix. With some gradings where a lean mix is used the first type of segregation may occur if the mix is too dry; addition of water would improve the cohesion of the mix but when the mix becomes too wet, second type of segregation would take place.

This influence of grading on segregation will be discussed later in detail but the actual extent of segregation depends on the method of handling and placing of concrete. If the concrete is transferred directly from the mixer or mixing place to the final position in the formwork, the danger of segregation is small. On the other hand, dropping concrete from a considerable height to the final position, the segregation is encouraged. Concrete should always be placed directly in the position in which it is to remain and must not be allowed to flow or be worked along the formwork. This prohibition includes the use of vibrator to spread a heap of concrete over* a large area. Vibrator provides a most valuable means of compacting concrete, but because a large amount of work is being done on the concrete, the danger of segregation due to improper use of the vibrator is incurred. This is particularly so when vibration is allowed to continue too long resulting the separation of coarse aggregate towards the bottom of the

formwork and of the cement paste towards the top. Such concrete obviously would be very weak.

It may be noted that entrained air reduces the danger of segregation.' On the other hand, the used of coarse aggregate whose specific gravity differs appreciably from that of the fine aggregate would lead to increased segregation.

Segregated is difficult to measure quantitatively but is easily detected when concrete is handled on a site in any of the ways discussed earlier as undesirable. With a correct method of grading handling, transporting and placing, the likelihood of segregation can be greatly reducing.

2. **Bleeding:** Bleeding (known also as 'water gain') is a form of segregation in which some of the water in the concrete z tends to rise to the surface of freshly placed concretes. This is caused by the inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards. Bleeding is a special case of sedimentation. It can be expressed quantitatively as the total settlement per unit height of concrete.

   As a result of bleeding the top of concrete becomes too wet and if the water is trapped by supper imposed concrete a porous, week, and non-durable concrete will result. If the bleeding water is remixed during finishing of the top surface, a weak wearing surface will be found. This can be avoided by delaying the finishing operation until the bleeding water has evaporated. On the other hand, if evaporation of water from the surface of the concrete is faster than the bleeding rate, plastic shrinkage cracking may result (to be discussed later).

Some of the rising water becomes trapped on the underside of the particles of coarse aggregate or of reinforcement thus creating zones of poor bond. The tendency of bleeding depends largely up to the properties of cement and is also affected by certain chemical factors: there is less bleeding when the cement has a high alkali content, a C_3A content or when calcium chloride is added.

Rich mixed are less prone to bleeding then lean (weak) ones. Reduction in bleeding is obtained by the addition of pozzolana or of an aluminum powder. Air entrainment also effectively reduces bleeding. Physical properties of fine aggregate (size) also affect bleeding.

Bleeding of continues until the cement paste has stiffened sufficiently to put an end to the process of sedimentation.

3. **Laitance:** Laitance is the formation of a crust of squeezed out mortar on the surface of concrete. This is due to bleeding and had workmanship. This produces a bad or weak concrete. For preparing watertight concrete, segregation, bleeding and laitance should be very carefully avoided.

10.5 Properties of Concrete: The following are the desirable properties of concrete (1) Strength, (2) Elastic properties. (3) Fatique (4) Durability (5) Impermeability and (6) Workability.

Strength. Strength of concrete is commonly considered its most valuable property, although in many practical cases other properties like durability and impermeability may in fact be more important. Nevertheless, strength usually gives the over a picture of quality of concrete. Strengths of concrete

are following types: (a) compressive strength (h) tensile strength (c) flexural strength and (d) shear strength.

Compressive Strength Test: Two types of test specimens are used in our country: (i) Cubes and (ii) Cylinder.

The cube specimens of concrete of a desired proportion are cast in steel or cast-iron moulds, normally 6-inch cube. The standard cylinder specimen of concrete is 6 inch in diameter and 12 inch high and is cast in a mould generally made of cast iron.

The standard practice is to fill the cube mould with concrete in three equal layers. Each layer of concrete is compacted by not less than 35 strokes of a 1-inch square steel punner. Ramming is continued until sufficient compaction has been achieved. The top surface of the cube is to be finished smooth by means of a trowel.

Cylindrical specimens are made in a similar way to the cubes but are compacted either in three layers using a 5/8-inch diameter steel rod or in two layers by means of an immersion vibrator.

After preparation, the cubes and cylinders are stored undisturbed for 24 hours at a temperature of 58° to 66° and a relative humidity of not less than 90 percent. After 24 hours the moulds are stripped of and the cubes and cylinder are further cured in water at 58° to 66°F (B.S.)

Standard cubes and cylinders are tested at prescribed ages, generally 28 days with additional tests often made at 1,3, and 7 days. The specimens are tested for crushing strength under a testing machine. The crushing strength is taken.

The cube tests give much greater values of crushing strength usually 20 to 30 per cent more than those given by cylinders Table 10.1 shows the typical test results on cubes and cylinders on the same concrete.

Table 10.1 Crushing strength of Cubes and Cylinders.

Crush in Cube	strength, psi Cylinder	Ratio of strengths Cylinder/cube	Difference of strengths (cube cylinder)
1,300	1.000	0.77	300
2,200	1,700	0.77	500
2,900	2,200	0.76	700
3,600	2,900	0.91	700
4,000	3,500	0.87	500
4,200	3,800	0.91	400
4,300	3,900	0.81	400
5,200	4,600	0.89	600
5,300	5,000	0.94	300
6,100	5,300	0.87	z800
6,400	5,900	0.92	500
7,000	6,400	0.91	600
7,600	7,300	0.96	300

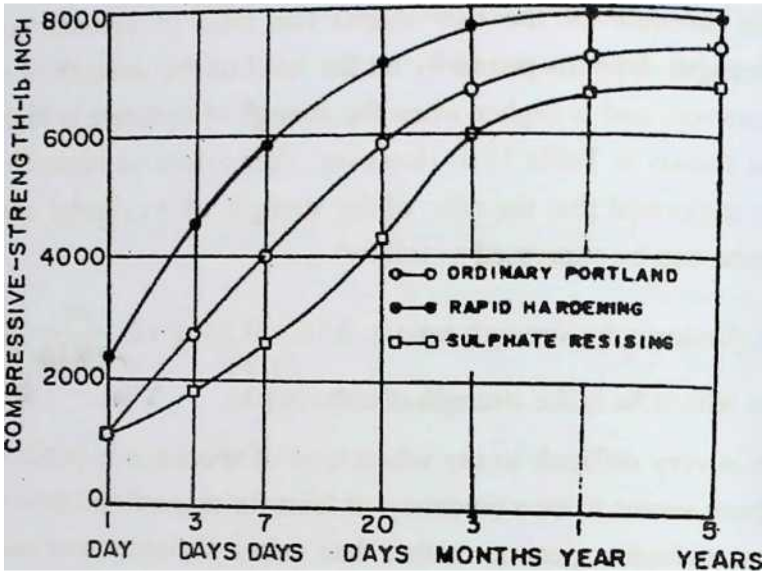
According to British standard the strength of a cylinder specimen is equal to three quarter, (75%) of the strength of the cube specimen, but the experimental results shown in Table 10.1 show that there is no definite relationship between the strength of the two shapes. The ratio of cylinder/cube strength depends primarily on the level of the strength of the concrete and is higher when the strength of concrete is higher as shown in Table 10.1. However, after extensive research, it is suggested that the ratio of the strength of *a* cylinder and a cube can be expressed as follow:

$$\text{Cylinder/cube strength ratio} = 0.76 + 0.2 \log 10\,(se/2.840) \qquad 10.1$$

in which Se is the strength of cube in psi.

It is very difficult to say which type of specimen is better but there seems to be a tendency, at least for research purposes to use cylinder specimen rather than cubes. Cylinder specimens are believed to give greater uniformity of results for nominally similar cube specimens because of the following reasons: (1) their failure is less affected by the end restraint of the specimen (2) their strength is less influenced by the properties of the coarse aggregate used in the matrix: and (3) the stress distribution on horizontal planes in a cylinder is more uniform than of a specimen of square cross section.

Effect of Age on Strength of Concrete: Concrete attains strength with time. The rate of gain of strength of different type of cement concrete has been shown in typical strength time curves in Fig 10.1. Ordinary' cement concrete (with ordinary Portland cement) gains above 70 to 75% of its final strength within 28 days and about 90 to 95 percent in the course of one year.



Age (Long Scale)

Fig. 10.1 Rate of Development of Strength of Different Types of Cement Concrete.

The rate of gain in strength of concrete is of interest in connection with testing. It is often desirable to check the suitability of a concrete long before the results of the 28-day test are available. When no specific data on the materials used in making concrete are not available, the 28 days strength may be assumed to be 1.5 times the 7 days strength. Tests have shown that for concrete made with ordinary Portland cement the ration of the 28 days to 7 days strength lie generally between 1.3 to 1.7 but the majority of the results fall above 1.5. The extrapolation of 28 days strength from the 7 days strength is, therefore quite reliable. However, in a hot climate country like Bangladesh, the gain in early strength is high and the ratio of the 21 days to 7 days strengths tends to be lower than in cooler weather.

In practice, the relationship between the 28 days strength, S_{28}. and the 7 days strength, S_7 is often taken to lie between;

S_{28}= 1.455_7+ 150 (10.2)

and $S_{28} = 1.75S_7 + 850$ (10.3)

Some engineers also recommended the use of an approximately linear relationship between the strength and the logarithms of age within the range of 3 days to 2 months. Thus, if the strength is determined at 3 and 7 days, it is possible to estimate the 28 days strength by extrapolation.

All the expressions mentioned here apply only to concrete made with ordinary Portland cement. Many of the other cements gain strength at different rates and when they are used, the prediction of strength should be based on experimentally results.

Tensile Strength: Concrete is very weak in tension. The tensile strength of ordinary concrete ranges from about 7 to 10 percent of the compressive strength.

Flexural Strength: The flexural strength of plain concrete is almost wholly dependent upon the tensile strength. Experiments show, however, that the modulus of rupture is considerably greater than the strength in tension. Flexural strength is of importance in the design of concrete pavents.

Shearing Strength: The shearing strength of concrete is almost important property of the material, since it is the real determining factor in the compressive strength of short columns. The strength of concrete beams depends also, under certain condition, upon the shearing strength of the material. The average strength of concrete in direct shear varies from about half of the compressive strength for rich mixtures to about 0.8 of the compressive strength for lean mixtures.

Elastic Properties: The elastic properties of concrete are of importance hot only because of their bearing upon the deformation of concrete structures under load but also for the design of reinforced concrete, it is necessary to know the relative stresses in the steel and concrete under like distortions.

Concrete is not perfectly elastic for any range of loading, an appreciable permanent setting taking place for even low loads and the deformation is not proportional to the stress at any stage of loading. The elastic properties of concrete vary with the richness of the mixture and with the intensity of the stress. They also vary with age of concrete.

3. **Fatigue of concrete:** Plain concrete when subjected to flexure, exhibits fatigue. The flexure-resisting ability of a concrete of a given quality is indicated by an endurance limit whose value depends upon the number of repetitions of stress. In concrete pavement design, the allowable Flexeril working stress is limit to 55 percent of the modulus of rupture strength of the concrete used.

Durability of concrete: It is essential that concrete should withstand the condition for which it has been designed without deterioration over a period of years. Such concrete is said to be durable.

The absence to durability may be caused either by the environment to which the concrete is exposed or by internal causes within the concrete itself. The external causes can be physical, chemical or mechanical; they may be due to weathering, extreme temperature changes, abrasion, electrolytic action and attack by natural or industrial liquids and gases.

The internal causes are the alkali-aggregate reaction (the reaction between the silica constituents of the aggregates and alkalis in cement), volume changes, due to the differences in thermal properties of aggregates and cement paste and above all, the permeability of the concrete. The last cause, permeability determines vulnerability of concrete to external agencies so that in order to be curable, concrete must be relatively impervious.

5. **Impermeability of concrete:** Penetration of concrete by materials in solution may adversely affect its durability, for instance when Ca $(OH)_2$ is being leached out or an attack by aggressive liquids (acids) takes place. This penetration depends on the permeability of the concrete and since this determines the relative case with which concrete can become saturated with water, permeability has an important bearing on the vulnerability of concrete to water and frost. Furthermore, in the case of reinforced cement concrete (concrete which is strengthened by using steel rods), the penetration of moisture and of air will result in the corrosion of steel. Since this leads to an increase in the volume of the steel, cracking and spalling of the concrete may well follow.

Permeability of concrete is also of interest in relation to water tightens of liquid retaining structures and some other hydraulic structures and also with references to the problem of hydrostatic pressure in the interior of dams. Therefore, concrete should be impervious for its durability.

6. **Workability of Concrete: The** strength of concrete of given mix proportion is very seriously affected by the degree of its compaction; it is, therefore, vital that the consistency the mix be such that the concrete can be transported placed and finished sufficiently easily and without segregation. A concrete satisfying these conditions is said to be workable but to say merely that workability determines the case of transportation, placement and finishing, and the resistance of concrete to segregation is too loose a description of this vital property of concrete workability can be best defined as a physical property which is the amount of useful external and internal works necessary to produce of compaction of concrete.

Another term used to describe the state or fresh concrete is consistency. In a simple language, the word consistency' refers to the firmness of a form of a substance or to the case with which it will flow. In case of concrete, consistency is sometimes taken to mean the degree of witness; within limits, wet concrete is more workable than dry concrete, concretes of the same consistency may vary in workability.

Factors Affecting Workability: The main factor is the water content of the mix, expressed in pounds per cube yard of concrete, it is convenient, though approximate to assume that for a given type and grading of aggregates and workability of the water content is independent of the aggregate cement ratio. On the basis of this assumption the mix proportions of concretes of different richness can be

estimated and Table 10.2 gives typical values of water content for different slumps and maximum size of the aggregates.

Table 10.2 Approximate Water Content for different Slumps and Maximum Sizes of Aggregates

Maxi	Water content in lb per cu yd of concrete					
Mum	1 -2-inch slump		3–4-inch slump	6–7-inch slump		
Size of Aggrae- gates inch	Rounded Aggrega tes	Angular aggrega- tes	Rounded aggrega- tes	Angular aggrega- tes	Rounded aggrega- tes	Angular aggrega- tes
3/8	320	360	340	380	390	430.
3.4	290	330	320	350	350	380
l'/2	270	290	290	320	320	350
2	250	280	280	300	300	330
3	230	260	260	280	270	310

Workability is also governed by the maximum size of the aggregates their gradings shape and texture. Grading and water/cement ratio have to be considered together, as a grading producing most workable concrete for one particular value of water/cement ratio may not be the best for another value of the ratio. In particular, the higher the water/cement ratio the finer the grading required for the highest workability. In actual fact, for a given value of water/cement ratio, there is only one value of the course/ fine aggregates ratio that gives the highest workability.

Air entrainment also increases workability. In general terms, entrainment of 5 per cent air increases the compacting factor of concrete by about 0.03 to 0.07 and slump by '/$_2$ to 2 inches but actual values vary with properties of the mix. Air entrainment is also effective in improving the workability of the rather harsh mixes made with light weight aggregates.

The reason for the improvement of workability by the entrained air is probably that air bubbles act as a fine aggregate of very low surface friction and considerable elasticity. It is also claimed that the air entrainment reduces both segregation and bleeding.

Measurement of Workability: Unfortunately, no test is known that will measure directly the workability, numerous attempts have been made, however, to correlate workability with some easily measurable parameter, but none of these is fully satisfactory although they may provide useful information within a range of variation in workability.

Slump Test: This is a test used extensively in site work all over the world. The slump test does not measure the workability of concrete directly but it is an indirect measure of the same. There are some slight differences in the details of procedure used in different countries, but these are not significant. The standard procedure is as follows:

The mould for the slump test is a frustum of a cone with top and bottom diameter of 4 inch and 8 inches respectively. The height of the cone is 12 inch (Fig. 10.2). It is provided with two handles for lifting being filled with concrete. It is

placed on a steel plate to have a smooth surface with the smaller opening at the top and filled with

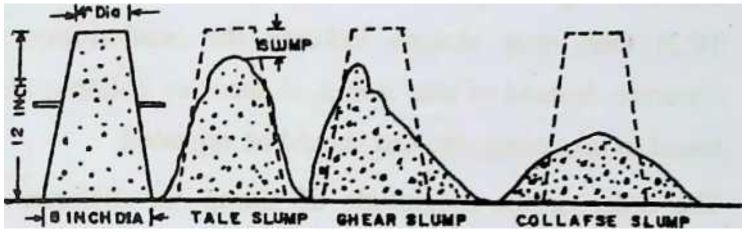


Fig. 10.2 Measurement of Slump

concrete in four layers. Each layer is tamped 25 times with a standard bull-nosed 5/8-inch diameter steel rod and the top surface is struck plain with a trowel. The mould must be held firmly against its base during the entire operation. Immediately after filing, the cone is slowly lifted very carefully and the unsupported concrete will now slump or subside and the depth of subsidence is a measure of the slump. In order to reduce the influence on the slump of the variation in the surface friction, the inside of the mould and its base should be moistened at the beginning of every test, and prior to lifting of the mould the area immediately around the base of the cone should be cleaned from concrete which might have dropped accidentally during the filling operation.

If instead of slumping evenly all round as in a true slump (Fig. 102), one half of the cone slides down an inclined plane a shear slump is said to have taken place. 1 he shears slump, indicates the lack of cohesion in the mix. Sometimes instead or true slump or shear-slump, the concrete may collapse and the resulting slump due to collapse is termed as thick (Fig. 10.2) Only true slumps indicate the workability of the concrete. Instead of true slump, if shear or collapse slump is found to take place, the test should be repeated.

The order or the magnitude of slump for different workability is given in Table 10.3

Slump test is very useful on the site as a check on the day to day or hour to hour variation in the materials being fed into the concrete mixer. An increase in slump may mean that the moisture content of aggregates has unexpectedly increased another cause would be a change in the grading of the aggregates, such as deficiency of sand. Too high or too low a slump gives immediate warning and enables the engineer in charge of proportioning and mixing the Concrete to remedy the situation, the slump test in general indicates the following: (1) Provided the grading of the aggregates and proportioning are correctly made, the slump is proportional to the water/cement ratio. But one thing is to be remembered.

Table 10.3 Values of Slump and Workability for Different Concrete Mixes

Slump value inch	Degree of workability	Use for which concrete is suitable
0-1	Very low	Precast and vibrated concrete works in roads and piles (vibrated by power operated machines).
1-2	Low	Road works (vibrated by hand operated machine). Mass concrete in foundation (without vibration). Lightly reinforced sections (With vibration)
2-4	Medium	Slabs (manually compacted), normal reinforced concrete (manually compacted), Heavily reinforced sections (with vibration).
4-7	High	For sections with congested reinforcement (not normally suitable for vibration).

that the actual a mound of water to be added to the concrete depends upon the moisture content of the aggregates particularly that of sand: (2) For a constant water/cement ratio and with a fairly uniform moisture concrete in the aggregates, an variation in the slump indicates the corresponding change in the grading of the aggregates.

These applications of slump test as well as its simplicity, are responsible for its wide spread use.

10.6 Factors Controlling Properties of Concrete:

The properties (strength, durability, impermeability and workability) of concrete depend upon the following parameters (factors):

1. Grading of the aggregates.
2. Moisture content of the aggregates.
3. Water/cement ratio.

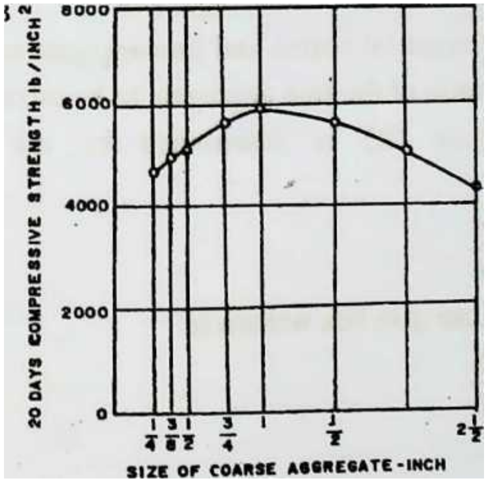
4. Proportioning of the various ingredients of concrete.
5. Method of mixing.
6. Placing and compaction of concrete.
7. Curing of concrete.

1. Grading of Aggregate: The term 'grading' indicates the art of combining various sizes of the particles composing the aggregate to produce a dense and an economic concrete using minimum amount of cement per unit volume for a desired strength. The fundamental principle of grading is that the smaller particles fill up the empty spaces in between larger particles. To secure proper interlocking of the various sizes of the aggregate, it is essential that the particles should be angular and sharp. It has been suggested that the main factor governing grading are: (1) the surface area of the aggregates, which determines the amount of water necessary to wet all the solids (2) the relative volume occupied by the aggregate (3) the workability of the mix and (4) the tendency to aggregation.

Surface area of Aggregate, It is recalled that if a given volume contains smaller size particles, the total surface area

of these particles is more than what would be if the same volume contained by larger size particles. This justifies the use of a smaller size of aggregate for stronger and richer concrete mixes because they require more cement.

Maximum Size of Aggregate: It is clear that the larger the aggregate particle the smaller the surface area to be wetted per unit weight. Thus, extending the grading of aggregate to a larger maximum size lowers the water a cement requirement of a concrete mix. Recent experimental results show that above the l$^{1}/_{2}$-inch maximum size of the aggregate, the gain in strength due to the reduced water requirement is offset by the detrimental effects of lower bond area and of discontinuities introduced by the very large particles. Concrete becomes grossly heterogeneous and results in lowering the strength. The graph in the Fig. 10.3 shows the influence of the maximum size of aggregate on the compressive strength of concrete. It is clear that from the view point of strength, there is on advantage in using aggregate with a maximum greater than



1 inch. There are of course, structural limitations too. The maximum size of the aggregate should be no more than $^{1}/_{5}$ to $^{1}/_{2}$ of the thickness of the concrete section and is Fig. 10.3 influence of maximum related also to spacing size of aggregate on the strength of reinforcement concrete.

1 **Sieve Analysis:** Proper grading of aggregates is done by the help of sieve analysis. The fineness modulus of a particulars type of coarse aggregate, the combined fineness modulus of different type of coarse aggregates and the ratio in which two types of coarse aggregates should be mixed, can be determined following exactly the same procedure described in chapter 8. Art. 8.8. The combined fineness modulus of fine and coarse aggregates can be determined by the Fq. 8.8. *after* re-denoting the terms as follows;

$$F\ com = \frac{mFc + nFf}{m + n}$$

where Fcom= the combined fineness modulus of fine and coarse aggregates

Fc=the fineness modulus of coarse aggregate f the fineness modulus of fine aggregate m and n =the amount of course and fine aggregate respectively. Similarly, the ratio of the fine aggregate to be mixed with 1 of coarse aggregate (R) is determined by the following relationship.

$$R = \frac{Fc-Fcom}{Fcom-Ff}$$

The Eq. 10. 5.. can also bek written as

$$R = \frac{Fc-Fcom}{Fcom-Ff}$$

in which: RI is the ratio of the fine aggregate in the combined aggregates.

Volume of Combined Aggregates: When the fine and coarse aggregates are mixed in a definite proportion the volume of the combined aggregates is not equal to the sum of their volumes, because there is always a shrinkage in volume. The shrinkage factor is determed as follows: Fine and coarse aggregates are mixed in the desired proportion and filled to compactness in a container. The volume before and after are measured and their ratio gives the shrinkage factor.

Example: The combined fineness modulus of fine aggregate (sand, Ff= 2.85)

and coarse aggregate (broken stones, Fc=6.77) was found in be 5.30. If 8.49 cu ft of combined and well packed aggregate is required, determine the volume of fine and coarse aggregates mixed initially. Take shrinkage factor to be -0.75.

Solution: Using Eq. 10.5.

$$\mathbf{F = \frac{6.77-5.30}{5.30-2.85} = \frac{1.47}{2.45} = 0.60}$$

.’. The fine and coarse aggregates are in the ratio of 60.100 Let Vf and Vc are the volumes of fine and coarse aggregates taken before compaction. If V is the total volume, then

$$V=Vf+Vc = \frac{8.46}{0.75} = 11,28 \text{ cu ft}$$

Since Vf/Vc= 60/100

$$\text{then } Vf = \frac{60}{160} \times 11,28=4.23 \text{ cu ft}$$

$$\text{and } Vc= \frac{100}{160} \times 11.28 = 7.05 \text{ cu ft.}$$

2. **Moisture Content of the Agreements:** he bulking of the legate (sand) due to the presence of small percentage of small has already been discussed in Chapter 8. Art 8.7 (see Fig 81). The bulking is very high in case of fine aggregate but it is less in case of coarse aggregate (fig. 10.4)

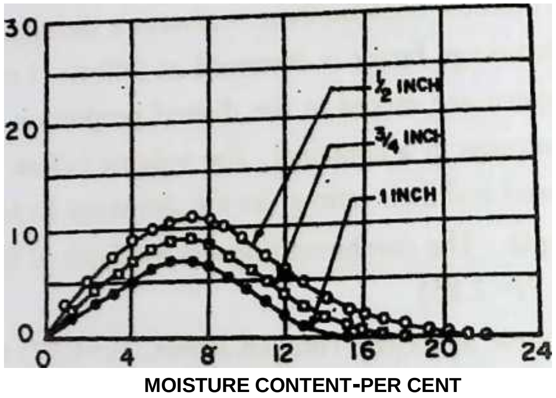


Fig. 10.4 Bulking of coarse aggregates with different percentage of moisture content.

It is seen from Figs. 8.1 and 10.4 that the bulking in fine aggregate (1/16 size) with 8 per cent moisture content *is* 33 percent and the same for the coarse aggregate (1/2” size) is 11 percent. Therefore, if I cu ft of dry material each is required then 1+0.33=1.33 cu ft of wet fine aggregate and 1+011 - 1.11 cu ft of wet coarse aggregate is to be taken.

Concrete mixes are designed on the basis of dry volumes of aggregates. The ratios used are the ’real mix ratios’. But in the field, the aggregates are generally wet, particularly when they £re washed for clearing. So, their moisture content must be determined and due allowance must be made in their volumetric measurement in the field. The correct ratios are then termed as "field mix ratios”.

Water/Cement ratio: In engineering practices, the strength of concrete at a given age and cured at a prescribed temperature is assumed to depend primarily on two factors:

(1) the water/cement ratio and (2) the degree of compaction. The proportion between the amount of water and cement used in a concrete mix is termed as the water cement ratio. The water in the concrete does primarily the three functions:

(1) to wet the surface of the aggregate (2) to impart work ability and (3) to combine chemically with cement.

When concrete is fully compacted. Its strength is taken to be inversely proportional to water/ cement ratio. It may be recalled that the water/cement ratio determines the porosity of the hardened cement paste at any stage of hydration Fig. (10.5)

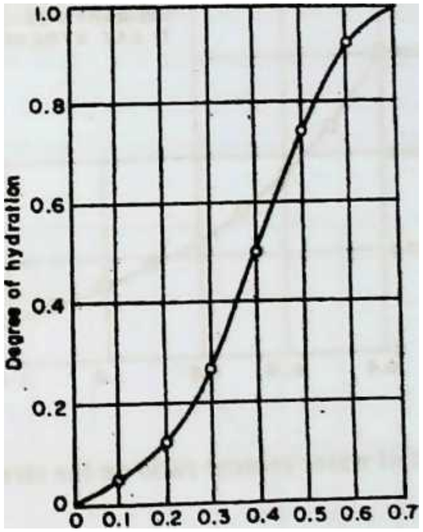


Fig. 10.5 Relationship between the water/cement ratio and the degree of hydration.

Experiments have own that the quantity of water in a mix determines its strength and there is a water/cement ratio which gives the maximum strength to the concrete. It will be found that there is a certain percentage of water below which the water will not be sufficient to hydrate the cement. The use of less water than that required will not give workability and will produce porous and weak concrete. On the other hand, if more water is used than that actually required, the concrete will be weak. The Figs. 10.6 and 10.7 show that the graph of strength against water / cement ratio is approximately in the shape of a hyperbola. It is a geometrical property of hyperbola. y=k/x that against 1/x plots as a straight line. The relationship between the strength and cement/water ratio between about 1.2 and 2.5 (Fig 10.7) This relationship is clearly more convenient to use than the water/cement ratio curve (Fig. 10.6) particularly when interpolation is desired.

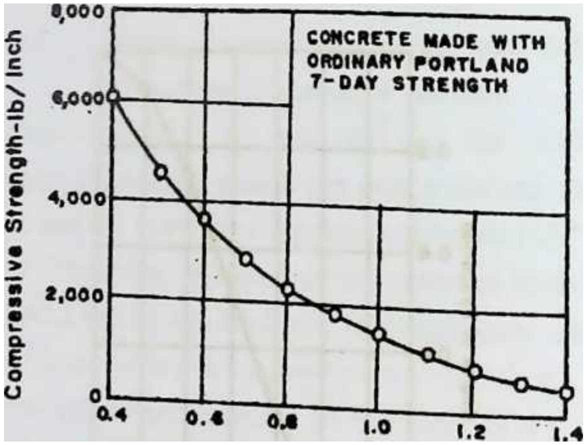


Fig. 10.6 Effect of water/cement ratio on the strength of concrete.

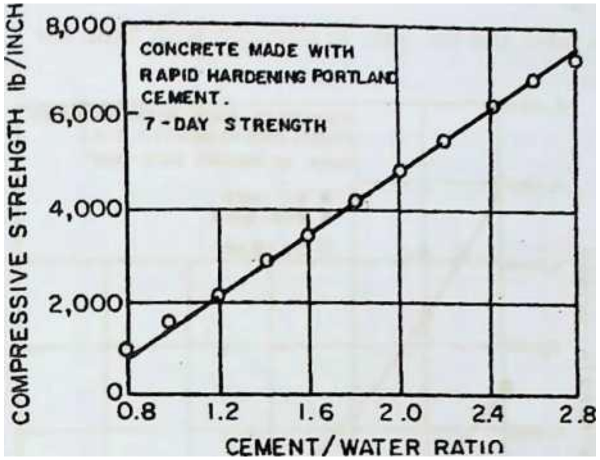
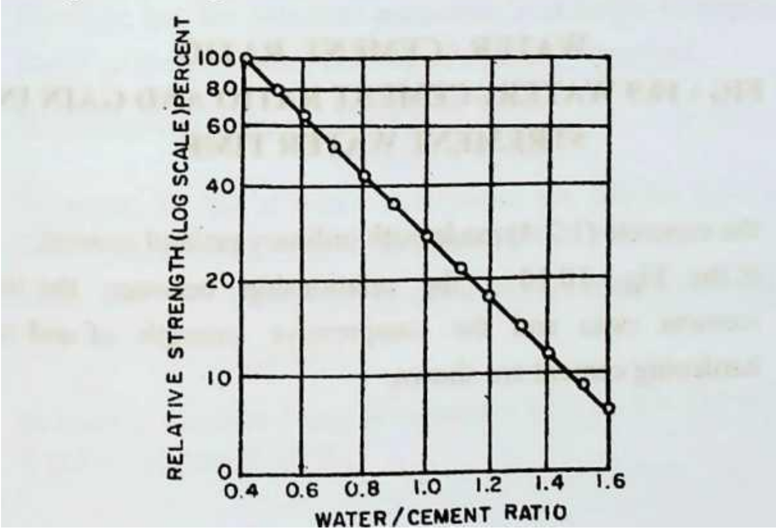
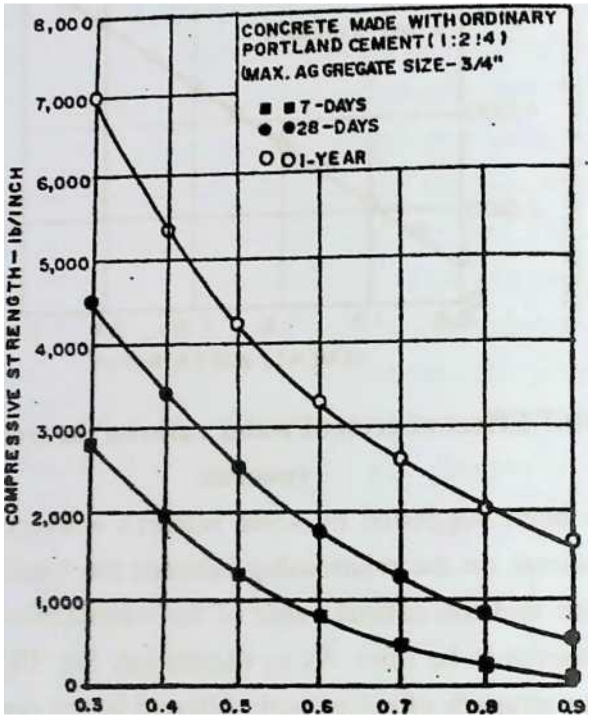


Fig: 10.7 Effect of cement/water ratio on the strength of concrete

It has been suggested by some research workers that as an approximate on the relationship between the logarithm of the strength and the natural value of the water/cement ratio can be assumed to be liner. As an illustration. Fig. 10.8 gives the relative strength of mixes with different water/ cement ratios, taking the strength at the water/cement ratio of 0"4 as unity.



The Fig. 10.9 shows the relationship between the water *I* cement ratio and the gain in strength with time for

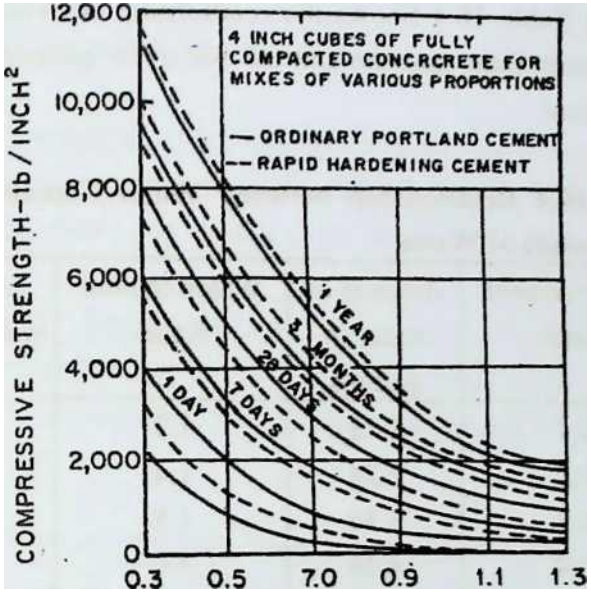


WATER/CEMENT RATIO

FIG: 10.9 WATER *I* CEMENT RATIO AND GAIN IN STREMENT WATER TIME

the concrete (1:2:4) made with ordinary Portland cement.

It the Fig. 10.10. the relationship between the water /cement ratio and the compressive strength of and rapid hardening cement are shown.



WATER / CEMENT RATIO BY WEIGHT

FIG 10.10. RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND WATER/CEMENT RATIO

The water/cement ratio is usually expressed as a decimal fraction, but for practical purposes, it is better to express it many gallons of water per bag of cement. Therefore,

$$\text{Water/cement ratio} = \frac{\text{Weight of cement}}{\text{Weight of cement}} \qquad 10.7$$

Suppose, 30 lbs. of water are required per 100 lbs. of cement then water/cement ratio = 30/100=0.3

This can be expressed as gallons of water per bag of

$$= \frac{0.3 \times 112}{10} = 3.36 \text{ gallons}$$

cement as because 1 bag of cement = 1.25 cu ft = 112 lbs and 1 gallon of water= 10 lb.

The Table 10.4 Shows the relationship between the water / cement ratio and amount of water in gallons per bag of cement.

Table 10.4 Relationship between Water/Cement Ratio and Amount of Water

Water/cement Ratio	Amount of water in gallons	Water/cement Ratio	Amount of water in gallons
0.1	1.12	1.3	14.55
0.2	2.24	1.4	15.68
0.3	3.36	1.5	16.80
0.4	4.48	1.6	17.92
0.5	5.60	1.7	19.04
0.6	6.72	1.8	20.16
0.7	7.84	1.9	21.28
0.8	8.96	2.0	22.40
0.9	9.08	2.1	22.52
10	10.20	2.2	23.64
11	11.31	2.3	25.76
12	12.44	2.4	26.88

Quality of Water for Mixing and Curing: The vital influence of the quantity of water in the concrete mix on the strength of the resulting concrete has been repeatedly mentioned. The quality of water also plays its role • impurities present in water may *interfere* with the setting of cement, may adversely affect the strength of the concrete or cause staining of its surface and may also lead to corrosion of the reinform cement. For these reasons the suitability of water for mixing and curing purposes should be considered. Clear distinction must be made between the effects of mixing matter and the attack on the hundred concretes by aggressive waters.

In many specifications the quality of water of concreting is cover by a cluse saying that the water should be fit for drink, pleasant to taste and suitable for domestic and industrial purposes.

As a rule, the water should not be saline or brackish and it should be free from acids. The following are the water quality standard recommended for mixing and curing of concrete (Table 10.5).

Table 10.5 Water Quality Standard for Concreting

Substance	Maximum permissible concentration, ppm
Dissolved solids	2.000
suspended solids	1,000
Chloride	500
Sulphates	2,000

Proportioning of Various Ingredients of Concrete:

The object of proportioning the ingredients (cement, fine aggregate, coarse aggregate and water) is to obtain a strong and durable concrete to suite all requirements. The following are the possible methods of proportioning the ingredients (cement, fine aggregate, coarse aggregate and water) is to obtain a strong and durable concrete to suite all requirements. The following are the possible methods of proportioning: (a) Arbitrary method (b) Minimum voids method (c) Sieve analysis method and (d) Trial mixture method.

Arbitrary Methods: In proportioning the concrete ingredients, the proportion of cement is taken as unity to be mixed with parts of fine aggregate and parts of coarse aggregate. The amount of water is determed from the strength versus water/cement ratio curves (Fig. 10.10) and from slump test. The table 10.6 shows the recommended proportions ions of the concrete materials for various type of works.

Table 10.6 Proportions of Concrete Materials for Various

Type of Works

Type of construction	Concrete Mix
Mass concrete in foundation and concrete blocks All R.C.C (Reinforced cement concrete) works in slabs, beams columns, walls, lintels etc. Dams, reservoirs, overhead R.C.C, water tanks, different units of water works and Sewage treatment plant, precast R. C. C. works etc.	1:3:6 1:4:8 1:2:4 1:3:6 **$1:1\frac{1}{2}:3$** 1:1:4

Minimum Voids Method: The fundamental principle of this method is that for a dense concrete the voids in the coarse and fine aggregates, should be completely filled up. Because the dense concrete imparts higher strength. The voids of the coarse aggregate are determined first and an amount of fine aggregate is used so as to be equal to the voids of the coarse aggregates. Generally, and extra of 5 to 10 per cent of fine of aggregate is used for having a dense mix. Similarly, the voids the combined aggregates are determined and an amount of

cement equal to the voids is used. Usually, an extra among of 8 to 10 percent of cement is used.

Sieve Analysis Method: This is also known as *Fineness Modulus Method First,* the fine and coarse aggregates are graded and their combined fineness modulus is calculated by Eq. 10.4 for a desired strength. Then the ratio of the fine and coarse aggregates is determined by using Eq. 10.5, taking the proportion of cement as unity.

Trial Mixture Method: In this method, fine aggregate and coarse aggregate are mixed in different proportion and the mixture of the same is taken after thoroughly compacted. The proportion which yields the heaviest mixture is taken for a dense concrete. Trail specimens (cylindrical) are made with a workable mixture of cement, fine and coarse aggregate with requisite quantity of water and tested after 28 days.

5. Method of Mixing of Concrete: The object of mixing is to coat the surface of all aggregate particles with cement past and to blend all the materials of concrete into a uniform mass. There are mainly two methods of mixing: (a) Hand mixing and (b) Machine mixing. Hand mixing does not generally produce a good concrete unless proper care is taken for a thorough mixing of the materials. On the other hand, machine mixing (mixing the materials in a concrete mixer) produces a good concrete. On the site there is often a tendency to mix concrete as rapidly as possible and it is therefore, necessary to know what is the minimum mixing time necessary to produce a concrete, uniform in composition and as a result of satisfactory strength. This time varies with the type of mixer and strictly speaking, it is not the mixing time but the number of revolutions of the mixer that is the criterion of adequate mixing. Generally, about 20 revolutions are sufficient. The average strength of concrete increases with an increase in mixing time, as shown in Fig. 10-11.

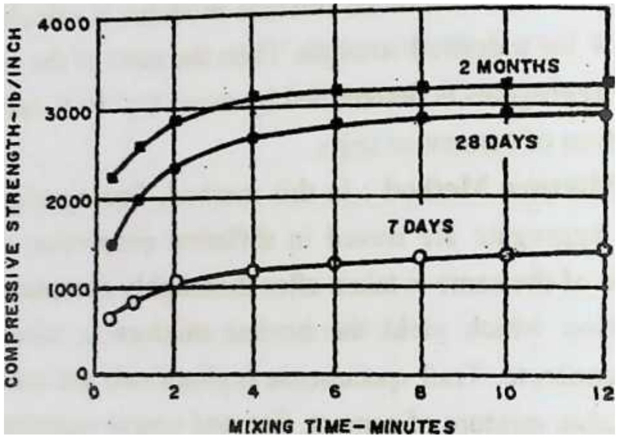


Fig. 10.11 Effect of mixing time on strength of concrete

6. **Placing and Compaction of Concrete:** Concrete must be transported from the place of mixing to the place of final placing as quickly as practicable, by the method which will prevent segregation of aggregates. Placing of concrete must be done in one continuous operation as far as possible to avoid the necessity of joints. Concrete should be deposited and not thrown or dumped from a distance to prevent segregation.

After placing, the concrete should be compacted or consolidated to eliminate entrapped air. The compaction is

done by a standard steel rod of recommended size forcing the concrete round the corners and edges to enable the spaces between the reinforcing bars (in use of R.C.C.) to be completely filled up.

The most modern means of compaction is vibration. There are various types of mechanical vibrators. These vibrators, of course, momentarily separate the aggregate particles but finally allow them to be drawn into a compact mass Compaction be vibrators produce and strong concretes.

7. **Curing of Concrete:** In order to obtain good concrete, the placing of concrete should be followed in a suitable environment during the early stages of hardening. Curing is the name given to procedure used for promoting the hydration of cement and consists of control of temperatures and of the moisture movement from and into the concrete. More specifically, the object of curing is to keep concrete saturated so that hydration of cement can take place in a suitable environment. Hydration at a maximum rate can proceed only under condition of saturation. The order of influence of curing on strength can be judged from the Fig. 10.13, obtained for concrete with a water/cement ratio of 0.5. It is seen from the Fig. 10.12 that the curing for 28 days imparts maximum strength on concrete.

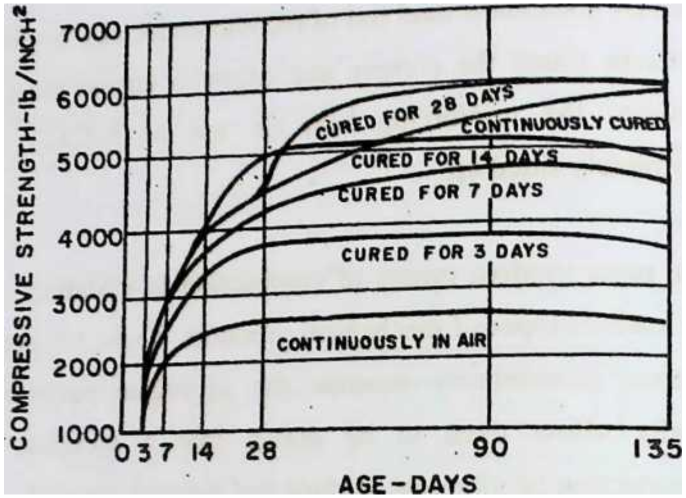


FIG. 10.12 INFLUENCE OF CURING ON STRENGTH OF CONCRETE (WATER/CEMENT RATIO=0.5)

Evaporation of water from concrete depends on the temperature and the relative humidity of the surrounding air and on the velocity of wind which effects a change of air over the surface of concrete. The difference between the temperatures of concrete and of air also affects the loss of water. In fact, the actual loss of water depends on the surface volume ratio of the specimen.

Methods of Curing: There are various methods of curing depending upon the conditions of the site and on the size, shape and position of the concrete structures.

In case of structures with small surface volume ratio, curing may be done by oiling and wetting the formworks before casting, the formworks may also be wetted during hardening and after stripping off the formworks the concrete should be sprayed with water and wrapped with polythene sheets or other suitable covering.

Large surface of concrete, such as road-slabs, present a more serious problem. In order to prevent crazing of the surface or drying out, loss of water must be prevented even prior to setting. As at the concrete is at that time mechanically weak, it is necessary to suspend a covering above the concrete surface. This protection is required only in dry weather but may also be useful to prevent rain from destroying the surface of fresh concrete.

Once the concrete has set, wet curing can be provided by spraying or flooding (ponding) with water or by covering the concrete with wet sand or earth, sawdust or straw or water hyacinth. Periodically, wetted hessian or cotton mats may be used. A continuous sparing of water is naturally more efficient.

The period of curing cannot be prescribed simply but it is usual to specify a minimum of seven days for ordinary Portland cement concrete. With slow setting cements, a longer curing period is desirable.

Maturity of Concrete: So far only the time aspect of curing has been considered but, as mentioned earlier, the temperature during curing also controls the rate of progress of the reactions of hydration and consequently affects the development of strength of concrete. This influence in shown in the Fig. 10.13. Since the strength of concrete depends on both age and temperature, it can be said that the strength is a function of L (time x temperature) and this summation is called maturity.

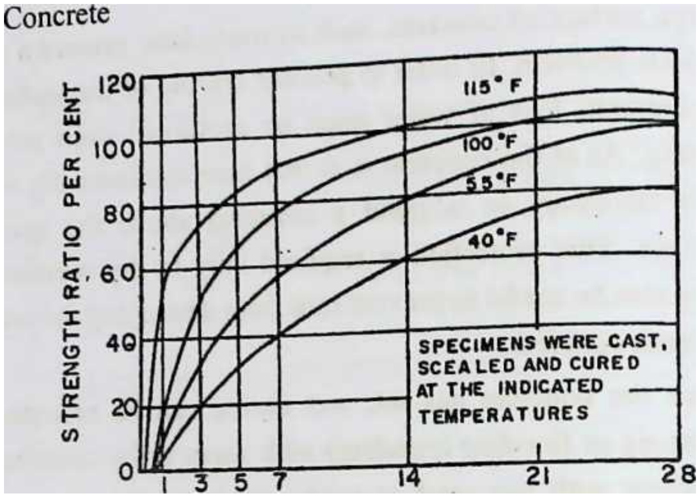


Fig. 10.13 Ratio of strength of concrete cured at different temperatures to the 28 days strength of concrete cured at 70° F (Water/cement ratio=0.5)

Influence of Curing Temperature on Strength of Concrete: It is recalled that a rise in curing temperature speeds up.

The chemical reactions of hydration and thus affects beneficially the early strength of concrete without an ill effect on the later strength (Fig. 10.13). However, a higher temperature during placing and setting although it increases the very early strength, may adversely affect the strength from about 7 days onwards. The explanation is that a rapid initial hydration appears to form products of a poorer physical structure, probably more porous, so that a large proportion of the pores will always remain unfilled. The Fig 10, 14 shows the effect of temperature during the first two hours after placing on the development of concrete with a water/cement ratio of 0.53. The range of temperatures investigated was 50 to 110°F. and beyond the age of two hours all specimens were cured at 70°F. The specimens were sealed so as to prevent movement of moisture.

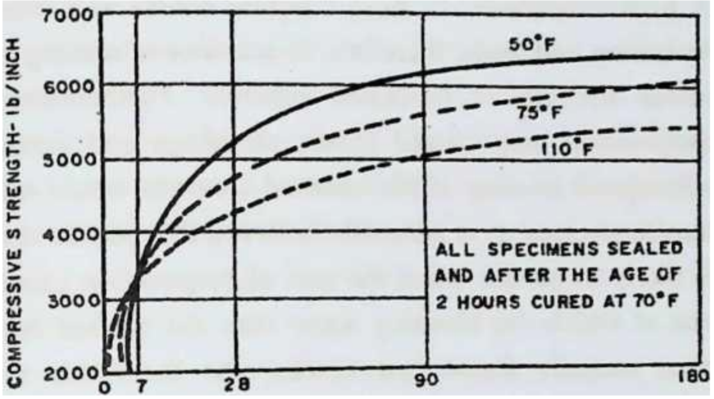


Fig. 10.14 Effect of temperature during the first two hours after casting on the development of strength, (water/ cement ratio - 0.58)

Steam Curing: The modern trend is to cure concrete by steam at atmospheric pressure and it is becoming a common practice to cure precast concrete structures in steam chamber. The primary object of steam curing is to obtain a sufficiently high early strength so that, the concrete products may be handled soon after casting: the moulds can be removed earlier than would be the case with ordinary moist curing and less curing strong space is required: all these mean an economic advantage. For many applications the long-term strength of concrete is of less importance.

10.7 Concreting in Hot Weather: There are some special problems involved in concreting in hot weather specially in a country like Bangladesh arising both from and increased rate of evaporation form the fresh mix. These problems concern the mixing, placing and curing of concrete.

A high temperature of fresh concrete results in a more rapid hydration and leads, therefore, to accelerated settling and to a lower strength of hardened concrete. Furthermore, rapid evaporation may cause plastic shrinkage and crazing and subsequent cooling of the hardened concrete would introduce tensile stresses. It is generally believed that plastic shrinkage is likely to occur when the rate of evaporation exceeds the rate at which the bleeding water rises the surface but it has been recently found that cracks also form due to rapid evaporation.

There are some further complications in hot weather concreting: air entraining is more difficult although this can be remediated by using larger quantities of the entraining agent. Curing also presents additional problems as the curing water tends to evaporate rapidly.

There is a member of remedial measures that can be adopted. First, the cement content should be kept as low as possible so that the heat of hydration does not unduly, aggravate the effects of high ambient temperature. The temperature of the- fresh concrete can be lowered by pre-cooling one or more of the ingredients of the mix. For instance, can be used instead of some of the mixing water but it is essential to see that ice melts completely before the mixing completed.

The influence of the temperature during setting on the strength at later ages has already been discussed. Here it is wise to say that a temperature not higher than about 60°F should not be exceeded.

The evaporation of freshly laid concrete and also the evaporation of curing water can be stopped by covering the surface by polythene sheets and other suitable devices.

10.8 Concreting in Cold Weather: Concreting in cold weather offers some special problems again. If it is done at a freezing temperature, the mixing water freezes with a (Consequent increase in the overall volume of the concrete. Furthermore, since no water is available for the chemical reactions, the setting and hardening of concrete are delayed, thus resulting in a poor concrete.

To avoid the ill effects of low temperature in fresh concrete certain precaution can be taken. The temperature at the time of casting can be raises by heating the ingredients of the mix. Water can be heated easily, but it is inadvisable to exceed a temperature of 100 to 140°F as the flash setting of cement may result: the likelihood of this happening depends on the difference between the temperatures of water and cement. If heating the water does not sufficiently raise the temperature of the concrete the aggregate may also be heated. Heating the aggregate again above 125°F is inadvisable.

The temperature of the mix ingredients must be controlled to make sure that setting does not occur at too high a temperature. Because this would advisedly affect the development of the strength of the concrete. In addition, a high temperature of fresh concrete lowers workability and may lead to high thermal contraction.

In this preferable for the concrete to set, say 50 to 70 F but it is essential that the temperature does not fall below about 50°F during the next three days. There are numerous precautions that should be taken in practice. For instance, concrete should not be allowed to cool unduly while being transported from the mixer to the formworks and should not be placed against a frozen surface.

Control of temperature after placing is obtained by insulating the concrete from the atmosphere and if necessary, by constructing enclosures around the concrete and providing a source of heat within the enclosure. The form of heating should be such that the concrete does not dry out rapidly, that no part of it is heated excessively & that no high concentration of carbon dioxide in the atmosphere results.

10.9 Joints in Concrete Works: There are mainly two types of joints which are provided in concrete works: (1) construction joint and (2) expansion joints.

Construction Joints: Concreting must be carried out continuously up to the construction joints the position and arrangements of which must be predetermined. Construction joints are so positioned that the strength of the structural member is not affected. The most suitable location is where the bending moment of the member is zero or the shear is maximum.

Expansion Joints: These joints are provided to take care of expansion of concrete due to temperature change or formworks for concrete.

10.10 Shuttering (Formworks): Shuttering or formwork for concrete must be of suitable quality and adequate strength to remain perfectly rigid and true to line during placing, ramming and setting concrete. The construction of formwork is a specialized job and is not as it commonly considered to be if the formworks are required to be correct in dimensions. The inner face of the shuttering should be clean and treated so

that a good surface is obtained. All formworks must be built so that they may be struck without harm to the finished concrete and must be watertight to prevent the loss of water from concrete when wet.

Generally, timber which is cheap, light in weight strong and smooth when finished, is used in formworks. Thickness of timber depends on the loads to be carried and the spacing of the supports below. Sometimes, plain C.I. (cast iron) sheets are used in place of timber. For important structures (large number of same size) like R.C.C. columns etc. steel sheet formworks are used. But this type of formworks is very costly. In Bangladesh, timber and C.I. sheets are generally used. Sufficient time must elapse before shuttering's are stiffed off so that concrete will be in a condition to bear its own weight and other loads which may come on it. It may be added that the removal of shuttering's is dependent primarily on the setting properties of cement used in the concrete. The following are the general practices for the removal of shuttering's in Bangladesh.

Table 10.7 Times for Shuttering Removal from Concrete Works.

Temperature Range: 50 to 70°F

Nature of concrete structures	Time of shuttering removal days	
	ordinary port land cement	Rapid Hardening Portland cement
Short beams (Spans less than 20 ft), walls, columns, roofs slabs etc.	10 to 14 days	6 to 9 days

Long beams (spans more Than 20 ft), supports or props uber horizontal member (heavy)	14 to 22 days	10 to 16 days

10.11 Concrete Surface Finishing: Concrete is essentially an artificial stone. It is subject to weathering agents like artificially stones. Therefore, the concrete surface should be given some finishing. The finishings are of various types, such as plastered finishing, shuttering finishing, dressed finishing and granolithic finishing.

Plastered Finishing: This is a very common type of concrete surface finishing. There are different types of plaster in use. Sometimes, the plastered surfaces are sand rubbed.

Shuttering Finishing: If the shuttering is very correctly made and the placing and compacting are done properly, the surface gives a good appearance when the shuttering is removed. Pre-cast concrete sections may simply be jointed at their sides, with their surface left in the same conditions as when cast. Sometimes, shuttering finishing is desired for important type of constructions, such as overhead R. C. C. water tanks, hydraulic structures, like dam’s bridge piers etc.

Dressed Finishing: In this type of finishing, the surface is given some form of ornamental touch with the help of dressing tools.

Granolithic Finishing: In this type of finishing, the concrete surface is finished when green. Common types of finishing are: (1) trowel finish with neat cement and (2) slightly rough finish with a wooden float. These finishings are generally used in dwelling houses and factory and industrial buildings,

ware houses, roads, institutions etc. To increase the resistance of wear and rear, small quantities of silicate compounds of sodium and magnesium are used. Sometimes cement during the setting action, combines with the solution and forms calcium silicate which forms a hard and wear and tear resisting surface.

10.12 Shrinkage of Concrete: Shrinkage is the contraction or concrete due to drying and chemical changes, dependent on the time but not directly dependent on stresses induced by external loadings. There are various causes for shrinkage in concrete. Shrinkages are classified according to their causes. The following are the main type of shrinkages: (1) Plastic Shrinkage (2) Drying shrinkage (3) Carbonation Shrinkage.

Plastic Shrinkage: During the progress of hydration, the cement paste (plastic in nature) undergoes a volumetric contraction whose magnitude is of the order of one per cent of the absolute volume of dry cement. This contraction is known as plastic shrinkage, since it takes place while the concrete is still in the plastic state. Loss of water by evaporation from the surface of the concrete or by suction by dry concrete below aggravates the plastic shrinkage and can lead to surface cracking, such cracking is also possible when on evaporation is permitted. Cracking develops usually over obstructions of uniform settlement, e. g. reinforcement or large aggregate particles or when a large horizontal area of concrete makes construction in that direction more difficult than vertically, deep cracks of an irregular pattern are teen found. Early shrinkage is greater the larger the cement of the mix and the earlier the stiffening of the concrete. It has been suggested that a greater bleeding capacity of the concrete, decreases the plastic shrinkage. But the relation between plastic shrinkage and bleeding has not been confirmed.

Volume changes occur also after setting has taken place and may be in the form of shrinkage or swelling, continued hydration, when a supply of water is present, leads to expansion (see next section, 10.13) but when no moisture movement to or from the paste is permitted, shrinkage occurs. Shrinkage of such *a* conservative system is known as autogenous shrinkage and it occurs is practice in the interior of a large concrete mass.

This shrinkage is relatively small and for practical purposes need not be distinguished from shrinkage caused by drying out of concrete. The latter is known as drying shrinkage and normally includes that contraction which is due to autogenous changes.

2. Drying Shrinkage: Withdrawal of water from concrete stored in saturated air causes drying shrinkage. The change in the volume of drying concrete is not equal to the volume of water removed. The loss of free water which takes place first, causes little or no shrinkage. As drying continuous, absorbed water is removed and the change in the volume of unrestrained cement paste at that stage is equal approximately to the loss of water. The relation between the loss of weight of water and shrinkage is shown in Fig. 10.15

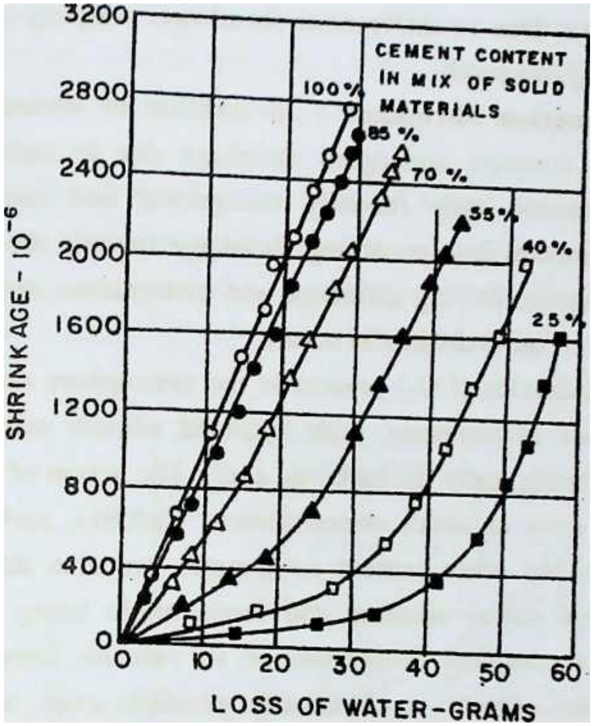


Fig. 10.15 Relationship between shrinkage and loss of water of concrete cured for 7 days at 70°F and then dried.

Factors affecting the drying shrinkage are (a) amount of aggregate (b) modulus of elasticity of concrete (shrinkage varies inversely with the modulus of elasticity of concrete at early ages) (c) the water content (d) the rate of evaporation or drying and (e) curing and storage conditions.

Differential Shrinkage: This is a special type of drying shrinkage takes place due to non-uniform shrinkage with the concrete member itself. Moisture loss takes place at the surface so that a moisture gradient is established in the concrete specimen, which is thus subject to differential shrinkage. This shrinkage is compensated by strains due to internal stresses tensile near the surface and compression in the core. Due to differential shrinkage, warping curving or bending can result.

3 Carbonation Shrinkage: In addition to shrinkage upon drying concrete undergoes shrinkage due to carbonation a phenomenon only recently recognized and most of the experimental data on drying shrinkage include the effects of carbonation. Drying shrinkage and carbonation shrinkage are however, quite distinct in nature. Carbon dioxide (CO_2) present in the atmosphere reacts in the presence of moisture, with hydrated cement minerals (the agent being really the carbonic acid). The action of CO_2 takes place even at small concentration. $Ca(OH)_2$ carbonates to $CaCO_2$ but other cement compounds are also decomposed hydrated silica, alumina and ferric oxide being produced. Such a complete decomposition of calcium compounds in hydrated cement is chemically possible even at the low pressure of CO_2 in normal atmosphere. The rate of carbonation depends also on the moisture content of the concrete and the relative humidity of the ambient medium. Carbonation is accompanied by an increase the weight of the concrete and by shrinkage. Carbonation shrinkage is probably caused by dissolving of crystals of Ca (OH), while under a compressive stress (imposed by drying shrinkage) and depositing -of $CaCO_3$) in spaces free from stress. The sequence of drying and carbonation greatly affects the total magnitude of shrinkage. Simultaneous drying and carbonation produces lower total shrinkage than when drying is followed by carbonation, (fig. 10.16 & 10.17)

Carbonation of concrete also results in increases strength and reduced permeability, possibly because water release by carbonation aids the process of hydration and $CaCO_2$ reduces the voids within the cement paste.

10.13 *Swelling of Concreted.* Cement concrete cured continuously in water from the time of castings exhibits a net increase in volume and an increase in weight. This swelling is due to the absorption of water by the cement gel.

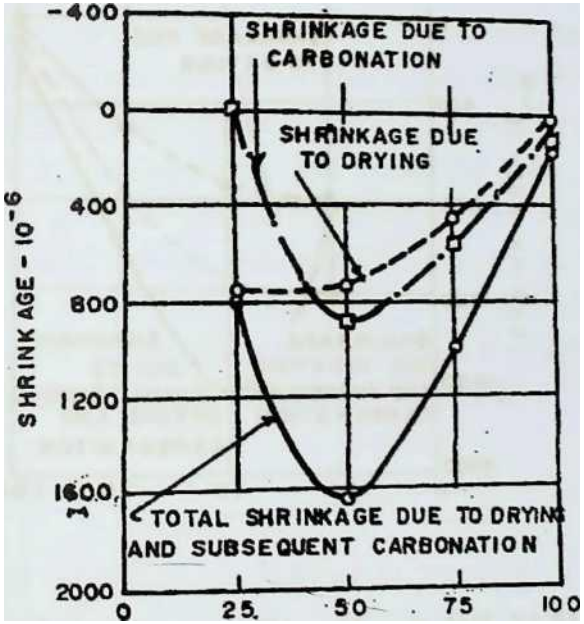


Fig.10.16 Drying shrinkage and carbonation shrinkage at different relative humidities.

Linear expansion of neat cement past (relative to dimensions 24 hours after casting) has typical values of $1,300 \times 10^{-6}$ after 100 days

2,000 x 10-^{6} after 100 days and

2,200 x 10-^{6} after 200 days.

It is to be noted that swelling, shrinkage and creep are expressed as linear strain.

The swelling of concrete is considerably smaller approximately 100 x W^{6} to 150 x IO'^{6} for a mix with a cement content of 500 lbs. per cu yd after 6 to 12 months of casting.

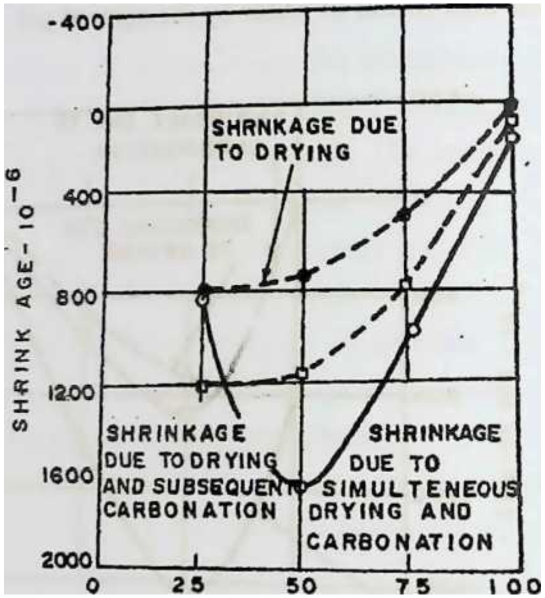


Fig. 10.17 Relative Humidity percent influence of the sequence of the drying and carbonation on shrinkage.

Swelling is accompanied by an increase in weight of the order of 1 percent. The increase in volume as water enters to occupy the space created by the decrease in volume on hydration of the system of cement plus water.

10.14 Creep of Concrete: In many applications, concrete structures are required to sustain steady loads for long periods of time, such as concrete roofs, beams etc. Under such condition, the concrete may continue to deform until its usefulness is seriously impaired. Such time dependent deformation may be almost imperceptible, but over the lifetime of concrete structure. They can grow large and even result in final fracture without any further increase in load.

Under short time loading, as in conventional, compression test, there is initial deformation that increases simultaneously with the load, as shown in the static stress-strain diagram. If under any condition, deformation continues when the load is held constant, this additional deformation is known as creep.

The relation between stress and strain for concrete is a function of time. The gradual increase in strain with time is due to creep. Creep can thus be defined as the increase in strain under a sustained stress (Fig. 10.18) and since this increase can be several times as the strain on loading, creep is of considerable importance in concrete mechanics.

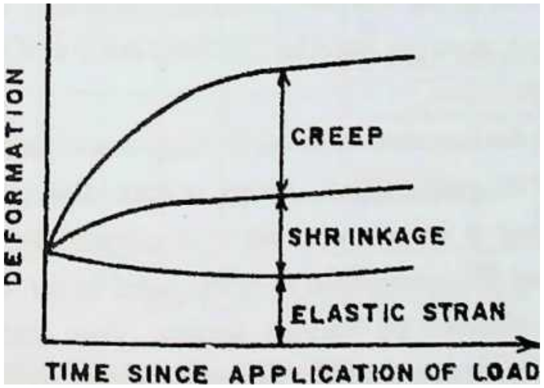


Fig: 10.18 Time dependent deformation in concrete subjected to a sustain load

Creep has in the past been referred to also a flow. How, plastic vied plastic deformation, many of these teams arising from imperfect upstanding of the nature of the phenomenon. Nowadays, the term imperfect upstanding of the nature of the phenomenon. Nowadays, the term creep is universally accepted.

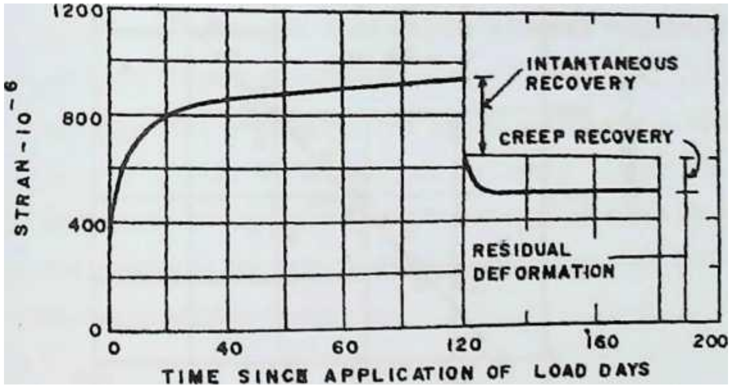
Under normal conditions of loading the instances strain recorded depends on the speed of application of the load and includes thus not only the elastic strain but also some creep. It is difficult to differentiate accurately between the immediate elastic strain and early creep, but this is not of practical importance is the total strain induced by the application of load that matters. Since the modulus of elasticity of concrete increases with age the elastic deformation gradually decreases and strictly speaking creep should be taken as strain in excess of the elastic strain at the time at which creep is being determined (Fig. 10.18). Often, the modulus of elasticity is not determined at different ages and creep is simply taken as an increase in strain above the initial elastic strain. This is alternative definition, although theoretically less correct, does not introduce serious error and is after more convenient to use.

Although the majority of the data more convenient here refers to creep in compression, creep occurs also under tensile loading and it is believed that the magnitude of creep in tension and in compression is of the same order, and both are similarly affected by various factors. This applies also to creep under torsion although few test data arc available.

So far, we have considered the creep of concrete stored under such conditions that no shrinkage or swelling takes place. If ^{a}

concrete specimen is drying while under load it is usually assumed that creep and shrinkage are additive. Creep is thus calculated as the difference between the total time deformation of the loaded specimen and the shrinkage of a similar unloaded specimen stored under the same conditions through the same period. 1 his is a convenient simplification, but shrinkage and creep are not independent phenomena.

If a sustained load is removed from a concrete specimen, the strain decreases immediately by the amount equal to the elastic strain at the given age, generally lower than the elastic strain on loading. This instaneous recovery is creep recovery (Fig. 10.19) The shape of the creep recovery curve is rather like that of the creep curve, but recovery approaches its maximum value much more rapidly, the reversal of creep is not complete and creep is not a simply reversible phenomenon.



Time Since Application of Load Days

. Fig. 10.19 Creep and recovery of a concrete specimen storied in air (relative humidity 95 percent) subjected to a compressive stress of 21.50 psi and then unloaded.

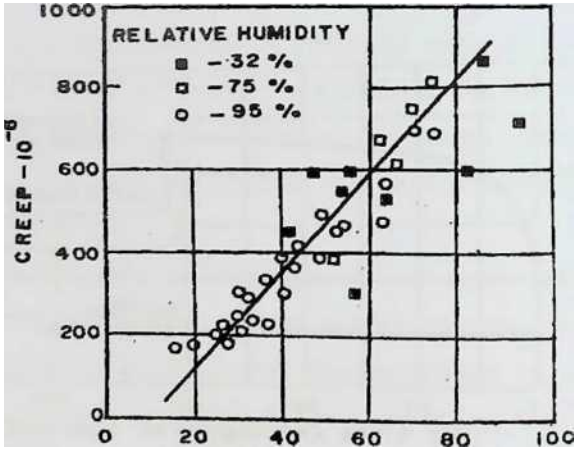
Factor Influencing Creep: Factors that influence creep are Relative humidity (b) Shrinkage (c) Strength (d)

Aggregate (e) Temperature.

(a) Relative Humidity: The relative humidity of the medium surrounding the concrete is an important factor. For a given concrete, creep is higher the lower the relative humidity.

(b) Shrinkage: Concrete which exhibits high shrinkage shows generally also a high creep. This does not mean that the two phenomena are due to the same cause but they may be both linked to the same aspect of structure of hydrated cement paste.

(c) Strength: The strength of concrete has a considerable influence on creep: within a wide range creep is inversely proportional to the strength of concrete at the time of application of the load. This is indicated in the Table 10.6. It is thus possible to express creep as a linear function of the stress/strength ratio (fig. 10.20) Since for a given mix. strength and modules of elasticity are related to one another creep and modulus of elasticity are also related.



STRESS/STRENQTH RATIO PER CEN7

Fig: 10.20 Creep of concrete specimens cured and stored continuously at different humidities

Table 10.6 Creep of Concrete of Different Strengths Loaded at the Age of 7-Days

Compressive strength of concrete, psi	Ultimate specific creep. 10-6 per Ib/inch2
2.000	1.40
4,000	0.80
6,000	0.55
8.000	0.40

From the influence of strength on creep it follows that creep is closely related to the water/cement ratio of the mix.

(d) Aggregate: Very recent tests have shown that the modulus of elasticity of aggregate controls the amount of creep and concrete made with different aggregates exhibit creep of varying magnitude.

(e) Age and Maturity: The age at which the load is applied greatly affects the magnitude of creep (Fig 10.21), the influence of age arising probably mainly from an increase in the strength of concrete with age. For the same reason, maturity affects creep.

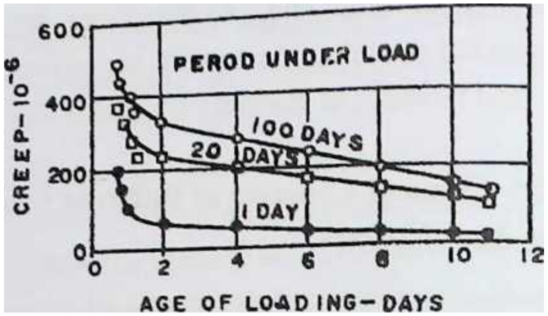


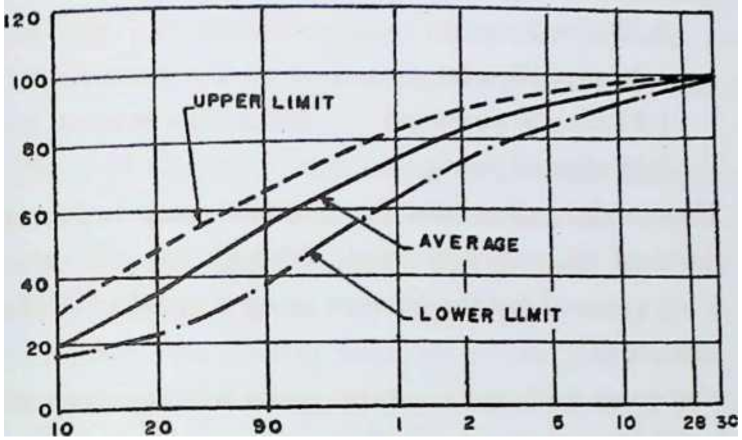
Fig. 10.21 Influence of age at loading on creep of concrete made with aluminous cement.

(i) Type of Cement: The type of cement affects creep so far as it influences the strength of the concrete at the time if application of the load. Portland blast-furnace cement results in a higher creep than the standard types of Portland cement.

(g) Fineness of Cement: Fineness of cement affects the strength development at early ages and thus influences creep. The finer cement the higher its gypsum (retarder) requirement which produces high shrinkage and therefore, high creep.

(h) Temperature: Creep of concrete at temperatures above normal is becoming of increasing interest since concrete is now used in the construction of pressure vessels in atomic reactors. Few test data are available but there is no doubt that a higher temperature leads to a higher initial rate of creep, compared with the behavior of the same concrete at room temperature. This is due to an increase in the mobility of water and also to activation of molecular processes of deformation. However, the rate of creep soon falls off and becomes the same at all temperatures. Nevertheless, in case

of young concrete creep at 200°F can be nearly three times the creep of the same concrete at 70°F.



H-----------OAYS----------h -- YEARS------------------H

TIME SINCE LOADING (LOG SCALE)

Fig. 10.22 Creep time curves

Relation Between Creep and Time: Creep is usually determined by measuring the change with time in the strain of a concrete specimen subjected to a constant stress and stored under appropriate conditions, under such conditions creep continues for a long time. The rate of creep, however decreases at a continuous rate and it is generally assumed that creep tends to a limiting value after an infinite time under load. The Fig. 10.22 shows the long-term measurements of creep and it can be seen that: 18 to 35 per cent (average 26 per cent) of the 20-year creep occurs in 2 weeks:

40 to 70 per cent (average 55 per cent) of the 20-year creep occurs in 3 months, and 64 to 83 per cent (average 76 per cent) of the 20-year creep occurs in 1 year.

If the creep after 1 year under load is taken as unity, then the average values of creep at later ages are:

1.14 after 2 years:
1.20 after 5 years:
1.26 after 10 years:
1.33 after 20 years and
1.36 after 30 years.

These values show that the ultimate creep is in excess of times of the one year-creep, although for calculation it is often assumed that the ultimate creep is equal to $^4/_3$ of the one year-creep.

Numerous mathematical expressions relating creep and time have been suggested. They are hyperbolic, logarithm, exponential or power functions. But the fundamental principle is that the rate of creep at any time is proportional to the creep still to appear-characteristic of visco elastic fluid. But it may be said that the present knowledge about creep is still largely qualitative but not quantitative.

Nature of Creep: The problem of the nature of the creep is still controversial. The seat of creep is cement paste and the creep may be related to internal movement of absorbed or intracrystalline water. The exact mechanism of creep is still unknown. But it is apparent that creep and many mechanical properties of cement paste, depend largely on a grosser structure of colloidal dimensions and only indirectly on the chemical constitution.

Although the nature of creep is still uncertain, one should have thorough understanding of the nature of deformation which dictates the nature of creep. An *elastic deformation is* always reversible on unloading. A *plastic deformation* is never recoverable can be time dependent and there is no proportionality between plastic strain. A viscous deformation is never recoverable on unloading is always time-dependent and there is always proportionality between the rate of viscous strain and the applied stress and hence between stress and strain at a given time.

Effects of Creep: Creep effects strains and deflection and often also stress distribution but the effects vary with the type of structure. Creep of plain concrete does not affect the strength although under very high stresses, creep hastens the approach of the limiting strains at which failure takes place. The influence of creep on the ultimate strength of simply supported reinforced concrete beam subjected to a sustained load is not significant but the deflection increases considerably and may in many cases be a critical consideration in design.

In reinforced concrete columns, creep results in a gradual transfer of load from the concrete to the reinforcement. In statically indeterminate structure creep may relieve stress concentration induced by shrinkage, temperature changes, or movement of supports. In all concrete structures, creep reduces internal stresses due to nonuniform shrinkage so that there is a reduction in cracking.

On the other hand, in mass concrete, creep in itself may be a cause of cracking when a restrained concrete mass undergoes a cycle of temperature changes due to the development of the heat of hydration and subsequent cooling. Creep relieves the compressive stress induced by the radix rise in temperature so that the remaining compression disappears as soon as some cooling has taken place. On further cooling of concrete, tensile stresses develop and since the rate of creep is reduced with age cracking may occur even before the temperature has dropped to the initial (placing) value. For tins reason, the rise in temperature in the interior of a large concrete mass must be controlled by the use of low heat cement, a low cement content precooling of the mix ingredients, limiting the height of concrete lifts, and coiling of concrete by circulating refrigerated water through a network of pipes embedded in the concrete mass.

Another instance of the adverse effects of creep are its influence on the stability of the structure due to increase in deformation. Even when creep does not affect the ultimate strength of a structure its effects may be extremely serious as far as the performance of the structure is concerned.

The loss of prestress due to creep is well known and indeed accounts for the failure of all early attempts at prestressing. It was only the introduction of high tensile steel, whose elongation is several times the construction of concrete due to creep and shrinkage, that made prestressing a successful proposition.

The effects creep may thus be harmful, but on the whole creep, unlike shrinkage is beneficial in relieving stress contentions and has contributed very considerable to the success of concrete as a structural material.

10.15 Chemical Attack of Concrete: The common forms of chemical attack are: (1) Leaching out of cement (efflorescence) (2) Action of sulphates: (3) Sea water attack (4) Acid water attack. In general terms the resistance of concrete varies with the type of cement used: it has been suggested that the resistance increases in the following order:

1 • Ordinary and rapid hardening Portland cement.

9. Portland blast-furnace cement and low heat Portland cement.
3. Sulphate resisting Portland cement and pozzolana cement.
4. Aluminous cement.

1. **Leaching (Efflorescence):** Leaching of lime compounds may under some circumstance lead to the formation of salt deposits on the surface of the concrete, known as efflorescence. This is found, for instance when water percolates through poorly compacted concrete or through cracks or along badly made joints and when evaporation can take place at the surface of the concrete. Calcium carbonate. CaCO$_3$ formed by the reaction of C (OH)$_2$ with CO$_2$ is left behind in the form of a white deposited. Calcium sulphate deposited are encountered as well.

Efflorescence can also be caused by the use of unwashed seashore aggregated. The salt coating on the surface of the aggregate particles may in due course lead to white deposited on the surface of the concrete. Gypsum and alkalis in the aggregate have a similar effect.

A part from the leaching aspect, efflorescence is ot importance only in so far as it mars the appears of concrete.

2. **Sulphate Attack:** Solid salts do not attack concrete, but when present in solution they can react with hardened concrete. Some clays contain alkali, magnesium and calcium sulphates and the ground water in such a clay produces a sulphate solution. Attack on concrete can thus take place, the sulphate reacting with Ca (OH)$_2$ and with calcium aluminate hydrate.

1 he products of the reactions, gypsum and calcium sulpho aluminate have a considerably greater volume than the

compounds they replace, so that the reactions with the sulphates lead to expansion and disruption of the concrete.

The rate of sulphate attack increases with an increase in the strength of the solution concrete attacked by sulphate has a characteristic whitish appearance. The damage usually starts at eddies and corner and is followed by progressive cracking and spalling which reduce the concrete to a friable state or even soft state.

The vulnerability of concrete to sulphate attack can be reduced by:

(a) the use of cement of low C_3 A
(b) the addition of pozzolana material with cement
(c) the use of dense and impermeable concrete
(d) the keep of high-pressure steam curing and
(e) the addition of calcium chloride to the concrete mix.

3. Sea water Attack: Sea water contains sulphate and attack concrete in manner similar to those described already in addition the chemical action, crystallization of the salts in the pores of the concrete may result in its disruption owing to the pressure exerted by the salt crystals. Because crystallization takes place at the point of evaporation of water this form of attack occurs in the concrete above the water level. Since, however, the salt solution rises in the concrete by capillary action, the attack takes place only when water can penetrate into the concrete so that impermeability of the concrete is once again its most important attribute, in tropical climates this attack is more rapid.

In some cases, the action of sea water on concrete is accompanied by the destructive agents of frost, wave impact

and abrasion and all these tend to aggravate the damage of the concrete.

In case of reinforced concrete, the absorption of salts established anodic and cathodic areas: the resulting electrolytic action leads to an accumulation of the corrosion products on the steel with a consequent rupture of the surrounding concrete, so that the effects of sea water are more severe on reinforced concrete than on Plaine concrete. It is therefore, re-essential to provide a sufficient cover to reinforcement (3 inch preferably) and to use dense and impermeable concrete. The type of cement used comes second, aluminous, sulphate resisting Portland blast-furnace and Portland pozzolana cements giving good results.

4. Acid Attack: In damp condition, SO_2, CO_2 and other acid fumes present in the atmosphere attack concrete by dissolving and removing part of the set cement, a soft and mushy mass being ultimately left behind. This form of attack occurs in chimneys and steam railway tunnels. Acid attack is encountered also under industrial conditions.

Although domestic sewage by itself is alkaline and does not attack concrete, severe damage of sewers has been observed in many cases, specially at high temperatures, when Sulphur compounds become reduced by an aerobia bacteria to ITS. This is not a destructive agent itself, but is dissolved in moisture films on the exposed surface of the concrete and undergoes oxidation by aerobic bacteria finally producing sulphuric acid. The attack occurs, therefore, above the level of the flow of the sewage. The cement is gradually dissolved and progressive deterioration of concrete in the sewer takes place.

Industrial wastes sometimes contain acid due to manufacturing processes. Thus, industrial waste attacks industrial sewers (concrete sewers) and surface drains.

The resistance of concrete to acid attack is increases successfully by the artificial surface treatment with coal-tar rubber or bituminous paints, sodium silicate, magnesium silico fluoride and other agents. Good protection of concrete for acid attack is obtained by subjecting concrete in a vacuum to the action of silicon tetrafluoride gas. This gas reacts thus with lime.

$2Ca(OH)_2 + SiF_4 \rightarrow 2CaF_2 + Si(OH)_4$ 19.8

This treatment can be applied to precast concrete only, which is then known as *Ocral-concrete.*

10.16 Various special types of concrete:

1. Precast Concrete: This is a type of concreted which is cast into moulds either in a factory or at the site. The better definition is that this is the concrete which is not laid in position directly, like green concrete which is placed in position directly, after mixing is termed as cast in situ concrete. The hardening and curing of precast concrete are also carried out where it is cast but not in the position where it is ultimately used. Precast concrete is used in simple units labs, line ties various types of ornamental and architectural works in buildings and different units of prefabricated concrete houses.

The advantages of precast concrete over cast in situ concrete are (a) better supervision (b) production not hampered by weather condition (c) less shuttering requirement (d) quick laying of precast units on the site and (e) hence time of construction is less.

The disadvantages are (a) during handling and transporting, there is always a risk of damage and breakage (b) large space is required for curing precast blocks and part (c) large structural members present major problem of handling transporting and placing in position.

2. **Reinforced Cement Concrete (R.C.C.):** Concrete is very strong in compression and again comparatively very weak in tension. On the other hand, steel is very strong in tension. Therefore, steel rods of recommended size are embedded in concrete to take care of tension. The concrete adheres quite well to the surface of the steel rods. In other words, the bond between concrete and steel is very strong. Therefore, the cement concrete which strengthen or reinforced by using steel rods is termed as 'Reinforced Cement Concrete' (RCC). There might be questions about why only steel rods are used as reinforcement and why not other materials like timber, bamboo etc. There are many reasons of superiority of steel over other materials as reinforcement, but the following three reasons are most important: (a) Steel as discussed already is very strong in tension (b) Co-efficient of thermal expansions of concrete and steel are approximately same and (C) Bond between concrete and steel is very strong.

Since most of the modern construction is made by reinforces cement concrete, the strength of bond between concrete and steel is of considerable importance. Bond arises primarily from friction and adhesion between concrete and steel and may also be affected by the shrinkage of concrete relative to steel. Bond involves, however, not only the properties of concrete but also the mechanical properties of steel and its position in the concrete member. In general terms, bond is related to the quality of the concrete and bond-strength is approximately proportional to the compressive strength of concrete up to about 3.000 psi. It has been found by research that for higher strength of concrete, the increase in bond strength becomes progressively smaller and eventually negligible. This is why most codes of practice restrict the permissible value of bond strength becomes progressively smaller and eventually negligible. This is why most codes of practice restrict the permissible value of bond in high strength concrete. The British Code of practice CP 114(1957) prescribes the permissible average bond as O_{cb} 12 f_{cb} up to fcb = 1,000 psi and 0.06 f_{cb}+60 above f_{cb}= 1,000 psi, where fca is the permissible compressive stress in bending and is equal to 1/3 of the 28 days cube strength.

The American Concrete Institute Code 318-56 prescribes permissible bond stress as a fraction of the compressive strength of concrete up to 3.500 psi put allows no increase in bond stress in concrete of high strength. The 1963 revision of the AC1 Code stipulates the bond stress, as a proportion of the square root of the compressive strength of concrete with an upper limit of 500 psi.

After formwork is prepared, the reinforcing rods are placed in position and tied. The subsequent operations of placing compacting and curing are the same as in case of plain concrete.

The steel rods should be embedded sufficiently and a covering of following specifications should be provided:

Slabs. Minimum cover is $^{1}/_{2}$ inch and should not be less than the diameter of steel rods.

Columns and Beams: Minimum cover 1 inch and should not be less than the diameter of steel rods.

Minimum clear distance between the steel rods should not be less than 1 inch or diameter of the rods in any case, the spacing should not be less than the maximum size of the coarse aggregate. The minimum clear distance between successive layers of rods should not be lens 3/4 inch. The working stress of steel rods in tension should be 23.000 psi. When the rods are spliced, a length of lap 40x diameter of the rod is to be taken in addition to an anchorage in stie form of a semicircular hook whose diameter should be 5x diameter of the rod (minimum). Details of standard hook is shown in Fig. 10-23. According to ACI Code, splicing at points of maximum tensile tress shall be avoided. All rods should be bent (from compression zone to tension zone and vice versa) preferable at an angle of 45°

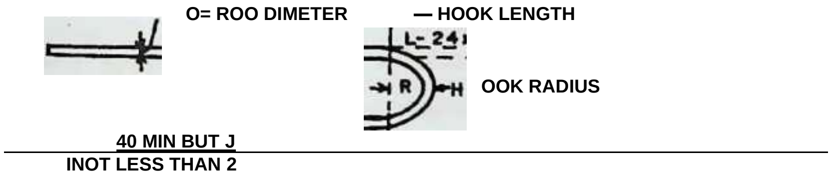


Fig. 10.23 Details of Standard Hook

Standard Hook Size (180° hook):

R=$2^{1}/_{2}$ d for rods $^{1}/_{4}$ to 5/8- inch diameter (minimum).

R$^{=}$3d for rods ^{3}/4 to 1 inch diameter (minimum).

R=3 ½ d for rods 5-to $1^{1}/_{2}$ -inch diameter (minimum).

Hook length. L=24 x Rod diameter.

Some typical sections (showing the reinforcement) of R. C. C. structural members (rectangular beams, T-beam with column and roof slab) are shown in Fig. 10.24

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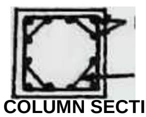


(b) R. C. C. Beam **(c) R. C. C. Roof slab**

Fig. 10.24. Typical Sections of R.C.C. Structural Members Allowable Stresses in Reinforced Cement Concrete: According to AC1 Code, the following are the allowable stresses:

(a) Allowable compressive stress in concrete f_c=0. 45 l^c where f_c =allowable compressive stress in concrete, psi and f_c=ultimate compressive strength of concrete, psi.

(b) Allowable tensile stress in steel reinforcement is generally taken to be 18,000 psi or 20,000 psi.

(c) Allowable bond stress Previous Value: V_c=0.04f_c

(For all conditions, but not to exceed 160 psi) Present Value:

for normal bottom rods. $V_c = \dfrac{2.4\sqrt{f_c}}{d}$

where d is the diameter of rods

for normal top rods. $V_c = \dfrac{1.75\sqrt{f_c}}{d}$

for deformed bars, $V_c = \dfrac{\mathbf{4.8}\sqrt{f_c}}{d}$ -

In any case, the value V_c should not exceed 160 psi.

3. **prestressed Concrete:** Concrete in which there have been introduced internal stress of such magnitude and distribution that stresses resulting from given external loading are counteracted to a desired degree. In reinforced cement concrete members, the prestress is commonly introduced by tensioning the steel reinforcement.

In prestressed concrete, high tensile steel is used which will have to be elongated a great deal before its strength is fully utilized. If the high tensile steel simply buried in the concrete as in ordinary reinforced concrete, the surrounding concrete will have to crack very seriously before the full strength of the steel is developed. Hence it necessary to pre stretch the steel with respect to concrete. By pre stretching and anchoring the steel against the concrete, desirable stresses and strains are produced in both materials. Compressive stresses and strains in concrete and tensile stresses and strains in steels This combined action permits the safe and economical utilization of the two materials which cannot be achieved by simply burying steel in concrete as is done for ordinary reinforced concrete. Therefore, prestressed concrete in nothing but an extension of the applications of the reinforced concrete to include steels of high tensile strength.

Classification: Prestressed concrete structure can be classified in number of ways, depending upon their features of design and construction. These are as follows.

(a) **Externally of Internally Prestressing.** External 1) prestressing is a term applied to prestressed structures were tressing is applied externally. Similarly, internally prestressing is used to describe the method of prestressing internally. Most of the prestressed concrete structures are internally prestressed.

(a) **Circular and Linear pre stringing:** Circular prestressing refers to prestressing in circular or round structures like tanks, pipes etc. where the prestressing reinforcement are wound around in circle. Prestressing all other members like beams slabs etc. termed as linear prestressing.

(b) **Pre-tensioning and post-tensioning:** The term pretension Ing is used to describe any method of - prestressing in which the reinforcement are stretched (tensioned) before the concrete is placed. The steel rods are temporarily encored against some posts when tensioned and the prestress transferred to the concrete after it has set. In contrast to pretension Ing, post tensioning is a method of prestressing in which the reinforcement is tensioned after the concrete has hardened.

(c) **Partial or Full prestressing:** When a member is designed so that under the working load there is on tensile stress in it then the concrete is said to be fully prestressed. If some tensile stresses will be produced in the member under working load, then it is termed partially prestressed.

Advantages and disadvantages of prestressed Concrete over Reinforced Concrete: The readers are already acquainted with reinforced concrete, so it will be interesting to compare prestressed concrete with it. The most outstanding difference between the two is the employment of materials of higher strength for prestressed concrete. In order to utilize the

full strength of the high tensile steel it is necessary to restore prestressing to prestress it. Prestressing the steel and anchoring it against the concrete produces desirable stresses and strains which serve to reduce or eliminate cracks in concrete. Thus, the entire section of the concrete becomes effective in prestressed concrete whereas only the portion of section above the neutral axis is supposed to act in the case of reinforced concrete.

The use of curved reinforcement will help to carry some of the shear in a member. In addition, precompression in the concrete tends to reduce the diagonal tension. Thus, it is possible to use a small section in prestressed concrete to carry the same amount of external shear in a beam.

High strength concrete which cannot be economically utilized in reinforced concrete constructions is found to be desirable and even necessary with prestressed concrete. In reinforced concrete using concrete of high strength will result in a smaller section calling for more reinforcement and will end with a more costly design. In prestressed concrete high, strength concrete is required to match with high strength steel in order to yield economical proportions. Now, the advantages of prestressed concrete as compared with reinforced concrete will now be discussed with respect to their service ability, safety and economy.

Service ability: Prestressed concrete design is more suitable for structures of long spans and those carrying heavy loads. Prestressed structures are more slander and hence more adaptable to artistic treatment they do not crack under working lords. Under dead load the deflection is reduced owing to the cambering effect of prestress. This becomes an important consideration for structures such as long cantilevers. Under live load the deflection is also smaller prestressed elements are more adaptable to pre casting because of the lighter weight.

Safety: If is difficult to say that one type of structure is safer than the other. The safety of a structure depends more upon its design and construction than upon its type. When properly designed prestressed structures have overloading capacities similar to and perhaps slightly higher than those of reinforced concrete. The ability to resist shock and impact loads and repeated working loads has been shown to be as good in prestressed as in reinforce concrete. The resistance to corrosion is better than that of the reinforced concrete for the same amount of cover owing to the non-existence of cracks. But if cracks are developed corrosion can be more serious in prestressed concrete.

Prestressed concrete members do require more care in design construction add erection than those of ordinary concrete, because of higher strength smaller section and same times delicate design features involved.

Economy: From the economic point of view, it is at once evident that smaller quantities of materials, both steel and concrete are required to carry the same loads, since the materials are of higher strength. There is also a definite saving in stirrups since shear in prestressed concrete is reduced by the inclination of the reinforcement and the diagonal tension is further minimized by the presence of prestress.

In spite of the above economic saving with prestressed concrete, its use cannot be advocated for all conditions.

First of all, the stronger materials will have a higher unit cost. More auxiliary materials are required, for prestressing such as anchorage devices, conduits and grounds etc. More formwork is also needed, since non-rectangular shapes are often necessary for prestressed concrete. More labor is required to place reinforcement. More attention in design construction and supervision is necessary. Skilled labor is required. From the above discussion, it can be concluded that prestressed concrete structure is more likely to be economical when the same unit is repeated many times or when heavy good and experienced designer of experienced and skilled laborer's, prestressing devices and of stronger materials often helps to tip the balance in favor of prestressed concrete.

Uses of Prestressed Concrete: Prestressed concrete is very popular nowadays in concrete constructions. It is used in the construction of slabs, span beams, bridges, dams, piles, posts and pipes.

Strength of Requirement for Concrete and Steel in Prestressed Concrete:

Concrete: Stronger concrete is required for prestressed than reinforced work. Present practice calls for 28 days cylinder strength of 4,000 to 5,000 psi for prestressed concrete while the corresponding value for reinforced concrete is around 2500 psi. High strength is necessary for the following reasons: (a) In order to minimize their cost, commercial anchorages for prestressing steel are always designed on the basis of high strength concrete (b) Concrete of high compressive strength offers high resistance in tension and in shear as well as bond (c) High strength concrete is less liable to shrinkage cracks

(d) it has also a high modulus of elasticity and smaller creep strain. Resulting in smaller loss of prestress in steel.

Steel: High tensile steel is almost the universal material for producing prestress and supplying the tensile force in prestressed concrete. Such steel can take any of three forms wires, stands, or bars. The most widely used at present are the wires, which are grouped, in parallel, into cables. The tensile strength is in the range of 150,000 to 270,000 psi.

4. Prepacked Concrete: This type of concrete is produced in two stages. In the first operation, the coarse aggregate is placed and compacted in the formworks. The voids between the particles, forming some 30 to 35 percent of the overall volume to be concreted, are filled with mortar in the second operation. The coarse aggregate must be thoroughly wetted before the mortar is intruded. The mortar is pumped under pressure through slotted pipes, starting from the bottom of the mass, the pipes being gradually withdrawn. A typical mortar consists of one part Portland cement, one part of very finely divided highly active pozzolana or fly ash (residue) the burning of powdered coal, and three to four parts of fine sand with sufficient water to form a fluid mixture. An intrusion agent, (representing about 1 percent of the weight of the cement plus the pozzolana or fly ash) containing a small amount of aluminum powder in order to improve the fluidity of the mortar and to hold the solid constituents in suspension is used. As an alternative, a mortar consisting of cement and fine sand can be mixed in special 'colloid' mixer which disperses the cement to such a degree that it remains in suspension until the pumping has been completed. For this

reason, the prepacked concrete is also known as *colloidal concrete.*

The following are the Advantages of Prepacked Concrete:

(a) Prepacked concrete is economical in cement.

(b) Concrete of uniform properties is obtained.

(c) Segregation is practically eliminated.

(d) Prepacked concrete can be placed in locations not easily accessible by ordinary concreting techniques: it can also be placed in sections containing a large number of embedded items that have to be precisely located this arises, for instance in nuclear shields.

(e) The drying shrinkage of prepacked concrete is considerably lower that of ordinary concrete.

(f) It is highly resistant to actions of freezing and thawing.

(g) Prepacked concrete is suitable for the construction of water retaining structures like dam’s water tanks etc. and for repair works.

(h) Prepacked concrete be used in mass construction where the temperature rise has to be controlled cooling can be achieved by circulation of refrigerated water is later displaced by the raining mortar. At the other extreme, in cold weather when the frost damage is feared, steam can be circulated in order to preheat the aggregate.

Prepacked concrete appears thus to have many useful features, but because of numerous practical difficulties (e.g. the need for an extremely clear coarse aggregate) considerable skill and experience in application of process are necessary for good results to obtained.

5 Vacuum Concrete: All the water used in mixing concrete is not. required for hydration and therefore if excess water is removed after placing the strength of the concrete will be improved.

The procedure is briefly as follows a concrete mix with good workability is place in the formworks in the usual manner. Since fresh concrete contains a continuous system of water filled channels the application of a vacuum to the surface concrete results in a large amount of water being extracted from a certain depth of the concrete, the vacuum is applied through porous mats connected to a vacuum pump. The final water/cement ratio before setting is thus reduced and as this ration largely controls the strength, vacuum concrete has a higher strength and also density a lower permeability and a greater durability.

Vacuum concrete stiffens very rapidly so that the formworks can be removed within 30 minutes of casting even on columns to 20 ft. high. This is of considerable economic value, particularly in a precast factory as the forms can be reused at frequent intervals. The surface of vacuum concrete is entirely free from pitting and the uppermost 1/16 inch is highly resistant to abrasion. These characteristics are of special importance in the construction of concrete structures which are to be in contact with flowing water at a high velocity. Another useful characteristic is that it bonds well to old concrete and can; therefore, be used for resurfacing road slabs and other repair works.

6. Air Entrained concrete: Entrained air in concrete is defined as the air intentionally incorporate by means of a suitable agent. The main types of air entraining agents are:

a) Animal and vegetable fats and oils and their fatty acids

b) Natural wood resins, which react with lime in cement to form a soluble resin ate.

c) Wetting agents such as alkali salts of sulphate and sulphonated organic compound.

The air entraining agents can be dispensed either as an admixture (a material adds to the mix when the ingredients are fed into the concrete mixer) or else as an addition to the cement, in which the agent is intergrown with the cement in fixed proportion. The air entraining agents represent between 0.005 to 0.05 percent of the weight of the cement, but to facilitate the dispensing Operation, a solution of the agent in water is usually made up.

Entrained air produces discrete cavities in the cement paste and therefore, reduces passage of capillary water.

It improves the workability because the air bubbles kept special by the surface tension act as fine aggregate of low surface friction and considerable elasticity. Air entrainment reduces segregation bleeding, permeability and formation of laitance. But if lowers the density of the concrete and is liable to shrinkage on drying. Air entrained concrete is frost resistant. The type of concrete is mainly recommended for used in dams, bridges tunnels and for reads in extremely cold countries and sulphate bearing soils.

Lightweight Concrete: In concrete construction, self-weight represents a very large proportion of the total load on the structure and there are clearly considerable advantages in reducing the density of the concrete, the chief of these are the use of smaller sections and the corresponding reduction in the size of foundation. Furthermore, with lighter concrete the formwork needs to withstand a lower pressure than would be the case with ordinary concrete and also the total weight of materials to be handled is reduced with a consequent increase in productivity. Lightweight concreted also gives better thermal insulation than ordinary concrete. The practical range of densities of lightweight concrete is between 20 and 120 Ib/ft.

Classification of Lightweight Concretes: There are three broad methods of producing lightweight concrete. First, porous lightweight aggregate of low apparent specific gravity is used instead of ordinary' aggregate whose specific gravity is approximately 2.6. The resultant concrete is generally known by the name of the lightweight aggregate used.

The second method of producing lightweight -concrete relies on introducing large voids within the concrete. These voids should be clearly distinguished from the extremely fine voids produced by air entraining. This type of concrete is variously known as aerated cellular, foamed or gas concrete.

The third means of obtaining lightweight concrete is by simply omitting the fine aggregate form the mix so that a large number of interstitial voids is present. Coarse aggregate of ordinary weight is generally used. This concrete is described by the term *No fines Concrete.*

In essence then, the decrease in density is obtained in each case by the presence of voids, either in the aggregate, or in the mortar or in the interstices between the coarse particles. It is clear that the presence of these voids reduces the strength of lightweight concrete compared with ordinary concrete, but in many applications high strength is not essential.

Lightweight concrete provides a very good thermal insulation but is not highly resistant to abrasion. In general, lightweight concrete is more expensive than ordinary concrete and mixing, handling and placing also require considerably more care and attention than ordinary concrete. However, for many purposes the advantages of lightweight concrete outweigh its disadvantage and there is a worldwide trend towards using more lightweight concrete and also toward using it is new applications.

Lightweight concrete can also be classified according to the purpose for which it is to be used; structural lightweight concrete (load bearing) and ordinary or non-structural lightweight concrete) non load bearing such as non-load bearing walls for insulation purposes and the like). Structural lightweight concrete should have a compressive strength measured on a standard cylinder specimen at 28 days of not less than 2,000 psi. The density of such concrete, determined in the dry state, is usually above 60 Ib/ft3.

Lightweight Aggregates:

Introduction: The process of using lightweight aggregate. as a construction material is about 2000 years Old. But the use of lightweight aggregate was not popular until recent years. The lightweight aggregate industry is mere infant compared to the sand, gravel and crushed stone industries. However, it is growing rapidly and even now occupies an important position in building construction. Ever increasing length of bridge spans and high of building have created structural problems due to excessive self-weight. In many places there is dearth of suitable material for use as coarse aggregate in concrete. Thin walls which are essential in tall building for reducing dead load have heat insulation problems. The solution of these problems and many other factors have led to the development of lightweight aggregate concretes.

Lightweight aggregate was first used by the Romans. They used to embed large pieces of pumice in the domes and walls of larger bulling. From the fall of Roman empire until the twentieth century very small number of lightweight aggregates were used. According to published reports, the Germans started using slag as concrete aggregate in 1822 and the American started using in 1890. Cinders from coalbuming furnaces were used as aggregates early in the present century in the industrial area of the United States.

The modem lightweight aggregate industry was born in earlier part of this century (1917) when a process was developed of expanding shale and clay into sound, hard lightweight pellets suitable for use as aggregate in structural concrete. This type of aggregate was used in a few concrete ships during the first World War and in more than hundred concrete ships and burgers built during World War 11. The concrete ship is no longer important, but it served to illustrate the fact that high quality concrete could be made with lightweight aggregates. During the past 30 years other materials such as pumice, vermiculite, and perlite have been widely used. One important factor has contributed to the use of lightweight aggregate was the radical change in building design, that was brought in the latter part of nineteenth century. The introduction of structural steel and structural concrete has changed the method of building design from load beginning will type to the framed structure. The

introduction of framed structure and lightweight aggregates helped in building skyscraper and long span bridges.

Principal Types of Lightweight Aggregates: The lightweight aggregates can be grouped into three general classes:

(1) Naturally Occurring lightweight aggregates.

(2) By-products lightweight aggregate.

(3) Synthetic (Manufactured) lightweight aggregate.

In naturally occurring aggregates the major ones are; pumice volcanic, cinders, scoria and diatomite. Industrial cinders or fly ash, sintered aggregates and blast furnace stage belong to by-products aggregates. The following aggregates belong to manufactured group : expanded clay, shale, diatomaceous shale, perlite, obsidian and vermiculite.

Naturally Occurring Lightweight Aggregates:

Pumice: Pumice is a light colored forth-like volcanic glass of cottony appearance, full of pores and light enough in weight to float on fresh water. It is produced by nature in prehistoric times by the extravasation of a water vapor at high temperatures. Those verities of pumice which are not too weak structurally make a satisfactory concrete with a density of 45 to 65 Ib/ft3 and with good insulating characteristics, but having high absorption and shrinkage.

Volcanic Cinders: A loose agglomerate composed largely of highly vesicular, glassy fragments of lava. These also produce a concrete of similar properties.

Scoria: A highly vesicular lava in which the vesicles are rounded on elliptical in cross section. Scoria aggregate resembles industrial cinders and usually red to black in color. This also produces a good lightweight concrete.

Diatomite: It is a consolidated sedimentary rock composed primarily of diatom skeletons (diatomaceous earth). This produces a satisfactory concrete of density 30 to 651 b/ft3.

By product lightweight aggregate:

Industrial Cinder or Fly Ash: The term Industrial Cinder or Fly Ash refers to the residue from the burning of powdered coal. As the powdered coal passed through the zone of high temperature within the boiler the carbon is burnt and the residue remains in the suspension in the form of fused particles. These particles, still in suspension, are quickly carried to a zone of comparatively low temperature where they solidify to form the fly ash. It is composed largely of silica, alumni, lime and iron with smaller quantities of magnesium and alkali compounds.

In all industrial areas of the world where coal is used as fuel, huge quantities of fly ash are being product every year which substantially is a waste product necessitating disposal. But this waste material can be successfully utilized concrete construction resulting in a number of added advantages over the usual cement concrete. They fly ash can be utilized both as a complete or partial replacement of any of the ingredients incorporated in mortars and concrete.

Sintered Aggregates: The lightweight aggregate produced by burning the coal and shale clays, cinders, slag, or ashes in moving grates or rotary kiln exposed to flames under drafts are known as sintered aggregates. The aggregates are crushed to the desired sizes after the sintering process. Cortile Sinterlite. Delite and Lylag are the better-known sintered aggregates.

Expanded Blast Furnace Slag: It is produced by treating molten iron blast furnace slag with controlled quantities of water, often combined with compressed air or steam. There are three methods for bringing the slag in contact with the proper quantities of water. In one process the molten slag is run into pits containing a right amount of water, which becomes steam due to heat and expands the material. In second method the slag is broken and water is sprayed to expand the material in third process, the slag is put into the top of a machine, where it is broken by paddles and blades revolving horizontally. This agitation plus water spraying expands the slag. All Processes result in the same end product lightweight cylinder, subsequently processed by crushing and screening in required sizes.

Synthetic Lightweight Aggregates: The term Synthetic Aggregate has recently been adopted by researchers and organizations to specify structural quality aggregates produced by firing clays, shales. As all these raw materials are essentially hydrous aluminum silicate with occasional substitution of aluminum by magnesium and iron. Chemically synthetic aggregate is predominantly a form of amorphous silicate.

Although lightweight aggregates have been produced by expanding clay, shales and slates for about 40 years, the mechanism and the reactions involved have not been thoroughly understood until recently. The principal obstacle to the understanding were the and lack of knowledge of the importance of the relatively minor components.

In commercial operations, shale, clay and slate aggregates are expanded in a rotary kiln or on a moving grate.

Expanded Clay a Shale: These type of clays and shales which are used for manufacturing bricks tiles, sewer pipes and similar wares are generally used for making, bloated (expanded) products. In the bloating process the basic-mineral structure of the clays does not play part. The constituents responsible for the bloating are usually known as impurities in a clay or shale. These include carbonaceous materials, various iron compounds, limestone, dolomite & gypsum, which are potential sources of gases for bloating. The clay which does not contain the constituents which accuses bloating can be used only by adding the missing constituents. The organic material such as coal and oil are also used as gas producing agents. The gases developed from these materials may be retained in the fused materials to accuses bloating or the organic material is only decomposed to leave avoid without much expansion of the aggregate.

The most suitable expansion temperature is between 900 to 1200°C. Illite fuses a 1000 to 1530°C and kaolinite at 1650 to 1780c. A wide temperature range of softening coincident with evaluation help in getting optimum results and satisfactory performance in the rotary kiln. A high percentage of illite in the samples produces satisfactory bloating. The studies made to determine the time and temperature effects on bloating weight may be reached in many cases by either high temperatures in a short time or lower temperatures over a long period. To get lower weights a high temperature

for a long period is needed. Better known expanded clay and shale aggregates arc. Haydite, Rocklite, Gravelite, Gel-Seal. Nodulite, Claydite and Featherlite.

Expanded Slate: Expanded slate is manufactured by rotary kiln process. Slates when hated becomes sticky and sticks to the kiln. To overcome this difficulty the slate is crushed and screened to sizes and coated with a refractory material. The refractory material can be separated from the burnt slate and reused.

Processed Diatomaceous Shales: Discrete and Raylite aggregates are manufactured from diatomaceous earth or shale by crushing and screening to desired sizes, spraying with oil and burning in a rotary kiln. Airrox, another *diatomaceous* shale product is made from and oil-impregnated shale by two processes. On one process the raw shale is crushed and screened to desired size and coated with powdered limestone and heated in a rotary kiln and in the other process it is produced by heating raw crushed shale in open beds at a temperature below fusion.

Expanded Perlite: Perlite is one of the natural volcanic glasses and is related in origin to pumice. The rock from which perlite lightweight aggregate is manufactured has a structure resembling tiny pearls compacted a bound together. The perlite is raised to a high (about 1150°C) temperature and as a result of the process the material expands with disruptive force and breaks into small expanded Particles. Generally expanded perlite is manufactured only in the sand sizes. The unit weight of perlite may be as low as 4 Ib/ft3. This type of aggregate is used in insulation.

Expanded Obsidian: Obsidian is a volcanic glass: When it is heated[1] to the fusion temperature, gases are released which expand the material. The surfaces of the particles are smooth and quite impervious but the interior becomes vesicular. In the process raw materials is crushed and screened to sizes. A material of higher fusion characteristics is used as a coating to prevent agglomeration during the heating process.

Vermiculite: Vermiculite is a material with a platy structure somewhat similar to that of mica. Upon calcination, vermiculite expands at right angles to the cleavage into a fluffy mass the volume increasing as much as thirty time. The aggregate is a good insulating material. It is sold under the trade name of *Alexite, Vosicon. Vesco and Zonolite.*

Properties of Lightweight Aggregates: Many lightweight aggregates are angular and have a rough surface. The essential characteristic of all lightweight aggregate is high porosity.

Based on properties and uses the lightweight aggregate can be divided into two broad groups. The first group is low cost, low strength aggregate suitable for building blocks and insulated walls on which a compressive strength of 1,000 psi is quality aggregates used in structural concrete which must have strength of 2,000 psi or more.

The following are the desirable qualities of good lightweight aggregates:

1. They should be uniform in composition and properties.
2. They should be suitably graded for their intended use and the desired grading should be maintained.

3 They should have a low specific weight

4. They should have a large number of small, well-disposed internal voids but should not have a minimum number of large external voids that gave to be filled with mortar or paste.
5. The aggregates should possess adequate strength for its intended purpose.
6. Particles should be of proper shape to promote good workability.
7. The particles must bond well with the cement paste.
8. The particles should be inert chemically.
9. They should have good resistance to weathering, moisture insects and fungi.
10. If used for insulation purpose they should have high thermal insulation.
11. A low water absorption is desirable.
12. They must have low production cost.

Uniform composition and properties are desirable in order to make concretes or other product of uniform strength and like qualities.

The size gradation is an important requirement to ensure good workability, as the aggregate must be composed of a range of sizes, including sufficient quantity of fines.

Lightweight is desirable to provide worthwhile saving in the weight of the structure. The lightweight aggregate should not be more than half weight of the standard aggregate it replaces.

Strength is an essential quality so the individual particles should be as strong as possible. In a concrete of a given strength. aggregate will need less cement than a weaker one, thus saving cost.

The inertness of aggregates with respect to reactions with both cement and reinforcing steel is required. The compound that would then to react with the cement and affect its setting should not be present.

Low water absorption is desired because, if the aggregated much water in the concrete, it dehydrates the cement with resulting deteriorating effect upon the setting of the concrete. The lightweight aggregate of a given type are likely to vary considerably because of difference in manufacturing method and source of raw materials. This is most important because changes in the aggregates will certainly be reflected in the concrete made with them unless special precautions are taken. Lightweight aggregate of given type is likely to vary considerably because of difference in manufacturing method and source of raw materials. This is most important because changes in the aggregates will certainly be reflected in the concrete made with them unless special precautions are taken. Lightweight aggregate used for structural concrete should have ignition loss less than 5 percent, while those used for masonry units should have less than 8 percent.

The lightweight aggregates if meant for structural concrete or masonry units should have a proven record of durability.

Table 10.7 shows the list of some physical properties of the commonly used lightweight aggregates.

Table 10.7 Physical Properties of the Commonly Used Lightweight Aggregates.

----- - ------- Name	Unit Weight lb. per Clift.	Bulk Specific Gravity	Water Absorption, percentage by weight	Crushing Strength at 2-inch compaction psi.
Expanded Clay	28-52	1.1-1.9	20-34	4,000-10,000
Expanded Shale	60-80	1.8-2.1	7-8	4,000-15,000
Expanded Slate	39-73	1.3-2.2	8-15	2,000-8,000
Processed Diatomaceous Shales	20-35	1.3-1.5	50-74	3,500-5,000
Expanded perlite	4-16	1.7-1.1	10-50	60,400
Blast Furnace Slag	25-70	1.2-2.3	5-25	300- 1,500
Vermiculite	6-12	0.9-1.3	20-35	34-45
Pumice	30-55	10-1.7	8-50	1,000-2,000
Sintered fly Ash	40-65	1.7-21	9-16	400-1,000
Scoria	65	2.0-2.3	8-9	4,000-6,000

Characteristics of Lightweight Concrete: Lightweight concrete covers extremely wide field: using appropriate materials and methods, the density of concrete can be varied between little over 20 and about 115 Ib/ft3 and the corresponding strength range is between 50 and nearly 5,000 psi. For any particular aggregate, strength increases with density but depending on the type of aggregate, 3,000 psi concrete may require between 400 to 680 lb of cement per cubic yard of concrete, the corresponding range lor 4.500 psi concrete is 560 to 840 lb per cubic yard.

Table 10.8 Typical Properties of Lightweight Concrete

Type o1 concrete	Mix, propor- tions by volume of Cement aggregate	Dry, density y of concrete	Compressive strength, psi	Drying shrinkage e, 10-6	Thermal conductivity, Btu/ Ft 2toF/ft	Type of curing
Expanded	1:2	75	2000	550	0.19.-027	Vibration
Clay	1:12	60	850	500		
Expanded	1:6	81	1400	450	0.06-0.12	“
shale	1:9	73	800	400	0.12-0.18	’’
Pumice	1:6	45-70	200-550	400-800		“
Industrial	1:4	92-56	3400	450	0.19-0.21	Normal
cinder or	1:6	75.80	2700	450		
fly ash	1:9	70-75	1500	400	0.11-023	“
Cellular	1:1	45-76	900-	600-1200		
	1:3	40-70	500-750			
No-lines	1:6	125	2100			
concrete	1:8	118	1600	120-130	0.40.054	Vibration
	1:10	115	1000			

All concrete made with lightweight aggregate exhibit a higher moisture movement than is the case with normal weight concrete. They have high initial drying shrinkage, about 5 to 40 percent higher than ordinary concrete. The creep is of the same order as for ordinary concrete. Lightweight concrete has

lower thermal expansion and higher fire resistance than ordinary concrete.

The strength of lightweight concrete used for non-structural purposes is not of primary importance. The main requirement is: thermal insulation a good surface for rendering and not too high a shrinkage.

The Table 10.8 shows the typical properties of some lightweight concrete.

Special Varieties of lightweight concrete: Cellular Concrete or Aerated Concrete: As earlier mentioned one method of obtaining lightweight concrete is by introducing gas bubbles into the plastic cement mix to produce a material with a cellular structure, somewhat similar to sponge rubber. For this reason, the resulting concrete is known as *cellular or aerated concrete.* There are two basic methods of producing aerations and appropriate name being given to each end product: *(1) Gas concrete and (2) Foamed concrete.*

Gas Concrete: Gas concrete is obtained by a chemical reaction generating a gas in fresh mortar, so that when it sets it contains a large number of gas bubbles. Finely divided aluminum power is most commonly used, its proportion being the order of 0.2 percent of the weight of the cement.

The reaction of the active power with a hydroxide of calcium or alkali liberates hydrogen, which forms the bubbles Powdered zinc can also be used. Sometimes hydrogen peroxide is used: this generates oxygen.

Foamed Concrete: Foamed concrete is produced by adding to the mix a foaming agent (soap and synthetic detergents) which introduces and satirizes air bubbles during mixing at high speed.

Cellular concrete may or may not contain aggregate, the latter generally being the case with non-structural concrete required for heat insulation when a density of 12 to 20 lb ft can be obtained. More usual mixes have densities between 30 and 70 Ib/ft^3 when mixture of cement and very fine sand is used. Cellular concrete has a high shrinkage and moisture movement and these may be reduced by high pressure steam curing.

Cellular concretes are mostly used for partitions for heat insulations purposes because of its low thermal conductivity and for fire proofing.

No-Fines Concrete: This is a form of lightweight concrete obtained when fine aggregate is omitted, i.e., consisting of cement, water and coarse aggregate only. No fines concrete is thus and agglomeration of courses aggregates particles, each surrounded by a coating of cement passed up to about 0.05 inch thick.

The strength of no-fines concrete varies generally between 200 and 2.000 psi, depending mainly on its density. The density generality varies between 100 and 125 lb/ft3. Shrinkage of no-fines concrete is considerably lower than that of normal concrete: a typical value is 120 x 10. The coefficient of thermal conductivity of no-fines concrete is between 0.40 and 0.54 Btu/ft^2 h°F/ft.

Sawdust Concrete: It is a lightweight concrete consisting of roughly equal parts by volume of Portland cement, sand and sawdust with water to giver slump of 1 to 2 inch. Such a concrete bonds well to the ordinary concrete and is a good insulator. The sawdust should be clean. The sawdust concrete has a density of between 40 and 100 Ib/ft3.

8. High Density Concretes: Of recent years has found yet another application of concrete: the consultation of biological shields for atomic reactors. Since the ability of concrete to absorb gamma rays is almost proportional to its density, the thickness of the shield can be reduced if concrete with higher density than normal is used.

In order to increase the density of the concrete, some or all the ordinary aggregates can be replaced by a material of very much higher specific gravity, usually over 4.0 (compared with the specific gravity, of ordinary aggregate of about 2.6). Natural and artificial heavy aggregates are used.

One of the common natural aggregates is barytes (barium sulphate). It has specific gravity of 4.1 and occurs as a natural rock with a purity of about 95 percent Barote behaves rather like ordinary crushed stone aggregate an does not present any special problem so far as proportioning of mixes is concerned. Baryte concrete does not stand up well to weathering but for most applications of high-density concrete, this is of little importance. Shrinkage is reduced by $^1/_4$ to $^1/_2$ of that of ordinary concrete. The co-efficient of thermal expansion is about twice as the of ordinary concrete: the specific heat, thermal Conductivity and infusibility are all considerably lower.

The density of this concrete Vries between 225 and 245 Ib/ff using a mix of 1.4:6 with water/cement ratio of 0.48. The strength measured on standard cylinders has been found to about 6,200 psi and with a water/cement ratio of 0.90. about 3-500 psi.

Artificial heavy aggregates are also used, mostly steel and sometimes lead is also used. Steel shots make concrete with, a heavy high density up to 345 Ib/ft.

10.17 Architectural and Ornamental Concrete: Concrete with special aggregate in the surface may be polished by grinding stones to bring out the colours and designs in order to produce a pleasing ornamental effect. Sometimes, coloured cement is used. The following are the important varieties: *(1) Art Marbles (2) Mosaic and (3) Terrazzo.*

Art marbles made of colured cements and crushed marbles aggregates are used to imitate marble. Precast units of various shapes and colour combinations may be moulded using only a thin layer of special materials. After hardening the concrete surface is ground to bring out the aggregate.

Mosaic concrete is prepared with coloured cement and stone chips. It may be precast or cast-in-situ. After happening the surface is polished with special polishing stones.

Terrazzo is art marble moulded in place in walls and particularly floors of public buildings. Special aggregates are rolled into the surface of the fresh concrete: after hardening the surface is ground smooth, exposing the aggregates which may be arranged to produced design.

10.18 Concrete Products: Building units are made either plain, reinforced or prestressed concrete. These are slabs, beams, columns, lintels walls etc.

t

Concrete is used for the construction of bridges, roads, air fields, dams and other hydraulic structures.

Concrete masonry blocks are made of varying shapes and sizes to conform generally to the requirements of desire designs.

Concrete pipes are made of either plain or reinforces. They are used for sewers, drains, culverts and water pipes.

Cast stones consist of precast concrete shapes for use as sills copings, facings, steps and other architectural and ornamental works.

10.19 Design of Concrete Mix: Desing of concrete mix may be defined as the process of selecting suitable ingredients of concrete and determining their relatives' quantities with the object of producing as economically as possible concrete of certain minimum properties, notably consistency, strength and durability. This definition stresses two points: (1) the concrete is to have certain specified minimum properties and (2) it is to be produced as economically a possible a most common requirement in engineering.

There are mainly four different methods of designing of concrete mixes. These are:

1. Fineness Modulus Method
2. Minimum Voids Method
3. Trial Mixes Method
4. Arbitrary Method.

Fineness Modulus Method: In Figs. 10.25 and 10.26 are shown two types of graphs to explain the relationship between four factors (water/cement ratio, slump, size of the coarse aggregates and fineness modulus) with strength. To design a concrete mix by this method, the relationships shown in figs. 10.25 and 10.26 are very essential.

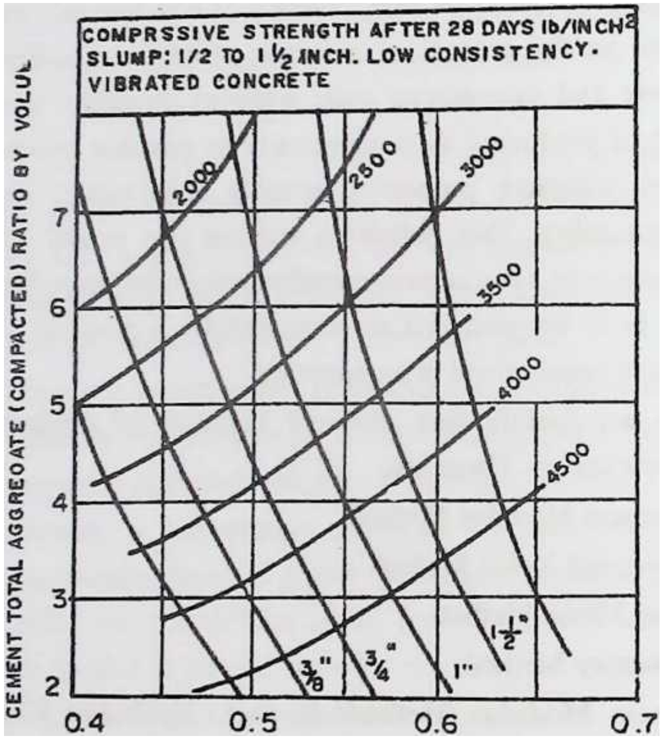
Example: Design a concrete mix for design compressive length of 3500 psi after 28 days from the following data. Maximum size of the coarse aggregate = $^{3}/_{4}$ inch

Size of the fine aggregate $^{1}/_{16}$ to $^{3}/_{16}$ inch

Fineness modulus of fine aggregate=2.85

Fineness modulus of coarse aggregate=6.27

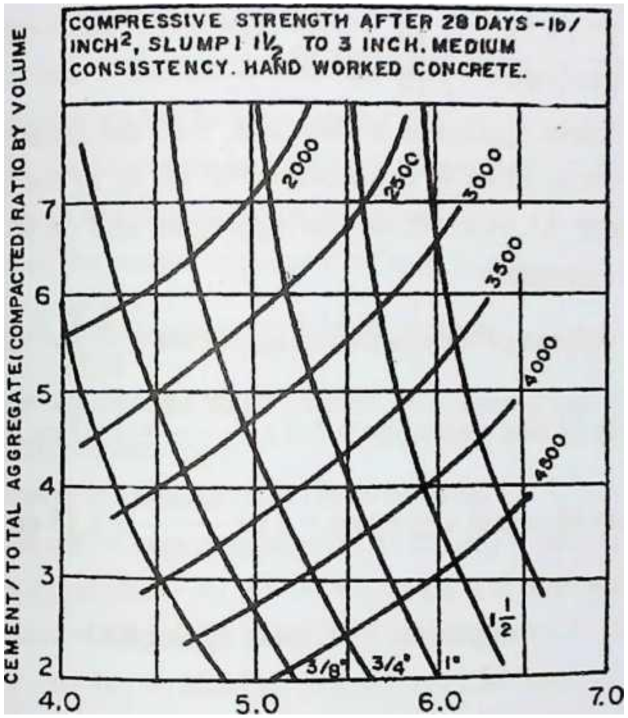
Moisture content in the fine aggregate (sand)=5 precent.



FINENESS MODULUS OF COMBINED AGGREGATE OF CONCERETE

Relationship of strength with cement/total aggregate ration

ze of coarse aggregate and combined fineness modulus



FINENESS MODULUS OF COMBINED AGGREGATE

10.26 Relationship of strength of concrete with cement/total aggregate

Moisture content in coarse aggregate (brick khoa) = 3 P. C.

shrinkage factor = 0.75

?

Hand worked concrete with desired slump of 2-inch Ordinary Portland cement is to be used •

Solution: Applying strength 3500 psi and the size of them coarse aggregate ¼ inch in fig. 10.26, the combined fineness modulus is 5.13 and the volume of the compacted aggregate is 3.75 cu ft. for one cu ft. of cement.

Ratio of the fine aggregate to be mixed with 1 of coarse

aggregate,

$$x = \frac{6.27-5.13}{5.13-2.85} = \frac{1.14}{2.28} = 0.50$$

If the coarse aggregate is 100 cu ft. then the quantity of fine aggregate is 50 cu ft. or in every 100 cu. ft. of the combined aggregate. 33.34 cu ft. is fine aggregate and 66.66 cu ft. is coarse aggregate.

$$\text{Loose volume of the combined aggregate} = \frac{3.75}{0.75} = 50 \text{ cu ft}$$

$$\text{Quantity of fine aggregate} = 5.0 \times \frac{33.34}{100} = 1.67 \text{ cu ft.}$$

$$\text{Quantity of coarse aggregate} = 5.0 + \frac{66.66}{100} = 3.33 \text{ cu ft.}$$

Real mix ratio is:

Cement	Fine aggregate	Coarse aggregate
1	1.67	3.33

Taking into consideration of the moisture contents in aggregates, the bulking of fine aggregate for 5 percent, moisture is (from Fig. 8.1) 29.5 percent and that of the coarse aggregate for 3 percent moisture (from Fig. 10.3) is 6 percent.

Amount of fine aggregate = 1.67 x 1.295 = 2.16 cu ft.

Amount of coarse aggregate = 3.33 x 1.06 = 3.52 cu ft

Field Mix Ratio is:

Cement	Fine aggregate	Coarse aggregate
1	216	3.52

This falls in the category of 1: 2: 3.5

2. Minimum voids Method: The method of concrete mix design is based on the assumption that the fine aggregate fills in the voids of the coarse aggregate and that the cement fills in the voids of fine aggregate.

Example: Design a concrete mix by the minimum voids, method from the following data:

Voids in the coarse aggregate = 45 percent

Voids in the fine aggregate = 30 percent

Size of the coarse aggregate = $^3/_4$ to 1 inch

Size of fine aggregate = 3/16 to $^1/_4$ inch

Allow an excess of 10 percent for cement and 7 percent for fine aggregate. Ordinary Portland cement is to be used.

Solutions: Coarse aggregate (Assumed) = 100 cu ft.

Fine aggregate = 40 x 1.07 = 42.8 cu ft.

Cement=42.8 x 0.30 x l.10 = 14.32 cu ft.

This can be written as follows on the basis of 1 cu ft. of cement:

Cement = 1

Fine aggregate = 3

Coarse aggregate = 7

The mix shall have the portion 1:3:7

The amount of water required will be determined from the slump test for desired workability. The strength has to be tested by making cylindrical specimen and curing for 28 days.

3- Trial Mixes Method: In this method, fine and aggregates are mixed in different proportions and the mixture « filled in a container of known volume. After it is thoroughly compacted, its weight is noted per cu ft. of each proportion.

The proportion which gives heaviest unit weight is taken for a dense concrete. Test cylindrical specimens are then made with the concrete of this proportion to determine the compressive strength after 7 and 28 days.

4. **Arbitrary Method:** In this method of concrete mix design the proportion of cement is taken as 1 part to be mixed with 'x' parts of the fine aggregate and '2x' parts of the coarse aggregates. For example, the common proportion are 1:1 — -;

3, 1:2:4. 1:3:6. 1:8: etc. The quantity of water is not specified but it is often taken to be 30 percent of the cement plus about 5 percent of the aggregates when all the quantities are measured by weight. Generally, 100 cu ft. of wet concrete requires 150 cu ft. of dry.

Example: 'Determine' the volume (in cu ft) of the different ingredients of a cement concrete of the proportion 1:3:6 per cu ft.

Solutions: Wet volume = 100 cu ft.

Dry volume = 150 cu ft.

$$\text{Cement} = \frac{150}{10} \times 1 = 15\text{cuft} = 12 \text{ bags}$$

(1 bag= 1.25 cu ft)

$$\text{Fine aggregate} = \frac{150}{10} \times 3 = 45 \text{ cu ft.}$$

$$\text{Coarse aggregate} = \frac{150 \times 6}{10} \; 90 \text{ cu ft}$$

Water = 15 x 0.30 + (45 x 90) x 0.05
= 4.5 + 6.75
11.25 cu ft.

$$\text{Water/cement ratio} = \frac{11.25}{15} = 0.75$$

From Table 10.4 number of waters = 8.40 gallons.

Out of four methods of concrete mix design, only two methods fineness modulus method and arbitrary method are in practice nowadays.

With the recent development of concrete science and technology, new methods concrete mix design has been developed. The following methods are most widely used nowadays.

Absolute Volume Method (British Method): This method assumes that the volume of the compacted concrete is equal to the sum of the absolute volumes of all ingredients.

It is usual to calculate the quantities of ingredients of produce 1 cubic yard of concrete. Then, if W. C. Af and Ac are the required weights of water, cement, fine aggregate and coarse aggregate respectively, then

$$\frac{W}{64.4} + \frac{C}{62.4\,Sc} + \frac{Af}{62.4Sfag} + \frac{Ac}{62.4Scag} = 27$$

where S with the appropriate suffix represents the specific gravity of each material since the density of water (62.4) is expressed in pounds per cubic foot, the total value (1 cubic yard) has also to be expressed in cubic ft. The mix design calculations give the values of whence the values W. C. Af

$$\frac{W}{C} \quad \frac{C}{Af + Ac}. \quad \text{and} \quad \frac{Af}{Ac}$$

Ac can be found. C represent the cement content Pounds per cubic yard of the concrete and W is the water content in the same units.

When an additional ingredient, such as pozzolana, is present, additional term of similar form is to be added to the Eq 10.9. When entrained air is present and its presence is, say p percent of the volume of the concrete, the right-hand side of the Eq. 10.9 would read as 27 (1- p/100)

If the aggregate contains free moisture whose weight is say.
M percent of the weight of the dry aggregate, then the weight
of the added water W and of (wet) aggregate must be
adjusted. The weight of free water in A pound of aggregate is
x such that

$$\frac{m}{100} = \frac{x}{A-x} \qquad 10.10$$

Whence, x =

$$\frac{A}{1} \times \frac{m}{100+m} \qquad 10.11$$

weight is added to A to give the weight of wet aggregate per batch.

A {1+m/(10+m)} and is subtracted from W to give the weight of added water, W = Am/(100+m)

Generally, each size fraction of aggregate has a different moisture content and the correction should be applied to At Ac. etc. with an appropriate value of M.

Combining Aggregates to Obtain Particular Type Grading: While there is no ideal grading, it is desirable to proportion the available materials in such a way that the grading of the combined aggregate is properly achieved. Suppose the gradings of the fine aggregate and two coarse aggregates (size fractions are listed in Table 10.9) are desired to combine the materials so as to appropriate to the coarses

grading. According to British standard, 24 percent of the total aggregate should pass through 3/16-inch sieve (BS) and 50 percent through inch sieve.

Table 10.9 Example of Combining Aggregates to obtain a Type Grading

B.S. Sieve size	cumulative percentage passing for			(l)xl (4)	(2) xo.34 (5)	(3)X2.59 (6)	aggree (4) (5) (6) (7)	Giading of omfainc d aggie (8)
	Fine aggregate (1)	$1^{3}/_{b}$ $1^{3}/_{4}$nch (2)	¾ $1^{1}/_{2}$ Inch (3)					
$1\frac{1}{2}$	100	100	100	100	94	259	453	100
$^{3}/_{4}$	100	99	13	100	93	34	227	50
$^{3}/8$	100	33	a	100	31	21	152	34
3/16"	99	5	2	99	5	5	109	24
No.7	76	0	0	76	0	0	76	17
No. 14	56			58			58	13
No.25	40			40		40	40	9
No.52	12			12			12	3
No.100	2			2			2	$^{1}/_{2}$

Let x, y and z be the proportions of fine, $^{3}/_{16}$ to $^{3}/_{4}$ inch and $^{3}/_{4}$ to $^{1}/_{2}$ inch aggregates respectively. Then to satisfy the conditions that 50 percent of the combined aggregate should Pass through inch B.S sieve, we have

$$1.0x + 0.99y + 0.13z = 0.5 (x + y + z) \qquad 10.12$$

The condition that 24 percent of the combined aggregate should pass through $^3/_6$-inch B.S. sieve can be written as

$0.99x + 0.05y + 0.02z = 0.24 (x + y + z)$ 10.13

From these two equations (Eqs. 10-12 and 10.13), it is found

x: y: z=l: 0.94 :2: 59 10.14

i.e the aggregates are combined in the proportions 1: 0.94: 2.59.

Example: A concrete mix with a mean compressive strength of 5,000 psi at 28 days is required for used in a road slab. Ordinary Portland cement will be used. Compactions will be affected by vibrations. The aggregate/cement ratio is 7.2.

24. Percent and 50 percent of the total aggregate should pass through 3/16- and 2-inch B.S. sieves respectively.

Assume the specific gravity of cement to be 3.15, that of coarse aggregate 2.50 and of fine aggregate 2.60.

Water/cement ratio (Fig. 10.10) = 0,48

Solution: Total parts of aggregate = 1 + 0.94 +2.52 = 4.53

Cement = 1 part

Fine aggregate = $1 \times \frac{7.2}{4.53}$ = 1.59 parts

Coarse aggregate. (3/16- $^3/_4$ inch) = $0.94 \times \frac{7.2}{4.53}$ = 1.5 parts

Coarse aggregate, ($\frac{3}{4}$ ... $1\frac{1}{2}$ - inch) =$2.59 \times \frac{7.2}{4.53}$ =4.11 parts

Cement content, C. in pounds per cubic yard of concrete (Applying Eq. 10.9).

$$\frac{0.48C}{62.4} + \frac{C}{3.15 \times 62.4} + \frac{1.50\,C}{2.60 \times 62.4} + \frac{(1.50+4.11)}{2.50 \times 62.4}$$

: C= 462 lb/cubic yard

The weights of the ingredients per cubic yard of concrete are:

Cement = 462 lbs.
Water= 0.48 x 462 = 222 lbs.
Fine aggregate = 1.59 x 562 = 735 lbs.

Coarse aggregate (3/16 $^3/_4$ inch) = 1.50 x 462 = 693 lbs.

Coarse aggregate ($^3/_4$-inch) 4.16x462 = 1.900 lbs.

Total =4,012 Ibs

The density of the concrete= 149 Ib/ft^3

A trial mix should now be made and the proportions adjusted as necessary. It is important to remember that if the workability is to be changed but the strength is to remain unaffected, the water cement ratio must remain unaltered. Changes can be made in the aggregates/cement ratio or, if suitable aggregates are available in the grading of the aggregates.

American method of concrete Mix Design: The ACI method utilizes the fact that for a given maximum size of aggregate the water content in pounds per cubic year of concrete, determines the workability of the mix. It is thus possible to design a concrete mix by selecting the water content from the Table 10.10 (by ACI).'A further assumption is made that the optimum ratio of the bulk volume of coarse aggregate to the total volume of the concrete depends only one the maximum size.

Table 10.10 Mixing Water Requirements (Approximate) for Different Slumps and Maximum Size of Aggregates.

Slump inch	Water requirement lb per cubic yard of concrete inch Size of the aggregate					
	3/8	1/2	3/4	1	1½	2
1 to 2	350	333	308	300	276	253
3 to 4	384	367'	342	326	300	384
5 to 7	408	384	358	242	317	300

of aggregate and on the grading of the fine aggregate. Table 10. 11 gives values of optimum volume of coarse aggregate when used with fine aggregates of different fineness modulus.

Table 10. 11 Bulk Volume of coarse Aggregate per unit Volume of concrete.

Maximum size modulus aggregate inch	Bulk volume of rodded coarse aggregate unit volume of concrete for fineness sand of per of sand of			
	2.40	2.60	2.80	3.00
3/8	0.46	0.44	0.42	0.40
1/2	0.55	0.53	0.51	0.49
3/4	0.65	0.63	0.61	0.59
1	0.70	0.68	0.66	0.64
1½	0.76	0.74	0.72	0.70
2	0.78	0.77	0.75	0.73

Example: Design a concrete mix from the following data. Design means compressive strengths 5,600 psi:

Cement to be used: Ordinary Portland cement Slump desired=2 inch.

Maximum size of aggregate= 1½-inch, its bulk density = 100 lb/ft^3

and its specific gravity=2.64

Fineness modulus of fine aggregate 260 and its specific gravity= 2.58

Specific gravity of concrete -3.15

Solution:

From Table 10.10 water requirement -275 lb per cubic yard of concrete.

Water/cement ratio (from Fig 10.10) -0.48

Quantity of cement - 275/0. 48-573 lb/yd^3

From Table 10.11. the bulk volume of coarse aggregate per unit volume of concrete (using the given fineness modulus of 2.60) is 0.74. Hence, the weight of coarse aggregate per cubic yard of concrete-0.74x 1100x27-2,000 lbs.

The absolute volumes of the mix ingredients per cubic yard of concrete are:

$$\text{Cement} = \frac{573}{3.15\times 62.5} -2.92\ \text{ft}^3$$

$$\text{Water-} = \frac{275}{62.4} - 4.41\ \text{ft}^3$$

2000
------------ - 1240 ft^3
2.64 x 624
Coarse aggregate = --------------------
Total- 19x62 *ft^3*

Hence, the volume of the fine aggregate=27-19.73

= 7.27 ft^3

The weight of fine aggregate-7.27 x 2.54 x 62.4 -1,170

The weights of the materials per cubic yard of concrete are

Cement	-573 lb
Water	-275 lb
Fine aggregate	1.170 lb
Coarse aggregate	-2.000 lb
	Total- 4,018 lb

Hence, the density of the concrete- $^{4.018}/_{27}$ 149 lb/ft^3 27

Design of Lightweight Concrete: Design a lightweight concrete mix from the following data:

Dry lose density of fine a aggregate= 56 lb/ft^3

Dry lose density of coarse aggregate= 44 lb/ft^3

Sum of the bulk volumes of the two aggregates in one *cubic* yard of concrete 32ft^3 (16 fit^3 of each size to be used) Cement concrete=550 lb/yd^3 water/cement ratio=0.88

Solution:

The weights of the material are:

Cement		= 550 lb
Fine aggregate	= 16x56	= 195 1b
Coarse aggregate	= 16x44	= 7051b
Water	= 550x0,88	=315 lb
	Total=2.635 lb	

Density of the resulting concrete $^{2.635}/_{27}$ =97.6 lb/ft^3

Volumes of the in ingredients are:

550
Cement = -----------------2.80 ft^3
3.45x62.4

Volume of the aggregate= 27 = (2.80+7.78) = 16.42 ft

Therefore, volume of fine aggregate =8.21 fit^3

Volume of course-aggregate =8.21 ft^3 the water content is necessary.

Concluding Remarks: All the procedures of concrete mix design are mostly empirical and give the impression of being nonscientific, but the variability of the properties of both cement and aggregate as such that our calculations are really only guesses. However, the better our knowledge of the various properties of the ingredients of concrete the more accurate our guesses could be. With this knowledge and experience in the use of engineering materials involved satisfactory mixes can be designed, although the procedure can never become automatic but is an art as much as science.

Question

1. What is concrete? State the various materials that go to from it, pointing our clearly the function played by each material.

2. What is a lime concrete? Discuss briefly how it is made? / Enumerate its uses in engineering constructions.

3. What is cement concrete? Discuss its ingredients. What are the advantages and disadvantages of cement concrete over other materials of construction.

4. Critically examine the desirable properties of cement concrete.

5. What is meant by the workability of concrete? Name and discuss the factors affecting workability of a concrete.

7. Discuss critically the factors controlling the quality of a concrete.

7. (a) Critically examine the effects of the gradm₆ of the aggregates in a good concrete.

(b) The combined fineness modulus of a mixture of sand (fineness modulus = 2.90) and brick khoa (fineness modulus = 663) is 5.25. ft 5.50 cu ft of combined well compacted mixture is required, determine the volumes of sand and brick khoa in lose state Assume shrinkage factor to be 0.82 Ans. sand= 2.5 cu ft, brick khoa= 4.25cu ft.

8. (a) What are water/cement ratio and cement/aggregate ratio? Discuss their importance on the properties of a good concrete. State the quality of water for mixing and curing of concrete.

(b) In designing a concrete mix, the water/cement ratio was taken to be 0.8 Determine the amount of water required in gallons per bag of cement.

Ans. 8.96 gallons.

9. Discuss the various methods for proportioning a good concrete mix. Which of the methods do you think best and why?

10. What is meant by curing of concrete? Discuss its importance and the various methods adopted for the same with specials reference to Bangladesh. State the influence of curing temperature of the strength of concrete.

11. Describe any two important standard tests that you will perform to ascertain the suitability of concrete to be used for structural purposes.

12. What are the special problems you will face in concerting in summer when temperature ranges between 85 and 100° F in Bangladesh. What necessary precaution you will adopt both in concreting and curing?

13. (a) What special technique you will employ in concreting in cold weather (temperature range; 35 to 40°)?

(b) What is the ideal temperature range for concreting and why?

14. Write explanatory notes on the following:

(a) Segregation (b) Bleeding (c) Laitance (d) Efflorescence (e) Construction joints (0 shuttering or formworks (g) concrete surface finishing (h) slump.

15. What do you mean by term ‘Shrinkage’ in concrete? Discuss the various types of shrinkage and their respective effects on concrete structures.

16. What is meant by the term creep of concrete? Explain briefly the factors influencing creep in concrete. What are the effects of creep on concrete structures?

17. What is reinforced concrete? Explain the parts played by steel in reinforced concrete. Enumerate the merits and demerits of reinforced concrete over ordinary plain concrete.

18. Write short notes on: (a) Prepacked concrete (b) Vacuum concrete (c) Precast concrete (d) Effects of age on the strength of concrete (e) Standard hook for reinforced steel (h) Air entrainment in concrete.

19. What is a lightweight concrete? Enumerate its advantages and disadvantages over ordinary plain concrete.

What are the different varieties of lightweight aggregates?

What are their desirable properties?

20. What are the different varieties of lightweight concrete. Explain the properties and specific uses of each, what is high density concrete? What are its specific uses?

21. What are the main varieties of concrete commonly used for different types of concrete structures in Bangladesh?

Explain their special characteristics and the specific use for which they are employed.

22. Discuss the principles governing the design of a good concrete mix. Name and explain the different methods that are commonly employed for designing a concrete mix.

23. (a) Explain the principle governing the design of a concrete mix by 'Absolute Volume Method

(b) Design a concrete mix by the above method from the following data.

Desired strength=6000 psi (at 28 days)

Aggregate/Cement ratio=7.24

25 per cent and 52 per cent of total aggregates should pass through $^{3}/_{16}$- and 3/4-inch B. S. sieves respectively.

Specific gravity of cement=3.15

Specific gravity of fine aggregate= 2.62

Specific gravity of fine aggregate= 2.49

Two types of coarse aggregate, 3.16 to $^{3}/4$ -inch and to $^{3}/4$ - inch should be used. Normal Portland cement is to be used.

Assume standard value of date not supplied.

Consult necessary tables and diagrams.

Ans. Density of the concrete= 136 lb ft^3

24. Design a concrete mix by the fineness modules method from the following data:

Desired strength=3,000 psi-after 29 days

maximum size of stones= $\frac{1}{4}$ inch

Size of sand = $\frac{3}{4}$ to $\frac{1}{4}$ inch

fineness modulus of sand=3.18

Fineness modulus of stones=6.15

Moisture content in the sand=45 per cent Moisture content in stones=3 percent Shrinkage factor).82.

Hand worked concrete with ordinary Portland cement. Consult necessary tables and diagrams.

Assume standard values of data not supplied.

Ans. Field mix ratio 1:2.75:4

25. Design a concrete mix with ordinary Portland cement to compressive strength of 5,000 psi after 28 days by the AC1 method from the following data:

Maximum size of aggregated inch, its bulk density =

110 lb/ft^3 and its specific gravity=2,65

Fineness modulus of fine aggregated.80

and its specific gravity=2.60

Specific gravity of concreted.5

Slump desired=2 inch

Consult necessary table and diagrams.

Assume reasonable values of data not supplied.

Ans: Density= 155/ft^3

26. Design a lightweight concrete mix with ordinary Portland cement from the following data:

Dry loose density of fine aggregate= 44 Ib/ft3

Dry loose density of fine aggregate = 56 1 b/ft3

Sum of the bulk volumes of the two aggregated in one cubic yard of concrete =32.4 ft (mixed in equal volumes).

Cement content = 750 Ib/per cubic yard.

Water/cement ratio	= 0.87
Ans. Density	=101 Ib/ft^3
Cement	= 3.12ft^3

27. Calculate the volume of different materials in 100 cu ft of following concrete:

(a) Plain cement concrete (1:2:4) and (b) Reinforced cement concrete (1:2:3) with 0.5 percent reinforcement.

Ans. (a) Cements 21.5 cu ft= 17 bags (approx.)
Sand = 43.0 cu ft.
Brick khoa = 85.5 cu ft.
Cement = 25 cu ft. = 20 bags.
Sand = 50 cu ft.
Brick khoa Steel = 75 cu ft.
Steel = 0.5 cu ft = 245 lb
(1 cu ft steel = 490)

CHAPTER-ELEVEN

IRON AND STEEL

11.1 **Introduction:** In one of its many forms, iron is still the most widely used engineering material in the world. This is because of its strength and strength/weight ratio together with such a degree of toughness as may be required to make effective use of the strength available.

The applications of iron are almost beyond count. Examples include the skeletal frame work for large multistoried building, the hulls and superstructures of ships. Spans and trusses for bridges, rail road's, supports for chemical processing equipment's, ducts, flumes, overhead water tanks, storage tanks, pressure vessels, equipment's and tools of various types, reinforcement in concrete, etc.

Iron is obtained from iron ores. From iron ores, first and impure form of iron is obtained called pig iron. Pig iron is not fit for any mechanical use. So, it is concertedly into cast iron, wrought iron and steel which are generally called *Ferrous Metals.*

11.2 **Irons Ores:** Iron ores consist essentially of compounds of iron, usually oxides mixed with aluminum, silica, clay etc. These of commercial importance contain 25 to 75 percent metallic iron. The following are the chief iron ores from which pig iron is extracted.

(1) Hematite: This is red ferric oxide (F2O3) and contains 70 Percent iron, but owing to the presence of earthy matter and other impurities yield about 55 to 60 percent iron only. This

is generally found to be the most important are in the manufacture of iron and steel.

2. Limonite: This is brown hematite ($2Fe_2O_3$, $3H_2O$) and is a hydrated ferric oxide which yields 60 percent of iron. But this is reduced to about 45 percent due to impurities.

3. Magnetite: This is black oxide of iron (Fe_3O4) containing 73 per cent of iron. It contains less impurities. This is considered to be the richest and hardest iron ore.

4. Siderite: This is gray or brown carbonate of iron (Fe_2CO_3 and when pure yields 40 percent of iron. This is also known as *spastic iron* ore.

5. Iron Pyrites: This is yellow sulphide of iron (FeS_2) containing about 45 percent iron. It is not considered to be a good ore for the extraction of iron because of its high sulphuric contents make the iron brittle.

11.2 Pig Iron: Pig iron is obtained by heating and melting the first three iron ores (which occur as oxides of iron) in a blast furnace at a temperature of about 3,000°F. Two processes generally take place in the blast-furnace; (1) de-oxidations of iron ores and (2) separation of iron ores from the impurities like clay, sand etc. Technically, the first process is termed *reduction* and the second process is termed as *gangue.*

For the process of reduction, carbon monoxide (CO) obtained from coke or charcoal) is employed to liberated oxygen from iron oxides to form carbon dioxide $C0_2$ at a temperature of about 3,000°F.

The common impurities in the iron ores are silica and alumina. To remove these impurities, limestone ($CaCO_3$) is added to the iron orcs along with coke or charcoal as it is put in the blast furnace. Limestone acts as a flux. Lime (CaO) becomes chemically active at about 2,000°F and forms silicates and aluminates of calcium. These silicates and aluminates of calcium as formed from the impurities of the iron ores are termed as slag and being lighter than iron collects on the top of the molten metallic iron. The slag is allowed to flow out into a separate container and then the heavier liquid is solidified in small lengths of 3 ft in the branches.

The whole process described above by which iron ores are reduces to form pig iron is known as *smelting.*

Table: 11.1 Composition of Pig Iron.

Constituent	Percentage composition
Iron	92-94
Carbon (both free and combined)	4-5
Silicon	1-2
Manganese	1-2
Sulphur and phosphorus	1-2

Table: 11.2 Composition of slag

Constituent	Percentage composition
Lime	40-45
Silica	30-35
Magnesia, Calcium	10-12
Sulphate. Manganese, Oxide etc.	6-8

Uses of Slag: Slag is used for various purposes. When cooled, it is crushed to suitable sizes for uses for the following purposes: (1) making of blast furnace cement (2) railway ballast (3) road metals (4) coarse aggregate for concrete and (5) fertilizer as it contains sulphates and phosphates.

Classification of pig Iron: The classification of pig iron is mainly based on the carbon content either free or combined. The free carbon is known as *graphite.* Free carbon imparts softness and a coarse crystalline structure to the metal while combined carbon makes the metal and gives a fine-grained crystalline structure. The following are the various types of pig iron.

1. **Gray Pig Iron:** It contains 3 to 4 per cent of free carbon (graphite) and less than 1 percent combined carbon. the percentage of silicones is almost the same as that of free carbon. This is a soft variety of pig iron containing bigger size crystals. It is suited for foundry casting. This is why it also known as *foundry pig iron.* Cast iron is generally manufactured from this variety of pig iron.

2. **White Pig Iron:** It contains 3 per cent or above of combined carbon and less than I percent free carbon. The percentage of silicon is also less than 1 percent. It is crystalline containing close grained crystals. It is very hard and strong and could be easily melted. This variety is used for manufacturing wrought iron. I his is also known as *forge pig iron.*

3. **Mottled Pig Iron:** It contains equal amount of free and combined carbon. It has mottled appearance and medium hardness. This is also known as *malleable pit iron.* Malleable cast iron is manufactured from the malleable pig iron.

Pig iron is also classified according to the presence of phosphorus. Such as high phosphorus pig iron (0.5 to 0.7 percent of phosphorus) and low phosphorus pig iron (0.3 to 0.5 percent of phosphorus).

11.4 Wrought Iron: Wrought iron is manufactured by melting the whiter variety of pig iron in a pudding furnace. Wrought iron is the purest form of iron containing less than 0.12 percent of carbon.

Table 11.3, Shows the different constituents of a typical high quality wrought Iron.

Table 11.3: Different Constituent of Typical High Quality

Constituent	Percentage composition
Iron	96.00
Carbon	0.10
Silicon	0.20

Phosphorus	0.25
Sulphur	0.05
Manganese	0.10
Slag	3.25

Properties of Wrought Iron: Wrought iron becomes Pasty and very plastic at red heat and could be easily forged about 1650°F. It melts at2800°F.

Wrought iron is very malleable and ductile. The tensile strength varies from 48.000 to 50.000 psi. It is stronger in compression by 25 percent. The shearing strength varies from 20,000 to 35.000 psi on a longitudinal plan and from 3,000 to 45,000 psi on a transverse plane. Wrought iron shows good resistance to fatigue (repeated stress) and corrosion. One of the valuable properties of wrought iron is the comparative case with which it is welded.

Wrought iron as a Material of Engineering Constructions:

Wrought iron has certain properties, among which are resistances to corrosion and repeated stress that will always class it as a material of importance in engineering construction. The principal uses of wrought iron are for standard pipes, bars, rods, wires, plates. Sheets, welding fittings rivets etc. Wrought iron products are used in building construction, bridge construction and for the rail road, marine and petroleum and chemical industries, corrugated sheets (C.J. sheets) & ornamental works.

Nickel-Alloy Wrought Iron: This is a special variety of wrought iron manufactured by adding 1.5 to 3 percent nickel to the molten wrought iron. Addition of nickel increases the tensile strength by 25 to 30 per cent. Nickel alloy wrought iron gives a very good resistance to impact repeated stress and corrosion.

11.5 Cast Iron: Cast iron is manufactured by remolding gray pig iron (foundry pig iron) in a cupola furnace and running it into moulds of shape required. Cast iron differs considerably both in chemical composition and in physical characteristics from wrought iron. The most important consideration affecting the character and properties of cast iron is the carbon content. Based on the different states in which the carbon occurs cast iron is divided into their principal classes.

1. **Gray Cast Iron:** Gray cast iron is that in which the carbon occurs chiefly in the graphite state (free carbon).
2. **White Cast Iron:** White cast iron is that in which the carbon occur chiefly as the carbide of iron (carbon in chemical combination with iron)
3. **Mottled Cast Iron:** It is a mixture of gray iron with particles of white iron.

Properties of Cast Iron: Cast iron is strong in compression but weak in tension. It is brittle and does not absorb shocks. It does not possess the properties of ductility and malleability. Gray cast iron is softer than white cast iron.

Shrinkage of cast iron is an important consideration for pattern making, because the shrinkage, varies from 0.5 to percent depending upon the type of casting. Due allowance for shrinkage therefore, must be made in the dimension of the pattern if the casting is to conform to the size called (or by the drawing.

Cast iron has a very low cost of production and it can be cast to any convenient shape easily.

Uses of Cast Iron: It is used for making C. I. pipes (used for water mains and sewers), covers (manhole covers, etc.) columns with their caps and bases, struts, carriage wheels, parts of machinery and other structured subject to compression, gates, railings, expanded metals, window frames, strains and other ornamental works.

Malleable Cast Iron: Malleable cast iron is of special compositions which after having been as or rolled to its final form is rendered malleable by a process of annealing. Annealing is a process of heating metal above the critical temperature range, holding at that temperature for a specific period of time and then slowly cooling. It is essential that the iron used be a white iron before malleablizing in order that the carbon may be almost wholly in the combined form, the malleablizing process will then result in the conversion of the combined carbon into free carbon in the crystalline from as graphite. This amorphous carbon will exist as isolated particles in a continuous mesh of metal. Through this process the casting is rendered very much tougher than white or gray cast iron and its ductility and malleability are increased to such an extent that it may be bent or twisted to a considerable degree even when cold. Malleable cast iron combines the advantages of ordinary cast iron with respect to the case with which complicated forms may be cast with a considerable degree of toughness, ductility and strength.

Among the more common applications of malleable cast iron may be especially mentioned its use in automobile construction for rear axle housing. 5, brake supports, steering- gear housings hubs and pedals. In railroad equipment manufacture, couplers, journal boxed, brake fittings and many other small fittings for rolling stick are made of malleable cast iron. Other used include many parts of agricultural machinery, pipe fittings elbows union sockets, valves, etc. and household hardwires such as parts of locks, hinges, rings, and window and door fittings. Another class of uses includes carpenter tools, such as hammers, saws, hatchets, chisels, etc.

11.6 Steel: Steel is an Iron-carbon alloy having carbon content less than 2.0 percent and generally below 1.5 percent. It is usually malleable as cast iron and exhibits properties of toughness as well as strength. Steel also may be defined as a malleable alloy of iron and carbon, usually containing substantial's quantities of manganese.

There are four grades of steel depending upon the percentages of carbon

1. Soft, mild or low-carbon steel containing from 0.05 to 0.15 per cent carbon:
2. Medium carbon steel or medium hard steel containing from 0.15 to 0.30 percent carbon.
3. Medium high carbon steel or half-hard steel containing from 0.30 to 0.60 percent carbon.
4. High carbon steel or hard steel containing from 0.60 to 1.5 percent carbon.

Steel is manufactured from the pig iron by the processes shown in Table 11.4 with typical products.

Table 11.4 Steel Making process with Typical Products

Process	Typical products
Basic Bessemer	Pipes, tubes, wires, sheets, etc.
Acid Bessemer	Structural shapes, sheets, wires, tubes, etc.
Basic open hearth	Large castings and forgings, armor plates, high-strength wires etc.
Acid open hearth	Special alloy steels, small castings of carbon and alloy steel.
Acid Electric	Special alloy steel, tool steels, high speed steel, high-grade carbon steels, etc.
Basic Electric	

Different variety of steel are manufactured under carefully controlled conditions, their properties are determined in laboratory and described in a manufacture’s certificate. Thus, the design engineers need only to specify the steels as complying with a relevant standard and the site engineer s supervise on, is limited to the workman ship of the connection between the individual steel members (in case of steel structures) and placement, bending (in -case of reinforces concrete structure). Therefore, the manufacturing

processes of different types of steel are beyond the scope of this book.

Physical Properties of Steels: The principal factors influencing the physical properties of steel (Strength, ductility and elastic properties) are: (1) the carbon content (2) the percentage of silicon, guipure, phosphorus, manganese and other alloying elements and (3) the heat treatment and mechanical working. The factors are not necessarily dependent and their effects are usually combined. The nature and extent of the effect of heat treatment and mechanical working depend inevitably upon the amounts of carbon and other elements present.

Effects of Carbon upon Physical Properties: The distinctive properties of the different grades of plain carbon steel are due to variations in carbon content more than to any other single factor. Carbon always acts as a hardener and strengthener, but at the same time, it reduced the ductility.

Elects of Silicon, Sulphur, Phosphorus and Manganese:

Silicon: Then direct effect of silicon (usually not over 0.2 percent) upon strength and ductility is very slight. Increasing the silicon content to 0.3 or 0.4 per cent has the effect of raising the elastic limit and ultimate strength of the steel considerably without reducing the ductility greatly.

Sulphur: Sulphur within reasonable limits (0.02 to 0. 10 percent) has no appreciable effect upon the strength or ductility of steels. If the Sulphur content is more than 0.10 precent, it reduces both the strength and ductility.

Phosphorus: Phosphorus is the most undesirable oi all the elements commonly found in steels. Its effects upon the properties of steel are very capricious, hut it is always detrimental to toughness or shock resistance, and often detrimental to ductility under static load.

Manganese: Manganese has a tendency to improve the strength of plain carbon steel. With less than 0.3 percent manganese, the steel is likely to be impregnated with oxides, the harmful effects of which outweigh any beneficial effect due to the manganese. Between 0.3 to 1.0 percent manganese the beneficial effects depend upon the amount of carbon present. As the manganese content rises above 1.5 or 2.0 percent however the steel becomes so brittle as to be worthless.

Effects of Heat Treatment: Heat treatment improves strength ductility and elastic properties of steel depending upon the various compositions.

Important Physical Properties of Steel: The Important properties of steel that concern the engineers are strength, elasticity, stiffness, ductility, malleability and brittleness.

Strength: The strengths of steel are of various types: (1) tensile strength (2) compressive strength (3) flexural strength and (4) shearing strength. Steel is very strong in tension. So tensile strength is considered to be the most important property of steel. The Fig.11.1 shows the tensile test diagram of a typical variety of structural steel (mild steel). The graph may be divided into three parts indicated respectively in the Fig 11.1 by AB, BC and CD.

Between A to B the graph is a straight line this is within the limit of proportionality between stress and strain. This part of the graph is very important from the point of view of design. Between B to C as the stress reaches a value slightly higher than the elastic limit, a definite yielding takes placed in the test specimen. The strain value increases, without increasing the stress. The stress at the point is known as the yield point stress. Upon further stretching the specimen, the material recovers its resistance and as seen from the diagram the tensile force increases with the elongation up to point C. where the force attains it maximum value. The corresponding stress is called the *ultimate stress* of the material.

Between C to D beyond the point C. elongation of the specimen takes place with diminution of the load and fracture finally occur at a load corresponding to the point D of the diagram. But, cast iron breaks with very little elongation or lateral contraction (Fig. 11.2)

It cannot take greater tensile stress. It can be seen from the diagram that very little part of the curves is straight. The increase or extension with the increase of stress is greater at higher stress.

The strength of steel in coordinal shear is about 68 percent of the true tensile strength.

Tensile properties of various steels are shown in Table 11.5 **Magnetic Properties of Steel:** Large quantities of steel are consumed in the construction of electrical machine!}, motors, generators, transformers, etc. where the magnetic properties of steels used are of supreme importance. The magnetic properties are (1) corrosive force, (2) hysteresis an (permeability.

The carbon percentage of steel should be less than 0.1 percent, because, the higher carbon percentage affects the magnetic properties of steel. The presence of silicon diminishes hysteresis loses considerably. Manganese appears to be detrimental to magnetic properties if present in amounts exceeding about 0.3 percent. Both Sulphur and phosphorus were found to be elements whose presence in amounts exceeding about 0.3 percent (for both combined) constitutes a distinct injury to magnetic properties.

Table 11.5 Steel for Various Structural Uses

(ASTM Specification)

Kind and use of steel	Tensile of strength psi	Ultimate tensile strength psi
Structural steel for building and bridges:		
(a) Structural	60.000-72,000	1.350.090
(b) River	52.000-62.000	1,400,000
Concrete reinforcing rode		
(a) Structural grade	65,000-70.000	1.400.000
(b) Inter modal grade	70,000-90,000	1.300,000
(c) Hard grade	80,000-(minimum)	1.100,000
Structural steel for ships:		
(a) structural	58,000-71,000	1 360 000
(b) Rivet	55,000-65,000	1 400 000
Structural steel for locomotives and cars	75,000-(minimum)	1,000,000

Galvanized Iron and Steel: These consist of ordinary cast Iron and ordinary steel coated with a layer or zinc formed by dipping the cast iron and steel in molten zinc. This process is meant to make non and steel more resistance to corrosion. They are used in manufacturing of wires (G.I. wires), plain and corrugate sheets (GJ. Sheets), and pipes (G.I pipes) etc.

Alloy Steel: Alloy steel may be defined as steel that owes its distinctive properties chiefly to some element or elements other than carbon. Very little of the Iron employed in engineering construction purposes is pure. In fact, most of the iron used by engineers is purposely alloyed with one or more elements in order that the modification of inherent properties of iron will enhance the utilities of the resultant alloy.

All alloy steels bear the names that indicate the alloying elements present. The alloying elements are divided into two major classes: (1) those like nickel, silicon and copper which do not combine with carbon to form carbides, and (2) those like manganese, chromium, tungsten, molybdenum & vanadium which do combine with carbon to form carbides.

Alloying elements such as a titanium, aluminum, and vanadium are sometime used to act as scavengers and otherwise facilitate manufacture. Alloy steels are also manufactured which contain more than two alloying elements such as nickel chrome steel.

In general, it may be said that the alloying elements influence the properties of steel through the changes which they affect (1) in constitution and structure (2) In shifting the position of the critical ranges on heating and cooling and (3) in promoting stability of structures in wide variations of loads and temperatures.

When distinctive properties are produced by them, additions of only one element to carbon steel, the alloy is called ternary alloy. When two such elements are added to the carbon stee the resulting alloy is called quaternary alloy.

The principal classes of alloy steels are those listed below

Ternary Alloy Stends	Quarter nary Alloy Steel
Nickel steed	Chrome-nickel steel
Silicon steel	Chrome-vanadium steel
Copper steel	Chrome-molybdenum steel
Manganese steel	Manganese-silicon steel
Chromium steel	Nickel-molybdenum steel
Tungsten steel	
Molybdenum steel	
Vanadium steel	

Other special alloy steel:

Nickel-chromium-molybdenum steel
Chromium bearing steel
Chrome-nickel stainless steel
Chromium stainless steel
High-nickel steel
High chromium steel
High Manganese steel

All alloy steels are classified in three general groups

1. High-strength low-alloy steels.
2. Standard alloy steels.
3. High alloy and special purpose steels
4. Structural steels for reinforcing and pre-stressing.

1. **High Strength Low Alloy Steels:** This group of structural and equipment steels have improved mechanical properties and corrosion resistance as compared to carbon steel. Typical elements added comprise copper, chromium, molybdenum, Nickel, phosphorus and silicon. One or more elements m small percentages are adding to low carbon steel which may contain varying amounts of manganese.

Minimum tensile strength of this group of alloy steels is 70,000 psi, they are corrosion resistant.

These steels are used in large quantities for highway and railway bridges, railroad freight and passenger cars trucks trailers, earthmoving equipment's like bulldozers graders' sheep foot rollers, concrete mixers.

This group of steels is again divided under three trade names: (1) AL decor, (2) Cor-ten and (3) Hi-steel.

Table 11.6 shows the compositions of these steels.

Table 11.6 Composition of Typical High Strength low Alloy Steels

Trade Name	AL decor	Cor-ten	Hi-steel
Elements	Chemical	composition,	percent
Carbon	0. 12 max.	0.12max	0.12max
Manganese	0.15-0.40	**0.20-0.50**	**0.50-0.90**
Sulphur	0.05 max	0.05 max	0.05_max
Phosphorus	0.08-0.15	0.07-0.15	**0.05-0-12**
Silicon	0.35-0.75	0.25-0.75	0.15 max
Copper	0.35-0.60	0.25-0.60	0.95-1-30
Chromium	**0.25-0.55**	**0.50-1.25**	**0.35-1.40**
Nickel	**0.65 max**	**0.65 max**	**0.45-0.75**
Molybdenum	**0.16-0.82**	**0.16-0.24**	**0.08-0.18**
Aluminum	**0.06-0.8**	**0.06-0.12**	**0.12-0J7**

2. Standard Alloy Steel: These, steels have medium percentage of alloying elements and are generally heat treated to improve mechanical properties. The following steels come under this group.

Nickel Steels: The nickel content varies from 1.0 to 4.5 percent with carbon contend ranging from 0.15 to 0.60 percent.

Nickel improves, the tensile strength and reduced brittleness also imparts hardness and ductility to the steel. Nickel steel and also imparts high resistance to corrosion and fatigue:

Uses of this nickel steel include gun and tank parts, propellers shafts and aircraft engine parts. It is also used for the construction of large bridges.

Silicon Steel: Silicon steel contains more than 5 percent of silicon. Silicon imparts hardness to steel. It is used for the pole pieces of dynamos and transformer cores.

Copper Steel: Copper steel containing from about 0.15 to 0.25 percent copper increases the resistance to atmospheric corrosion as compared to ordinary carbon steel. It is used for culverts.

Manganese Steel: The manganese content ranges from 1.60 to 1.90 percent with carbon from about 0.30 to 0.50 percent. The effect of manganese is to strengthen and harden the steel. Manganese steel has high tensile strength, fair ductility and excellent abrasion resistance.

This steel is used for shafts gears aircraft and locomotives railways points and crossings, parts of grinding, crushing and excavating machinery.

Chromium Steel: Steel containing 0.50 to 2 percent chromium and 0.20 to 1.5 percent carbon is extensively used for surfaces where great hardness, high strength and fair degree of toughness arc required. The great hardness capacity of chromium steel (or simply chrome steel) is due to the combinations of chromium with cementite, thus forming double carbide with iron. Steels with about 0.50 percent chromium and 0.60 to 0.90 percent of carbon are generally used for manufacturing chisels, drily, razors saw blades roller for bearing, crusher jaws etc.

Tungsten Steel: Tungsten steel is the oldest of the alloy steel, but with modern development of different types of alloy steel. It is now of minor importance; Tungsten steels contain tungsten form 3 to 6 percent. This is used for manufacturing of permanent magnets, lathe tools, springs, and high-speed tools.

Molybdenum Steel: This steel has a composition of molybdenum ranging from 0.20 to 0.30 percent. Carbon ranging from 0.20.to 0.70 percent and manganese ranging from 0.70 to 1.0 percent.

High strength, good hardness and relatively high resistance to Impact are the characteristics, Uses are for hand tools scraper blades, automobile gears, axles, springs drive pinions and bolts.

Vanadium Steel: Vanadium is a costly element and the percentage is generally kept below 0.1 Vanadium imparts strength toughness and hardness of steel. It is commonly used for manufacturing automobile parts and is alternating stresses and vibration.

Chromium-Nickel Steel: 1 his steel has a composition chromium ranging 0.55 to 1.75 percent, nickel from 1.1 to 3.75 percent and carbon ranging from 0. 14 to 0.43 percent, this steel has a very high tensile strength, great toughness and considerable ductility. It is markedly resistant to repeated stress and impact.

This steel is used for aircraft engine parts, heavy duty shafting trucks, bearing and pneumatic tools.

Chrome-Vanadium Steel: The composition is as follows Chromium. 0.70 to 0.90 percent; vanadium 0.10 to 0.15 percent: and carbon, 0.17 to 0.55 percent. This steel has high strength high ductility, good machinability and good weldability[7]. Typical uses include aircraft propeller blades, locomotive spring bolts for high temperature service in oil refineries automobile gears and springs, and marine engine crankshafts.

Chrome- Molybdenum Steel: Molybdenum is more effective as an alloying element when used in combination with chromium. The composition of this type of steel is follows: Chromium 0.40 to 1.10 percent, molybdenum; 0.20 to 0.40 percent and carbon, 0.20 to 0.40 percent. This type of steel has great hardness as its outstanding feature and it possesses great strength and toughness. It is used mainly for in manufacturing hydraulic machinery and aircraft parts.

Manganese- Silicon Steel: This is a spring steel having the following composition: manganese 0.55 to 0.65 percent. It is used for flat and leaf spring and helical springs.

Nickel- Molybdenum Steel: I his steel contains 1 .65 to 3.75 percent nickels 0.20 to 0.30 percent molybdenum and 0.17 to 0.23 percent carbon. This steel has good toughness. It is used in petroleum industry, for brake drums, sheaves and valves, in aircraft industry for gears, pins and forgings, and in automobile Industry for transmission and differential gears.

Nickel Chromium Molybdenum Steel: This steel has the following composition

Nickel	0.40-2.00 percent
Chromium	0.40-0.90 percent
Molybdenum	0.15-0.30 percent
Carbon	0.28-0.40 percent

This steel has high tensile strength and high fatigue resistance. This steel is used for aircraft and automobile parts where usually high stresses are involved.

5. **High Alloy and Special Purpose Steels:** The following types of high alloy and special purpose steels are generally important

A. **Corrosion and Heat Resisting Steels:** Chrome-nickel stainless steels chrome stainless steel, and high nickel steel.

B. **Wear Resisting Steel:** High manganese steel and high chromium steel.

C. **Structural Steel:** Structural silicon steels.

D. **Tool and Die Steels:** High carbon steels, high speed steels.

Chrome Nickel Stainless Steels: This steel is of first order importance. Its corrosion resistance is its most important characteristic; other characteristics such as tensile strength ductility, hardness and resistance to creep are possessed to a varying decree by individual steel of this group.

The composition of this steel is as follow: Chromium 11.5 to 2400 percent: nickel 8.00 to 1.400 percent: and carbon, 0.08 to 0.20 percent.

This steel is highly resistant to corrosion and will not rust under ordinary atmospheric condition and will not be affected by common acids. It is light in weight having high tensile strength. Resistance to corrosion makes it more durable and attractive as a surfacing material. It can be manufactured in thin sheets.

This steel is used for external surfacing of aero planes, acid containers, cooking and dining utensils, cutlery goods diary' equipment's, table tops, laboratory' equipment's, hardware materials etc.

Chrome Stainless Steel: Chromium ranges from 10.0 to 40.0 percent. This steel is suited for parts requiring high strength with moderate resistance to corrosion. It is mainly used for automobile fender guards and body trim heat-controlled valves and shafts. This is also used for manufacturing cooking utensils and cutlery goods.

High- Nickel Steels: it contains 18.0 to 40.0 percent nickel. It is highly resistant to corrosion. High nickel steels are use where exposure of corrosion is very severe, as in Parts of pumps, salt-water connection and sparking plugs.

High Manganese Steel: It contains generally to 14.0 percent manganese. It is an important wear- resisting steel. The

outstanding properties are: extreme tough hardness and resistance to wear by abrasion. I ensile strength is 130000 psi and proportional limit is 35,000 psi, it is used in construction of those parts of machines (crushing and grinding both) which are subjected to sever shock and abrasion.

High-Chromium Steel: It contains 12.0 to 14.0 percent of chromium. It is highly resistant to both wear and corrosion. Applications are shear blades, dies and lathe centers.

Structural Silicon: Structural silicon steel is used for structural purposes because of its high yield point, high tensile strength and good ductility. It is used particularly in long span bridges in order to reduce heat weight. Its Composition is as follows: Silicon 0.57 percent, manganese 0.78 percent, carbon 0.35 pet-cent.

High Carbon Steel: It has a carbon content ranging from 0.6 to 1.4 percent. This steel has great hardness and excellent toughness. It is used to manufacture cutting tools and die sets like shear blades drills, screw-cutting dies, mandrels, pneumatic chisels etc.

High Speed Steel: The outstanding characteristic of high-speed steel is its ability to retain cutting hardness up to temperature of a red heat. Its composition is as follows.

Manganese 0.28 percent, silicon 0.28 percent. Chromium 4.0 percent; Tungsten 18.Q percent, molybdenum 07.5 percent, vanadium 1.0 percent and carbon 0.73-0.83 percent.

Applications are for metal cutting tools, such as drills, taps and reamers.

6. Structural Steels for Reinforcing and Pre-stressing Concrete.

Reinforcing and Steel for Concrete: Round steel bars are generally used as reinforcement in concrete. 1 he allowable tensile stress in reinforcement is taken to be 18.000 psi or 20.000 psi.

Table 11.7 shows the different sizes of reinforcing steel bars with cross-sectional area, perimeter and weight per linear foot.

Seize in inch.	**Area in Sq. inch**	**Perimeter in inch.**	**Wt. per foot in lb**
1/4	**0.049**	**0.785**	**0.168**
5/16	**0.077**	**0.982**	**0.261**
3/8	**0.110**	**1.178**	**0.376**
7/16	**0.150**	**1.375**	**0.511**
1/2	**0.196**	**1.570**	**0.668**
5/8	**0.307**	**1.960**	**1.043**
3/4	**0.442**	**2.360**	**1.500**
7/8	**0.601**	**2.750**	**2.040**
1	**0.785**	**3.140**	**2.670**
$1^{1}/_{8}$	**0.994**	**3.530**	**3.380**
$1^{1}/_{4}$	**1.227**	**3.930**	**4.170**
1 $3/_{8}$	**1.484**	**4.310**	**5.044**

pre-stressing Steel for Concrete: High tensile steel is almost the universal material for producing supplying the tensile force in pre-stressed concrete. Such steel can take any of three forms: wires strands or bars. The most widely used at present are the wires, which grouped parallel into cables. Strand is fabricated in the factory by twisting wires together, thus decreasing the number of units to be handled in the tensioning operation. Steel bars of high strength, has also been developed and successfully applied to pre-stressed concrete, resulting in Considerable economy at times.

The chemical composition of pre-stressing wires may vary with the manufacturer, but a typical analysis is as follows:

Name of Elements	Percentage composition
Carbon	0.60-0.85
Manganese	0.70-100
Phosphorus	0.050 max
Sulphur	0.055 max

Some manufactures use a certain amount of silicon in the steel High strength bars up to 150.000 psi or more are made by cold-working special alloy steels, by alloying high carbon steel with proper agents such as silicon and manganese high strength is obtained. A sample composition of high strength steel bars is as follows:

Name of Elements	Percentage composition
Carbon	0.60
Silicon	2.00
Manganese	0.70-100

Phosphorus	0.20 max
Sulphur	0.20 max

In order to get better bond between steel and concrete, especially in pre-stressing, where bond is critical at the ends corrugated or waved wires are employed. Various forms of surface indentation afford direct mechanical keys with the surrounding concrete.

Physical Properties: The ultimate strength of steel wires, strands or bars varied with their manufacture so that it is frequently necessary to obtain sample taste for each lot of products. However, the general ranges of values are listed below:

Type of steel	Ultimate strength psi.
Wirer of varying diameters and make	200.000-300.000
Strands of uncoated small wires	230.000-270.000
Strands of 19 or more galvanized wires	200.000-220.000
Strands of 19 or more uncoated wires	220,000-240,000
Bars	140.000-170.000

Typical stress-strain diagrams for high tensile wire and a high tensile bar are shown in Fig. 11.3.

Creep: One of the important characteristics required of pre-stressing Steel is minimum creep under maximum stress. Creep in steel is the loss of it's when it is pre-stressed and maintained at a constant strain for a period of time- Approximate creep characteristic, however are known for most of the pre-stressed in steels now in the market. Speaking in general, the percentage of creep Increases with increasing stress, and when steel is under low stress, the creep is negligible. Pre-stressed wires will have 2 to 3 percent creep when subject to 0.05 f_{ls} (where f_{IS} = ultimate unite stress in steel), but when stressed to 0.70 f_{ls}, the creep will still be not more than 5 percent.

While creep in steel is a function of time, there is evidence to show that under the ordinary working stress for high tensile steel, creep takes place mostly during the first few days. Under constant strain, the creep ceases entirely after about 2 weeks. If the steel is stressed to a few percent above its initial pre-stress and that overstrains is maintained for a few minutes, the eventual creep can greatly lessen, and it practically stops in 3 days.

Comparative physical properties of various types of steels:

For comparative purposes, physical properties of various types of steels are tabulated in table 11.8. 0

Table 11.18 Physical Properties of Various Types of Steel.

Types of steels	Tensile strength psi	Field strength gravity	Specific gravity	Melting point of steel
Low carbon steel	50,000-120,000	30,000-90,000	7.8-7.9	2750-2800
High carbon. steels	100,000-200,000	75,000-175,000	7.8	2600-2750

Cast iron ad malleable iron	25,000-120.000	Upto 60.000	7.0	2100-2400
Standard alloy steels	70.000-250.000	50.000-210.000	7.8-8.8	2500-2750
Stainless steels	100.000-250.000	50.000-125.000	7.4-8.0	2500-2800
Tool and die steels	110.000-250.000	80.000-200.000	7.5-10.0	2600-2800
Prestressing steels	125,000-275.000	85.000-220.000	7.6-8.2	2750-2900

Question

1. Name the common iron ores, and state their chemical formula. What is pig iron? Give its composition. Name and discuss different varieties of pig Iron.
2. What is flux? What materials are used as flux in reducing iron ores?

   What is slag? Give its composition and state its uses.
3. Distinguish between wrought iron and cast Iron. Give the properties of wrought iron. Discuss wrought Iron as a material of construction.
4. What Is cast iron? Name the different varieties of cast Iron. Give its typical uses.

5 Discuss the physical properties of malleable cast Iron. Name typical articles manufactured from malleable cast Iron.

6. What is steel'? Classify the steel on the basis of carbon content? Name the different processes of manufacturing steel and their typical products.
7. Discuses briefly the physical properties of steel.
8. Draw the stress-strain diagram for mild steel and explain. Compare the same with that of cast iron.
9. Explain briefly the importance of steel as a material of construction. Enumerate its various uses.
10. What is an alloy steel? What is the purpose of alloying steel? Name the most common elements that are used as alloying agents.
11. What are the special properties of nickel steel? Why the nickels steel is valuable as a structural steel?
12. What are properties of chrome nickel steel? State its specific uses.
13. State composition of chromium-molybdenum steel. What are some outstanding properties and uses of this type of steel.
14. State the outstanding properties and special uses of nickel- stainless steel.
15. What is stainless steel? State the uses of chrome nickel stainless-steel.
16. State types of steel or other ferrous metals that you would select as being the best suited for the following uses.

(a) Railway tracks, (b) multistoried building, (e) important structural members of long span bridge, (d) ball bearings (e) reinforced concrete (f) pre-stressed concrete, (g) shear blades (h) parts of aircrafts and (i) cutlery goods and cooking utensils.

17. Write short notes on:

(a) Smelting (b) Vanadium steel (c) High-nickel steel (d) High chromium steel (e) Creep (0 Galvanized iron and steel.

CHAPTER-TWELVE

NON-FERROUS METALS AND ALLOYS

12.1 Introduction: The non-ferrous metals of greatest engineering and industrial importance comprise aluminum, copper, lead, magnesium, nickel, tin, and zinc. Those of secondary importance include antimony, bismuth, cadmium, mercury and titanium. A number of the latter metals are chiefly important as alloy elements and others, such as chromium, cobalt, molybdenum, tungsten and vanadium are used largely as alloy metals.

The non-ferrous alloy of greatest importance are the alloys of copper with tin, *the bronzes:* and the alloys of aluminum magnesium, nickel and titanium. Many important special bronzes and brasses are made, however, in which a third alloy element is included. For this purpose, tin or zinc lead, phosphorus, aluminum, silicon, iron, titanium and vanadium are most common.

A side from the bronzes and brasses, copper forms more or less valuable alloys with practically all the metals listed above, aluminum is the principal metal of a number of important alloys and the same is true of magnesium titanium, zinc, lead, tin, nickel and a few others.

12.2 Copper: The greatest proportion of the world’s supply of copper is derived from copper pyrites (CuFeF2). The ore is crushed to a fine powder, washed and floated in oil tanks to eliminate impurities (silica and iron). It is melted in reverberatory furnace where Sulphur is removed in the form of slage which floats on the top. The molten metal which also contains iron in the form of oxide *is* removed lor Castings which are again smelled and treated in a blast furnace. The metal thus obtained is called blister *copper* because of cavities formed by escaping gases. It is further relined in a reverberatory furnace which yields 95 percent copper.

Copper weight about 550 lb per cu ft. melts at l,085°C and is reddish in colour. It is very ductile processes very high thermal and electrical conductivity and resists corrosion excellently. It also possesses excellent hot-working and cold working properties. It is available in rods, tubes, pipes, structural shapes and wires. It is also used for heat-exchanges tubes, plumbing and gas lines, gasoline and oil lines. Owing to its high resistance to attack by many industrial chemicals, copper is extensively used for pipes, tubes, stills, condensers, evaporators, autoclaves and pumps. It is also used for making cooking and dining utensils, ornamental and decorative works. It is also used as alloying agent. It takes a high polish but furnishes easily and requires frequent clearing to deep it bright.

12.3 Zinc: Zinc occurs usually as a sulphide (known as zinc blender or black jack, ZnS), carbonate and silicate. But the main source is sulphide (ZnS) Which ordinarily carries 33 to 50 percent zinc. The ore is first finely grounded and slowly roasted in a reverberatory furnace until nearly all the Sulphur is expelled. Mixed with ground coal it is heated to a high temperature which removes oxygen. It cooled in liquid form in condensers from which it is purred into moulds. The zinc thus obtained is called *speller*. It is not only available as spelter (as metallic zinc) but also zinc dust, which is formed

in the distillation of zinc and as zinc Pigments, such as zinc oxide, *leaded zinc oxide and lithophone.*

Zinc possesses moderate strength, good ductility and excellent corrosive resistance. Zinc is a plastic metal and it tensile strength varies between 5,000 to 10,000 psi. It becomes malleable when heated to 1000-150°C and can be rolled into sheets. Zinc exhibits a certain amount of creep at ordinary temperature and consequently seldom used to with, stand stresses in a structured or machine. It is available in the form of wires, rods, strips, powder and pigments.

It is mainly used for alloying with copper and for galvanizing battery poles etc. Zinc oxide is very commonly used for paints.

12.4 Lead: Lead is extracted from the ore containing lead sulphide (PbS) known as 'galena' which contains 86.6 percent lead. The metallurgical processes involved in the extraction of lead from its ores comprise the following operation rousing of sintering of the ore: smelting in the blast furnace and collecting the molten lead.

The physical properties of lead commonly taken into account are its softness, plasticity, malleability, high density and excellent resistance to corrosion. It does not retain any good polish. It is bluish gray in and colour exhibits a dull metallic luster when freshly fractured. On exposure to the moist air, it becomes oxidized and loses its luster.

It is available in the form of sheets, tubes, pipes, rods, wires, cast lead fittings, lead wool etc. It is mostly used in the forms of oxides, such as white lead, red lead and litharge. It is used for plumbing works, solders, roof covering and damp roof courses. It is also used in printing for making type metal. In general, lead is very resistant to corrosion by the atmosphere natural waters and most mineral acids. Steel pipes, tanks, etc. are coated with lead and many water pipes and conduits for electrical conductors are made of lead.

Lead is often used because of its high density (707 lb/ft3) Since the ability of materials to shield against gamma rays is directly related to density, lead is utilized as a shielding material in nuclear reactors against gamma rays so as, to provide safe condition for personnel.

Lead is used to manufacture chemicals, such as red lead for metal protective paints, white lead as an ingredient in. exterior house paint, litharge for glass manufacture, storage batteries, tetraethyl lead for gasoline, various lead chemicals as stabilizers in plastics and in the ceramic industries.

12. 5 Tin: Tin is obtained from the ore, tin-stone (black oxide of tin) known as Cassiterite (SnO_2) containing 77 per cent tin. The extraction of tin from its ore involves the mechanical or combined mechanical, thermal and chemical concentration of the ore. Reduction by smelting with charcoal or coke in reverberatory furnace and refining of the crude tin derived by re-smelting.

This is a silvery white, lustrous and extremely malleable metal as can be seen by its form in tin foils. Its specific gravity is 7.3 and density, 450 Ib/ft_3 and it melts at 235°C. It oxidizes very slowly. Its tensile strength and ductility are very low: it cracks easily when, bent and is extremely brittle at high temperatures.

Tin is used quite extensively in the form of sheet-tin and as tin foil it is an important constituent of many valuable alloys. A large amount of tin is used as a coating on sheet iron and steel.

11.6 **Aluminum:** Aluminum is derived from bauxite and cryolite. Bauxite is a mixture of alumic and ferric hydrates containing widely varying amounts of alumina, ferric oxide, titanium oxide, silica, calcium and magnesium carbonates, water etc. Most bauxites carry from 55 to 56 percent alumina. Cryolite is a double fluoride of sodium and aluminum and containing when pure, 13 percent aluminum. Whatever be the original source of the materials, it is converted into alumina first before the metal is extracted.

The only method of extraction of aluminum of commercial importance consists tin the electrolysis of comparatively pure alumina dissolved in a bath of molten cryolite. Alumina for the purposes of electrolysis is usually made from bauxite, but is may be prepared be treating silicon bauxite with sulphuric acid. Bauxite is treated with a soda solution and the alumina is extracted as sodium aluminate. The alumina may be precipitated from the solution as hydroxide by carbon dioxide and subsequently washed, filtered and dehydrated by heating. The metal derived as the product of the above operation is the *commercial aluminum.*

The most important property of aluminum and alloy is lightness in weight. It is highly ductile and malleable and possesses moderate strength and great resistance corrosion. Alumina is a white metal of high metallic lustier and can be rolled into sheets. It weights 165/cu ft and melts 659°C.

It is used in certain portion of automobile bodies for cylinders and pistons in aircraft engines and for kitchen utensils. The low electrical resistance of aluminum is one of its most valuable properties, since a relatively high conductivity combined with its lightness and strength makes it especially well adapted for long span transmission lines. Pure aluminum is being used extensively in electrical work both as bus-bars and rods in power station and in large quantities for transmission lines with high voltages.

A side from the electrical uses of metallic aluminum, large quantities are consumed in the manufactures of many articles of every day domestic uses and in many industries where tanks, cooking vats etc. which must be heat-conductive, non- corrodible and non-poisonous, are used.

Pure aluminum is too soft to be used for many purposes, it is, therefore, alloyed with copper manganese, zinc, silica, nickel and magnesium for improvement in strength and hardness.

12.7 Magnesium: Magnesium is produced by the electrolysis of magnesium chloride which is obtained as a byproduct from the processes of purifying sodium chloride derived from brine wells or from sea water. A molten bath of magnesium chloride mixed with sodium and potassium chloride is electrolyzed at a temperature of about 700°C. The process is carried out in an airtight container. Chlorine gas is liberated at the anode and the magnesium at the cathode, where it rises to the surface and is powered off because of its lightness. This magnesium metal contains some non-metallic impurities

which may be eliminated by re-heating in vacuum or in contact with a flux to prevent oxidation.

Magnesium has tensile strength of 14,000 psi and compressive strength, 24,000 psi. It has a high thermal conductivity. Its melting point is 651 °C.

Magnesium is not used alone structurally, but alloys containing magnesium are' employed for structural parts principally because of their light weight,

12.8 Nickel: Nickel is extracted from (1) nickel-ferrous magnetic pyrites containing about 3 percent nickel and (2) hydrated nickel magnesium silicate containing 6 to 8 percent nickel.

Nickel ores (pyrites) are crushed, roasted and smelted in a blast furnace which produces a crude matter of nickel iron and copper. Iron is removed by the Bessemer's process and copper is removed by-treatment with dilute sulphuric acid. The residue is partially reduced by hot producer gas and volatilized at a low temperature into nickel carbonyl, which is later passed through a vented chamber where pure Nikel is deposited in granular form.

Nickel is a brilliant metal, silver in colour and takes good polish and does not varnish or corrode in dry weather. It is highly resistance to atmospheric, fresh water and salt water corrosion. For this reason, it is used for plating iron, steel and other metals. It is quite ductile and fairly malleable. In hardness, it is soft like steel.

Unalloyed nickel is not used in building and other works.

Pure nickel is used as an elect opiate. It is mostly Used for alloying with other metals and for making coins.

12.9 Titanium: It is extracted from the chief commercial ores *rutile* and *ilmenite,* Rutile is essentially titanium dioxide. Titanium has a silvery white colour and is extremely hard. Commercial titanium is available in the form of plated, sheet, rod, tubing, wire and forgings.

Titanium has high specific tensile strength and has a melting temperature of 31.35°F. If has excellent corrosion resistance. It is used for rivers, marine parts subject to sea water and for corrosion resistant chemical equipment.

12.10 Vanadium: It occurs in combination with lead etc. It is a hard, silvery, very brittle and infusible metal. It is not oxidized either by air water. Its specific gravity is 5.5 and melts at 1730°C. It is used for alloying with steel to produce high strength steel.

12.11 Molybdenum: This occurs in the form of molybdenum which is a di-sulphide of molybdenum (M°S) and resembles graphite.

Molybdenum is gray in colour. It has high tensile strength. It is brittle and has a high melting point.

It is generally used for alloying with nickel, manganese, etc. especially for making tools and die steels.

12.12 Chromium: Chromium occurs as an oxide ore (Cr_2C_3) with earthy impurities. It also occurs in the form of chrome iron ($FeCr_2O_4$) with impurities like silica, alumina and magnesia.

Chromium is a hard metal of brilliant gray colour and can be *easily* polished. It resists corrosion and retains its polish.

It is mostly used with other metals to produce alloys such as stainless steel and also many of her varieties of high strength steels.

12.13 Tungsten: It occurs mostly in the form of wolframite. It has a very high melting point (2,800°C) and can be rendered perfectly ductile by repeated heating and is, therefore, very much in filaments of electric bulbs. It is specially used for alloying with steels to which imparts strength, hardness, toughness and resistance to shocks.

2.14 Manganese: Manganese is found in nature in the form of manganese oxide (MnO_2) and it usually associated with carbonate and silicates of iron, calcium and magnesium. It is obtained by heating the manganese oxide with carbon at a high temperature.

It is grayish white metal like cast iron. It is brittle, hard and crystallin. Its specific gravity is 8.0 and its melting point is 1245°C. It oxidizes very quickly and absorbs oxygen quickly.

Pure manganese does not have any important application. It is chiefly used with iron in the manufacture of steel alloys. It is also for alloying with metals and its higher oxides are used as driers for paints a varnished.

12.15 Principal Non-Ferrous Alloys: The following are the principal nonferrous alloys: Brass, Bronze, Duralumin, Alclad, Y-alloy, Magnalium, Monel, Inconel, Satellite, Corbology, Dow metal, Electron metal, German silver and Solders.

12.16 Brass: This is essentially a copper alloyed with 10 to 45 percent of zinc. It is strong and ductile and does not varnish as rapidly as copper, although it needs regular cleaning if a bright appearance is desired. Its colour depends upto the percentage of zinc it contains.

There are mainly two broad classes of brasses. (1) Ordinary brasses and (2) Special brasses.

Ordinary Brasses: The following are the different type of ordinary[7] brasses:

Commercial Brass: This brass contains 90 percent copper and 10 percent zinc. It is used for grillwork's and marine hardware.

Red **Brass:** It contains 85 percent and 15 percent zinc. This is the best corrosion resisting plain brass. It is utilized for heat exchanger tubes, plumbing lines and electrical sockets.

Low Brass: It contains 80 percent copper and 20 percent zinc. It is generally used for ornamental works.

Cartridge Brass: It Contains 70 percent copper and 30 percent zinc. This type of brass is used for automobile radiator cores and tanks, lamp fixtured springs, ornamental goods and ammunitions components.

Yellow Brass: It (contains 65 percent copper and 35 percent of zinc) is employed for grillwork's, lamp fixtures, dining and cooking utensils, springs and plumbing accessories. It is strongest among the plain brass.

Ordinary brasses in general have good resistance to industrial, rural and marine atmospheres and some resistance to weak acid and bases. They all have excellent property of cold-working.

Special Brasses: The following is the brief description of special brasses:

Muntz Metal: It is a brass containing 60 percent copper and 10 per cent zinc. It can only be rolled hot. Sea water attacks it and forms zinc salts which prevent the fouling of the bottoms of ships by living or genism's. It is used for condenser tube in fresh, non-corroding water.

Naval Brass: This is also known as Tobin Bronze; it is made by adding about 1 percent of tin to muntz metal. This addition of tin markedly improves resistance to corrosion. It is used as condenser tube materials. Pump parts, motor boat shafting and marine hardware.

Admiralty Metal (Admiralty Brass): It is manufactured by adding about 1 percent of tin to cartridge brass (70 percent copper and 30 percent zinc). This addition of tin greatly increases corrosion resistance. Admiralty brasses generally used as the best condenser tube metal.

Lead Brass: The addition of small percentage of lead softens brass and renders it more easily cut by machine tools its free cutting properties being improved so that automatic may be employed, the presence of lead lowers the strength and decreases the ductility considerably.

Aluminum Brass: Aluminum is added to brass in amounts upto about 5 percent with beneficial effects on the tensile properties. The tensile strength and the elastic limit are considerable raised, the hardness and ductility are increase , Aluminum brass is principally used in making casting Machinery, marine works, forgings, rolled bars, plates etc.

Iron Brasses: Two brass alloys containing iron have been commonly used. These are: (1) *Stereo metal* contain about 60 per cent copper 38 to 38.5 percent of zinc, and 1.5 to 2.0 per cent of iron and (2) *Delta metal* varies in composition, but usually contains 55 percent of copper, 41 percent of iron and 1 percent of manganese phosphorus and other element. These metals particularly the delta metals possess a considerable high strength and better working qualities than the brass would possess without the iron addition. They are generally used for marine constructions.

White Brass: It contains less than 10 percent of copper and j more than 90 percent of zinc. This brass possesses most of the characteristics of zinc but is somewhat hardened and strengthened by the small amount of copper. It is principally used in making ornaments which are plated with bronze and solid under the name of French bronze.

12.17 Bronze: Originally the term bronze was applied only to copper-tin alloys, but common practice nowadays to designate as bronze of all copper-base alloys which have additions of any elements excepts zinc. The influence of tin upon the properties of copper is that of a pronounced hardener and strengthener, so long as the limiting percentage of 20 or 25 percent is not exceeded.

The Brozes exhibiting the greatest tensile strength and bending strength and the highest yield strength are those containing more than 80 percent of copper.

The following are the different varieties of bronzes:

Aluminum Bronze: The principal commercial alloy copper and aluminum is aluminum bronze. It contains 89 to

89.5 percent iron. The addition of iron aluminum and 1.0 to

2.5 percent iron. The addition of iron in small percentage improves the casting qualities.

Aluminum bronze is heat resistant, retaining its strength and hardness at high temperatures. It is highly resistant to corrosion.

It is used for ship fittings, propeller blades, pickling apparatus, pumps for acids, pipes, vats machine and automobile constructions.

Aluminum Manginess Bronze: This is the strongest and toughest type of bronze with excellent hardness equaling nickel alloy structural steel in tensile strength. The composition is as follow: copper, 60-68 percent: zinc. 20-24 percent: aluminum. 3-7 percent; manganese, 2.5-5 percent; and iron, 2-4 percent.

Aluminum-manganese bronze has good wear resistance under heavy or shock loads is capable of withstanding high fluid pressures and is resistant to corrosion. Its applications include hydraulic valves for pressures upto 20.000 psi, pump and fan impellers, tracks and rollers for sluice gates, and bearings.

Manganese Bronze: Manganese bronze is one of the hots valuable copper-zinc alloys. A typical composition of regular grade manganese bronze is copper, 56-64 percent, manganese, 1.0 percent maximum, aluminum 0.05-1.0 percent lead 0.4 percent, maximum, iron, 0.4-1.15 percent, and me the remainder.

It is one of the best copper alloys for hot working and makes excellent forgings and hot rolled rods. It is particularly resistant to corrosion by sea water and is resistant to attack by dilute acids.

It is very commonly used for steamship propellers and other ship fittings for piston rods, shafts, axles and for many kinds of castings and forgings employed in general machine, locomotives and automobile construction. It is also used for large valves and castings for water supply system and hydroelectric-power plants.

Turbine Metal: It is a modified manganese bronze containing nickel. It is highly resistant to pitting and corrosion. It is used for runners of hydraulic turbines and high-speed pumps.

Beryllium Bronze: This alloy contains a small percentage of beryllium alloyed with copper. This alloy contains beryllium. 1.90-2.15 percent, cobalt. 0.25-0.35 percent and the remainder, copper. It combines good electrical conductivity with the highest strength and hardness of any copper alloy when heat treated. It is a stable light-weight metal. It has good resistance to corrosion and wear. It is non-magnetic. It is also highly resistance to pitting action. This alloy is a good spring material and is utilized for burden tubes. Other applications are for resistance-welding electrodes and heavy-duty switches.

Gun Metal: Gun metal contains 88 percent copper, 8-10 percent tin and 2-4 percent zinc. It is a general-purpose bronze of good average mechanical properties and fairly good wearing qualities. It is resistant to corrosive action of

sea water and can be readily cast and freely machined. At one time, guns were commonly cast of it. Typical application includes pumps castings and impellers, water turbine runners, condenser heads and cylinder linings.

Nickel Bronze: Nickel bronze is a copper-tin-zinc red metal alloy to which from 1 to 10 percent nickel is added. Addition of nickel refines the grains and increases heat resisting, qualities. A typical composition is copper, 88 percent, tin, 5 percent nickel 5 percent, and zinc 2 percent. It had high tensile strength, 70,000 psi. It is used for pressure tight services.

Cupro=nickel is a 70 percent copper and 30 percent nickel alloy used for tubes of steel, condensers, evaporators and heat exchangers. It maintains its strength and hardness upto 800°F and is resistant to corrosion by salt water.

Phosphor Bronze: The addition of very small percentage of phosphorus to any bronze has a remarkable effect upon its properties. There is an increase of tensile strength, yield strength and endurance under repetition of stress. The amount of phosphorus varies from 0.5 to 1.2 percent Phosphor bronze is used for engine parts.

Leaded phosphor bronze contains 10 to 30 percent lead in phosphor bronze. ‘It is highly resistant to wear under severe conditions and in addition, possesses a very low coefficient of friction. It is mainly used in railway services.

Silicon Bronze: It is a general-purpose corrosion-resisting alloy contain 96 percent copper and 3 to 4 percent silicon with small addition of tin, manganese, zinc or iron. Silicon bronze is a free-flowing metal, having golden yellow colour.

It had excellent weldability and good machinability, it is available in forgings, rods, bars and sheets. Chief applications are for welded tanks, springs, condenser tubes and chemical equipment's.

Copper Tin-zinc Bronze: The copper-tin zinc alloy is among the most valuable and commonly used of all the bronzes. A very common bronze of this type contains 88 percent copper, 10 percent tin and 2 percent zinc. It is used for boiler tubes in ships and bearings and wherever resistance is required against weather actions.

Hydraulic Bronze: This bronze (also called *red brass, composition brass or ounce metal)* contains 85 percent copper, 5 percent zinc and 5 percent lead. It is a hard and corrosion resistant metal. It is used for valves, condenser heads and pipe fittings.

12.18 Duralumin: This is an alloy of aluminum with 3.5 to 5.5 percent magnesium and 0.5 to 0.8 percent manganese. It is light, having a specific gravity of 2.85 and has a strength of 28,000 psi. It can be easily heat-treated, which renders it highly resistant to corrosion. It is principally used for surgical instruments, aircraft and automobile parts and for other instruments.

12.19 Alclad: Duralumin when coated with a layer of pure aluminum to a thickness of about 3 to 7 percent of the core, is called alclad. This process imparts high anticorrosive property to duralumin. It is available only in rolled forms and is used in automobile and aircraft parts.

12.20 Y-Alloy: It is an important alloy which consists of aluminum alloyed with 4 percent *copper,* 2 percent nickel

and 1-5 percent *copper, 2 percent magnesium.* It is a very hard tough, light but costly alloy. It possesses great strength at high temperatures. It is mainly suitable for used in position heads, gear boxes, propellers blades etc.

12.21 Magnalium: It contains about 2 to 6 percent magnesium alloyed with aluminum. It is lighter than pure aluminum, easy to work, very strong and ductile. It is specially used as a deoxidizer in copper smelting operations.

12.22 Monel: It is an alloy of nickel with about 30 percent copper. It is as strong as steel but it is highly resistant to corrosion and tarnishing. It is very costly alloys. It is chiefly available in the form of sheet, stripes, wires, rods, tubes and castings and is mainly used for pipes, propeller shafts and pumps valves.

12.23 Inconel: This nickel chromium iron alloy (80 percent nickel, 13 per cent chromium and 7 percent iron) is very strong and has corrosion resistance against tarnishing and is nonmagnetic. It is generally used in food industries.

12.24 Bearing Metals: These are alloys of lead, tin. and antimony with copper in varying proportions. It is mainly of two types: (1) *White metal* containing 86 percent tin and (2) *Magnolia metal* containing 80 percent lead. Bearing metals are used in bearings which are subjected to excessive heat.

12.25 Satellite: This is an alloy containing 45 percent of cobalt, 30 percent chromium and 15 percent tungsten with small amounts of manganese silica, carbon and iron. It is very hard and is used for the tips of the cutting tools and facings of dies. It does not tarnish, therefore very suitable to make surgical instruments.

12.26 Corbology: Corbology is the trade name of an alloy of tungsten, carbon and cobalt. It is very hard and durable and is better than steel in maintaining a cutting edge at red heat. It is manufacturing high-speed cutting tools.

12.27 Dow Metal: Dow metal is the commercial name of a magnesium aluminum alloy. It contains 85 to 98 percent magnesium, 4 to 12 percent aluminum, 0.1 to 0.4 percent manganese with little copper and other elements. It is very light, soft, strong and ductile. It can be cast forged rolled and drawn into wires. It is principally used in aircraft and automobile parts.

14.28 Electron Metal: Electron metal is the commercial name applied to a magnesium alloy containing about 4 percent zinc and small percentage of copper, iron and silicon. It has a good tensile strength of 40.000 psi. Its application is similar to those of Dow metal.

12.29 German-Silver: This is an alloy of copper, nickel and zinc. It is white in colour and resists tarnishing very well but needs regular cleaning to keep it bright. It is available in sheet, strips, tubes, wires and rods. It is used for making resistance coils, as it has very low electric conductivity. It is commonly used as imitation silver.

12.30 Solders: Solder is an alloy of tin and lead with a little antimony. Soldering is only possible when the melting point of the solder is lower than that of the metals to be jointed whose surface are wetted by the melted solder, solders containing zinc only and not lead, are called hard solders and those which contain lead are called *soft Solders*. Soft solders are generally used in ordinary works.

The following are the different important grades of solders prescribed by the B.S. specifications:

Grade B: The tin-amith's solder containing 49 to 51 percent of tin, 3 percent antimony and the reminder lead.

Grade C: This is suitable for hard-soldering containing 39 to 41 percent tin, upto 3 percent antimony and the rest is lead.

Grade E: The solder for electric works containing lead alloyed with 94.5 percent tin and upto 0.5 percent antimony.

Flux: Flux is a material added to clean the surface of the metals be jointed. Table 12.1 shows the types of flux to be used for various metals to be soldered.

Table 2.1 Types of Flux Used for Soldering Various Metals

Metal to be soldered	**Type of flux to be used**
Iron and steel	Zinc or ammonium chloride
Wrought iron	Zinc chloride
Gold and silver	Zinc chloride
Copper, brass and gunmetal	Zinc or ammonium chloride
Aluminum	or resin
Lead	Stearin
Tin	Tallow or resin
Zinc and Galvanized steel	Zinc chloride
	Hypocaloric

12.31 Some Important Terms:

Galvanizing: This is zinc plating. The object or the article is first cleaned thoroughly, then it is dipped into a solution of hydrochloric acid and then into a bath of molten zinc. The zinc partly dissolves in iron and farms an alloy and a coating of zinc is deposited on the surface. This process is cheap but not durable. This is principally applied when the material is exposed to sea water or other solutions high in chlorides, it is mainly employed to coat submarine cables manned structures and naval crafts.

Tin Plating: This is a thin coating of materials with tin. The material to be coated is first washed in acid and then passed through a bath of molten tin.

If the plating or coating is of lead, or lead and then passed through a bath of molten tin.

If the plating or coating is of lead, or lead and tin alloy it is called 'Terme plating'. Sometimes a coating of aluminum is also done.

This is used in roofing materials, pipes, automobile gasoline tanks and non-food containers.

Electroplating: This is a process of deposition of the coating of a required metal on the object. Electroplating consists of: (1) *Electro-galvanizing* (here the electrolyte) is zinc sulphate, $ZnSO^4$) (2) *Nickel-plating* (electrolyte is $NiSO_4$): this is generally done after first plating the base metal with copper. This plating is mainly done for household articles and sometimes parts of machinery; *(3) Chromic ' plating:* This is applied over nickel-plating in order to get more thickness of the coating material. This is generally applied for preventing external corrosion and *(4)* Cadmium *platirg:* this gives a better appearance than ordinary zinc coating.

Porcelain Enamel: This is a commercial name given to the nonmetallic coating materials of various types. The articles to be enameled should be cleaned well first and then coating of cobalt oxide is given to provide for adherence of enamel. The 2 to 3 coatings of enamel are applied and the article is heated to a desired temperature and finally cooled down.

This type of coating is used for refrigerators, kitchen utensils and in chemical and industrial equipment’s.

Questions

1. What are the chief uses of copper, zinc, lead, tungsten nickel, vanadium and molybdenum.

2. What are the important sources, properties and uses of magnesium and titanium?

3. Distinguish between brass and bronze with respect to composition. properties and uses.

4. A bridge bearing is to be installed to withstand slow moving heavy loads. The metal must be strong, hard and shock resistant. What metal do you select? State your reasons.

5. What is the composition, properties a use of (a) phosphor bronze (b) silicon bronze (c) manganese bronze (d) aluminum bronze and (e) gun metal?

6. Describe the constitution of brasses. What is the composition of cartridge brass? How does its strength compare with that of copper? Where might it be used?

7. Compare the compositions and uses of admiralty metal naval brass and muntaz metal.

8. Compare between the following with respect to composition, properties and uses.

(a) Satellite and Corbology (b) Dow metal and Electron metal (c) Duralumin and Magnalium (d) Monel and Inconel (e) Alclad and Bearing metals.

9. Distinguish between a solder and a flux. What type of flux do you recommend for the following metals to be welded?

(a) Iron and steel (b) Gold and silver (c) Zinc and Galvanized steel (d) Gum metal (e) Brass (f) Lead (g) Tin and (h) Copper.

10. Write short notes on:

(a) Yellow brass (b) Chromium (c) Galvanging (d) Electroplating (Porcelain Enamel).

CHAPT ER-THERTEEN

SOILS

13.1 Introduction: Soil is very important engineering materials. Because any structure constructed by the civil engineering needs a stable foundation and all foundations constructed ultimately derive their support from the underlying soil or rock. Hence, soil and rock constitute the principal structural materials with which the civil engineers deal for the foundation of structures. Soil is not only important as foundation material but also as a construction material, as in the formation of an embankment, construction of dams, as a filling material or as a stabilized subgrade for roads, airports and runways. Soil is also an important raw material for the manufacture of bricks, tiles refractories, cement, mortal, synthetic aggregates, ceramics cooking and dining utensils glasses etc.

Soil is, therefore, of great importance to engineers as a material of foundation and also as materials of construction. A thorough knowledge of the origin, manner of occurrence, characteristics and the behavior under both static and dynamic loads (dead load and live load) of soils is very essential for the civil engineers for the successful practice of design and construction of foundations and other engineering structures like dams, rods, embankments, including cutting, filling and tunnelling.

13.2 Origin and Formation of Soils: Basically, the engineering definition of the word "Soil" is very broad one. Soil might be defined as all the earthy materials, both organic and inorganic which covers the rock-crust of the earth practically, all soils are the products of the disintegration and decomposition of the rocks of the earth crust. This process usually termed as weathering, has been brought about by the action of chemical and mechanical forces which have been exerted upon the parent rock-formations for countless ages. Included among these forces are those of temperature, wind, riming water, freezing and thawing, chemical decomposition, glacial action and many others.

13.3 Soil Classification: The principal terms used by the civil engineers to describe soils are gravel, sand, silt and clay. Most of the natural soils consist of mixture of two or more of these constituents. It is possible to classify soils into several principal groups based on the grain size. By grain size is meant the average dimension (or diameter in a general sense) of a soil particle contained within a soil mass. The table 13.1 shows the universally accepted soil classification (by AASHO)

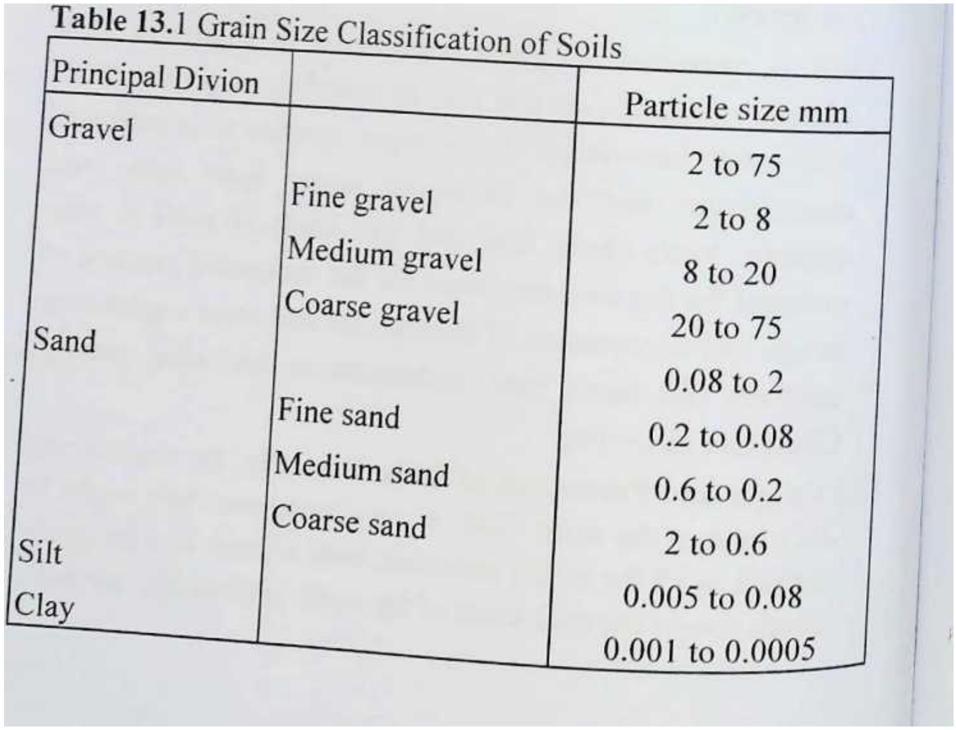


Table 13.1 Grain Size Classification of Soils

Principal Divion		Particle size mm
Gravel		2 to 75
	Fine gravel	2 to 8
	Medium gravel	8 to 20
	Coarse gravel	20 to 75
Sand		0.08 to 2
	Fine sand	0.2 to 0.08
	Medium sand	0.6 to 0.2
	Coarse sand	2 to 0.6
Silt		0.005 to 0.08
Clay		0.001 to 0.0005

Sand and gravel are coarse grained soil types possessing little or no cohesion. They are readily identified by visual inspection and are distinguished, generally speaking, by the relative stability under loads when confined, by their high permeability and by their failure to shrink or expand in detrimental amounts with change in moisture content.

Sill is the term applied to line grained soils low to medium plasticity, intermediate in size between sand and clay. Silts generally possess little cohesion, undergo considerable shrinkage and expansion with change in moisture and possess a variable amount of stability under loads. If the silts contain mica and organic particles, they are likely to be highly compressible and unstable.

Clays are principally composed of particles which are colloidal in size. Clay generally processes medium to high plasticity, have considerable strength when dry undergo extreme changes in volume with the change in moisture content and are practically impervious to the flow of water. Clay may be further distinguished by the fact that although they may possess considerable strength in their natural state, this strength is sharply reduced and sometimes completely destroyed when their natural structure is disturbed i. e., when they are remolded.

In addition to the general soil types which have been described, there are many other terms which are used to describe soils. Included among these are the following: loam. *loess, muck and pen.*

Loam is a term used to describe soil which is general} well graded from coarse to fine. This name frequently) appeals in soil engineering in combination with other terms. Thus a soil may be called a sandy loam or a clay loam depending the size of the predominating soil fraction.

Loess is a fine-grained soil characterized by its nearly uniform grain size, predominantly silt and by its low-density Highway cuts through loess deposits usually resemble those made in rock, in that this soil will stand on a nearly vertical slope, while it is readily eroded by rain water if flatter slopes are made.

Muck is a soft silt of clay, very high in organic content, which is usually found in swampy areas and river, lake or bell bottoms.

Peat is a soil composed principally of partially decomposed vegetable matter. It's extremely high-water content, woody nature and high compressibility make it and extremely undesirable foundation material.

13.4 Basic Soil properties: To have an understanding of the effects of application of loads on soils, an engineer must be familiar with certain basic properties of other engineering materials, such as stones, bricks, cement lime, sand, concrete iron and steels and timber. Engineers must have similar knowledge relative to soils. The job of the civil engineer in this respect is complicated by the fact that many soils are quite complex in nature, both physically and chemically and that soil deposits are likely to be extremely heterogenous in character. It must be remembered that the properties of any given soil depend not only on its general type but also upon its condition at the time at which it is being subjected to loads. The following are the basic soil properties.

1. **Moisture Content:** Water is extremely important constituent of soils. The moisture content is defined as the weight of water contained in given soil mass compared with the oven dry weight of the soil and is usually expressed as a *Percentage*. The following **expression** is used to determine the moisture content in the laboratory:

$$w\ (\%) = \frac{W - W}{W_2 - W_c} \text{x } 100 \qquad 13.1$$

Where w (%) = moisture content in percent

Vc = Weight of the contain in grams

W_1 = Weight of the soil and the container in grams

W_2 = Weight of the oven dry soil and the container in grams.

In the void spaces in a soil are completely filled with water, the soil is said to be *saturated.* The moisture content of a soil may then be 100 percent or more as might be the case in a saturated clay muck or peat soil. The stability of soils under loads is dependent upon the moisture content to a great extent.

2. **Specific Gravity:** By the terms 'specific gravity' as applied to soils, is meant the specific gravity of the dry soil particles or "solids". Values for the specific gravity refer to the ratio of the unit weight of soil particles to the unit weight of water at some known temperature (usually 4°C) and range numerically from 2.60 to 2.80. Within this range, the lower values for the specific gravity are typical of the coarse soils, while higher values are typical of the tine grained soil types.
3. **Unit Weight or Density:** The unit weight of a soil is the weight of the soil mass per unit of volume and is generally expressed in pounds per cubic foot. As commonly used in

soil engineering, the term 'Wet unit weight' or wet density refers to the unit weight of a soil mass having a moisture content which is anything different from zero, while the 'dry unit weight' or ‘dry density' refers to the weight of the soil mass in an oven-dry condition.

They are expressed as follow s: (√ read as gamma)

$$\text{Wet Unit Weight } \surd = \frac{W}{V} \qquad 13.2$$

$$\text{Dry Unit Weight } \surd d\ / = i\ \frac{W_s}{V} \qquad 13.3$$

$$\text{Or } \surd d = \frac{\frac{\surd}{100 + w\%}}{100} \qquad 13.4$$

Where W = total weight of the soil mass including the moisture content in pounds or grams. Ws=Oven-dry weight of the soil mass in pounds or grams. V = total volume of the soil mass in cu ft or cu cm.

If the soil is saturated its unit weight is termed as the situated unit weight and denoted by sat. It is sometimes desirable to have a knowledge of the unit weight and specific gravity of the solid constituents. These quantities are defined as Unit Weight at the Soil

$$\text{Constitution } \surd s = \frac{Ws}{Vs} \qquad 13.5$$

Specific Gravity of the solid constituents in cu ft or cu cm

Weight $\surd w$ = unite weight of water, taken as 62.5 Ib/cu ft in the English system and I gm/cu cm in the metric system.

The unit weight of soil may vary from 90 Ib/cu ft or less saturated organic soils to 130 lb/cu compacted granular soils.

4. Void Ratio: Another term that is significance in describing the weight-volume relationship of soils is the void ration. “The void ratio is defined as the ratio of the voids contained in a soil mass to the volume of the solids” Related terms are the "porosity", which is defined as the ratio of the volume of the voids to the total volume of the soil mass being considered and the 'degree of saturation' which is defined as the ratio of the volume of water contained in the voids to the volume of the voids. Both porosity and degree of saturation are normally expressed as percentages. These quantities are expressed follows:

$$\text{Void Ratio } e = \frac{V_V}{Vs} \qquad 13.7$$

$$\text{Porosity} = \frac{V_V}{Vs} \times 100 \qquad 13.8$$

$$\text{Degree of Saturations } Sr\ (\%) = \frac{Vw}{Vv} \times 100 \qquad 13.9$$

where in addition to the terms already explained.

Vv = volume of voids in cu ft or cu cm

Vw = volume of water in cu ft or cu cm

The void or porosity of a coarse-grained soil usually not itself furnish a direct indication of the behavior of the soil under load or during excavation, because at the same void ratio one soil may be in a dense state, when as another may be loose. Much more significant is the relative density which is defined by the equation,

$$\text{Relative Density } D_r = \frac{e^{max-e}}{e^{max} - e^{min}} \qquad 13.10$$

in which e_{max} is the void ratio of the soil in its looser possible state, e is the actual void ratio and e_{min} is the void ratio in the densest possible state. Thus. Dr-1.0 for a very dense soil and 0 (zero) for a very loose soil.

A simple example may serve to show the relationships existing among these latter terms e.g., unit weight, specific gravity and moisture content.

Example: Given a soil mass which has a wet unit weight of 120 ib/cu ft. a moisture content of 13.5 percent and a specific gravity of 2.65. Calculate the dry unit weight, void ratio, porosity, degree of saturation and the relative density. Assume, e_{max}.0.86 and e_{min}-050

Solution:

$$\text{Dry Unit Weight} = \frac{\text{wet unit weight}}{\frac{100-w\%}{100}} - \frac{120}{\frac{100-13.5}{100}}$$

$$= \frac{120}{1.135} = 105.7 \text{ lb/cu ft}$$

Now consider one cu ft of soil having this dry weight. Since the specific gravity of the solid particles is 2.65, the volume of the solids contained in this volume must be

$$V_s = \frac{105.7}{2.654 \times 62.4} = 0.639 \textit{ cu ft}$$

Therefore, the volume of void is

$$V_v = 1{,}000 - 0.639 = 0.361 \text{ cu ft}$$

$$\text{And } e = \frac{V_v}{V_s} = \frac{0.361}{0.639} = 0.56$$

$$\text{and } n = \frac{V_v}{V_sV_v} \times 100 = \frac{0.361}{1000} \times 100 = 36.1\ \%$$

In this volume is contained 120.0-105.7 = 14.3 lb of water.

Therefore, the volume of water

$$V_w = \frac{14\ 3}{62.4} = 0.229 \textit{ cu ft.}$$

and the degree of saturation

$$S_r = \frac{V_w}{V_v} \times 100 = \frac{0\ 229}{0.361} \times 100 = 63.4\%$$

and also, the relative density

$$D_r = \frac{e^{max-e}}{e^{max} - {}^{min}} = \frac{0.86-0.56}{0.86-0.50} = 0.84$$

Permeability: Permeability is the porosity of a soil mass which permits water to flow through it under the action of gravity or some other applied force. In soil engineering or in soil mechanic, permeability is expressed by the terms coefficient of permeability, (denoted by K) which is frequently define as the velocity of flow (of water) through soil mass under the action of a unit hydraulic gradient (slope). The co-efficient of permeability of a soil mass is principally dependent upon its void ratio, grain size and structure, as well as upon the density, temperature and viscosity of the water flowing through the soil mass. Coarse grained soils, such as sand gravel, have high co-efficient of permeability and are said to be previous. Fine grained soils like clay and sill have much lower co-efficient of permanently and are said to be relatively impervious or simply impervious soils.

5. **Capillarity:** By capillarity is meant that property which permits water to be drawn into the soil from a free water surface through the action of surface tension and in dependent of the force of gravity. Capillary flow in soils is generally associated with and upwards movement of water from the water level. Through capillary action a zone of “Capillary saturation" may exist at some considerable distance above a free water surface, especially in fine grained soils. The soil in this zone may not be completely saturated, as some air will probably remain in the void spaces and around the soil particles but it will probably attain a high degree of saturation over a period of time. Above this zone the soil may be partially saturated by capillary action.

Capillary flow- of water in soils is a complex phenomenon. However, the height to which water will be raised by the capillary[7] action is known to be primarily dependent upon the size of the void space and therefore, upon the size of the soil particles. From the standpoint of susceptibility to capillary flow of water in soils under certain conditions, the most critical condition is presumed to occur in fine silt. The eventual height of capillary rise of water may be greater in clays soils than silty soils but the upward flow of water in clays is much slower and the attainment of a high degree of saturation in a clay mass situated some distance above a free water surface will require a much longer time than which would be required for the same phenomenon to occur in the silty soils. Coarse sands and gravels are not normally subject

to the detrimental effects of capillary action, as the *light of* capillary rise in soils of the type is usually so small as to be practically negligible. Exact values of the height of capillary rise of water in any soil are not easily determined for any given set of field conditions, but this height may vary from a few inches in fine sands to 8 to 10 ft in a silty or clayey soil.

7. Shrinkage and Expansion: Many soils undergo very considerable reduction in volume as their moisture content is reduced from that existing when they are partially saturated or fully saturated. The shrinkage which occurs is the greatest in clays and other fine-grained soils. Some of these show[7] reduction in volume of 50 percent or more while passing from a saturated to an oven-dry condition. The same soils may show considerable expansion or swelling if they have been dried and their moisture content is later increased. Sand and gravels generally show little or no change in volume which change in moisture content.

Excessive shrinkage or swelling is a matter of great concern to the civil engineers for the construction of road, especially as related to the behavior of a subgrade soils used as support for a flexible or rigid base or pavement and also for the construction of dams, embankment; etc.

8. Compressibility: By compressibility is meant the property of a soil which permits it to consolidate under the action of an applied compressive load or force. Deformations caused by shearing failure are excluded from this definition. The terms "Consolidation" is applied to the compression of a saturated clay mass under a vertical load.

In their normal condition, all soils are compressible. In a general sense the compression of a saturated soil mass is assumed to be due to reduction in volume of the void spaces in the soil rather than to compression of the soil particle or of water in the pores of the soil. The amount of compression occurring in a given soil under a given set of conditions depends upon a variety of factors including the magnitude and method of application of the load and the void ratio, structure and the history' of occurrence of the soil mass concerned. The rate of compression or consolidation in saturated soils is eventually a function of permeability.

Compression of sand mass occurs very rapidly following the application of load, provided that the water can escape. Compression of sand is rarely a matter of practical concern, since all compressive deformation which is going to occur will take place during the period of load application. Deformation thus produced in sands are largely *permanent deformation* although sand massed in a compacted state may eventually attain more degree of elasticity under repeated application of loads.

Consolidation of clay and other fine-grained soils is a different matter, however, and may often be of practical concern. Such deformation occurs very slowly transferred from the water phase of the soil system to the solid phase. In thick compressive clay deposit, consolidation or settlement may continue for many years under, for example, the applied weight of a highway embankment. The settlement resulting from consolidation are rarely uniform and serious damage may result.

Elasticity: By elasticity is meant the property of a solid which will permit it to return to its original dimensions (or nearly so) after the removal of an applied load. Not soil is perfectly elastic but some soils possess elasticity to a degree which may be detrimental when they are used in the construction of subgrade for roads. Example of such soils are usually those silts and clays which contain a sizeable amount of a mica and higher percentage of colloids. Elastic silts and clays are quite common while highly organic soils such as peats may contain organic colloids and being highly compressible and somewhat elastic.

10. **Shearing Resistance:** Failures which occur in soil masses as a result of the action of loads in case of roads, embankments, dams etc. are principally shear failures. Therefore, the factors which go to make up the shearing resistance of a soil masses is commonly attributed to the existence of internal *friction and cohesion.*

A simplified explanation of these properties is most easily accomplished at considering two extremely different type of soils first, a cohesionless sand, and second, a highly cohesive clay in which the internal friction is assumed to be negligible. In a cohesionless sand, the force required to overcome shearing resistance on any plane is assumed to be given by the expression.

$S = P \tan \phi$ (Fig: 13.1)

Where S = Shearing resistance

P = normal force (stress) on the plane being considered

ϕ = angle of internal friction

The relation between normal force and shearing resist dry sand is graphically represented in Fig. 13.1

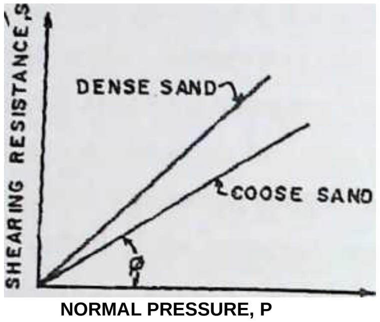


Fig. 13.1

The value of the angle of internal friction is assumed to include the factors of resistance to sliding (or rolling) of the soil particles over one another and any interlocking that may have to be overcome before a slip can occur, the value of 0 depends upon the relative density of the sand, on the grain size distribution and on the shape of the grains. It may be estimated with the aid of the Table 13.2

Table 13.2 Representative Values of ϕ for Dry Sand

Type of Sand	Values of ϕ in degrees	
	Round grains Uniform	Angular grains Well graded
Loose Sand	28.5	34.0
Dense Sand	35.0	46.0

For a dry. ϕ is primarily dependent upon density (void ratio), the lower the void ratio the higher the value of 0. The value of ϕ hither for a rough, angular sand than for smooth, very important, with ϕ being generally higher for sand which are well grades from coarse to fine. The angle of internal friction is relatively independent of moisture content for sand ϕ for a wet sand will be only slightly, if any lower than 0 for a dry sand, other conditions being the same.

It shearing resistance of dry silty sand is also given by the Eq. 1311, but the values of ϕ are somewhat smaller than those for sands. The ranger between 27° and 30° for loose silt and between 30° and 35° for dense silt.

In a saturated clay mass, it may be assumed for practical purpose, that the angle of internal friction is equal to zero and that the resistance to, sliding on any plane is equal to the cohesion, C (Usually expressed a lb per sq ft). The shearing strength of most clays decreases when their moisture content is increased and is frequently sharply reduced when their natural structure is destroyed. Factors influencing the shearing strength of cohesive soils are density, water content, loss of strength with remolding, drainage condition of clay mass when subjected to stress, variation of cohesion with pressure and variation in the angle of internal friction.

For larger majority of soils normally encountered in the field, shearing resistance is made up of both cohesion and internal friction. For these soils, the shearing resistance on any plane is frequently, although somewhat empirically, given by Coulomb's Law,

$S = P \tan \phi + c$ 13.12

and is graphically in the Fig 13.2

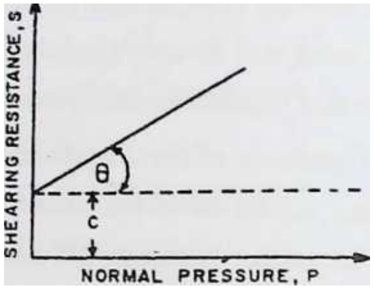


Fig. 13.2

Shearing resistance may be evaluated in the laboratory by the use of the unconfined compressive test, the direct shear test, or the triaxial compressive test. Samples any be tested in an undisturbed condition or under conditions which are similar those expected in the field. Direct measurement of the shearing resistance of the soil in its natural condition may be! made in the field through the use of loaded circular plate ' known as plate bearing test. In addition, the most efficient ' test, known as CBR (California Bearing Ratio) test had been enveloped to measure shearing resistance more or less directly in connected with the design of flexible and rigid pavements roads.

12. Soil-Moisture Relationships:

Index Properties: If the water content of a clayey soil mass is gradually reduced, the clay-water mixture passes from a

liquid, state thought a plastic state and finally into a solid state. Therefore, the limiting water content may serve as index properties useful in the classification of clays for engineering constructions like roads, levees, embankments., dams, etc.

The significance of the limiting water contents for each physical state was first suggested by A. Atterberg in 1911. Hence, these limits are commonly terms *as Atterberg Limits* and the tests required to determine them are the *Atterberg Limit Tests.* These limits are liquid limit, plastic limit and shrinkage limit.

The liquid limit (denoted b Lw) may be defined as the minimum moisture content at which the soil will flow under the application of a very mall shearing force. At this moisture contend the soil is assumed to behave practically as a liquid. The plastic limit (denoted by Pw) may be defined in general terms as the minimum moisture content at which the soil remains in a plastic condition. This limit may be further described as the lowest moisture content at which the soil can be rolled into a thread 1/8-inch diameter without crumbling.

The plasticity index of a soil is defined as the numerical difference between the liquid and plastic limits.

Plasticity Index. $Lw = Lw = Pw$ 13.13

The plasticity thus indicated the range of moisture content over which the soil is in a plastic condition. Sandy soils and silts have characteristically low plasticity index while clay soils show higher values of the plasticity index. Generally speaking, soils which are highly plastic, as indicated by high value of the Iw. are also highly compressible. It is also evident that the plasticity index is a measure of cohesiveness with a high value of the Iw indicating a high degree of cohesion. Soils which do not have a plastic limit, such as cohesionless sands, are reported as being no plastic.

Shrinkage factors are determined by evaluating certain volume weight relationships at known moisture content. The shrinkage limit (denoted by Sw) is the most important of the shrinkage factors and is defined as the maximum calculated water content at which, upon continuous drying the soil will continue to lose weight but will not decrease in volume. The same data may be used for calculating the shrinkage ratio, volumetric shrinkage and linear shrinkage when required.

One of the most important index properties of natural clay deposits is the liquidity index, defined by the following equation (Eq, 13. 14).

$$\text{Liquidity Index. If} = \frac{w-Pw}{Lw-Pw} \quad \frac{w-Pw}{Iw} \qquad 13.14$$

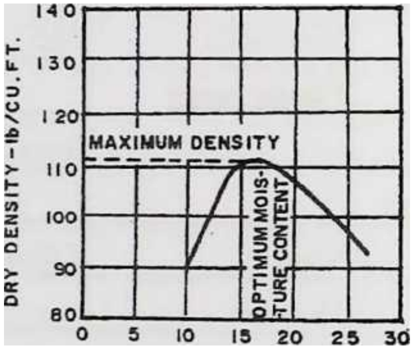
It may be seen that it is negative for soils having water contest less than the plastic limit. As the water content increase from the plastic limit to the liquid limit the value of increase from 0 to 1.0. If the water content is greater than the liquid limit, the liquidity index is greater than 1.0- consistency of a clayey soil, at least in the remolded state, may be estimated when the natural water content and the index properties are known. The relationships are illustrated i^{11} table 13.3

Table 13.3 Soil-Moisture Scale Showing Atterberg limits: Corresponding Physical States of Remolded Soil and Consistency.

Soil-Mixture Scale		Physical State when remolded	Consistency
		Liquid	Very soft
Lw	Liquid limit		Soft
		Plastic Index	
Iw		Semi Solid	Stiff
		Plastic range	
Pw	Plastic limit		Very Stiff
Sw	Shrinkage limit		
	Air dry	Solid	Extremely Stiff
	Hygroscopic	Moisture	
	Oven dry		Hard

12. Moisture-Density Relationships: Practically all soils exhibit a similar relationship between moisture content and density (dry unit weight) when subjected to dynamic compaction. That is practically every soil has an optimum moisture content at which the soil attains maximum density under a given comp active effort. This fact, which was first state by R R. Proctor forms the basis modern construction process used in the formation of highway, airport and runway subgrades, bases, and embankments, earthen dams, levees, landfills and other similar structures. In the laboratory, a dynamic compaction is achieved by the use of a freely falling weight impinge upon a confined soil mass (by the

Proctor apparatus) : in the field, similar compactor is secured through the use of rollers or vibratory compactors applied to relatively thin layers of soil during the construction process In the Fig. 13.3 is shown the relationship between moisture and density for a typical soil subjected to dynamic compactions The ordinate of the peak of the moisture-density curve is the *maximum optimum density* or 100 percent compaction and the abscissa is the moisture *content*, The curve in the fig. 133 was obtained in the laboratory.

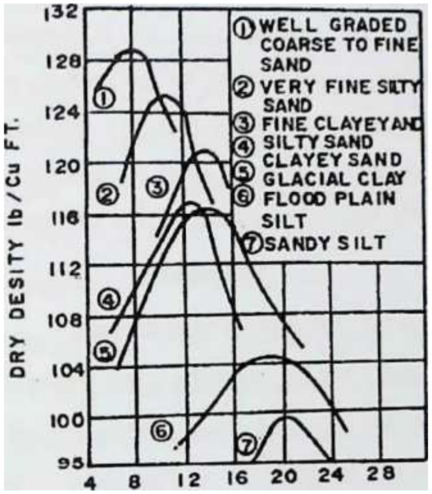


MOISTURE CONTENT-PER CENT

Fig. 13.3

In the field and attempt is usually made to maintain the soil at the optimum moisture content and to bring the soil to the maximum density or some other specified percentage thereof. The degree of compaction of soil in the field is determined by measuring the weight of the soil sample, the volume occupied by the sample and the moisture content. From these data the dry density in the field can be computed. The ratio between this value and that of the maximum density (at 100

percent compaction) from the moisture density curve in the laboratory on the same sample multiplied by 100 is defined as the percent compaction.



MOISTURE CONTENT-PER CENT

Fig. 13-4

contents which are somewhat less than optimum

Moisture-density relationship for seven different types of soils is shown in the Fig 13.4. It is apparent that the different soils react somewhat differently to compaction at moisture contents which are somewhat less than optimum.

13. **Bearing Capacity:** The being capacity of a soil may be defined as its capacity to bear the load a structure constructed on it without yielding this capacity is very important in designing the foundation of structures. The factors influencing the bearing capacity of soil are the density, specific gravity, grain size distribution void ratio and Permeability. For designing a sound foundation of a structure.

the bearing capacity and the settlement of soils are very important. The bearing capacity of soils ranges between 0 2 to 3.0 tons per sq ft. Soils with bearing capacity less than 1/2 ton per sq ft are not suitable for good foundation.

13.5 Remarks: To utilize soil as a successful engineering material for the construction of subgrade and bases of roads airports and runways, earthen dams, embankments, landfills levees and other structures and to design good foundations, should be determined very' carefully in the laboratory.

Question

1. Discuss soil as an engineering material.
2. Define soil and give its classification based on grain size
3. What type of soil do you recommend for a highway subgrade? Why? Explain.
4. Explain the basic properties of soils that are looked for in designing good foundation for a structure.
5. Write explanatory notes on any five of the following: (a) Loam (b) Peat, (c) Porosity (d) Relative density (e) Capillarity of soil (f) Index properties of soils (g) Bearing capacity of soils.

CHAPTER-FOURTEEN

KOAI) MATERIALS

14.1 Introduction: Road materials are of various types depending upon the nature of roads such as earth or gravel roads, macadam roads bituminous roads and concrete roads. Good and durable materials are required for the construction of good roads. The following are the various types of road materials: soils, bricks, natural stones, sands, cement, aggregates, steels, concrete and bituminous materials.

A road consists of two parts: (1) lower part called the subgrade or formation and (2) upper part called the pavement or crust (Fig. 14.1) The subgrade serves as the foundation for the pavement. Subgrade is the natural earth surface in its final shape prepared for the pavement to be laid on it. The subgrade should be compact and strong enough to bear the entire traffic load which it receives through the pavement. The only material required for the subgrade is the suitable natural soil.

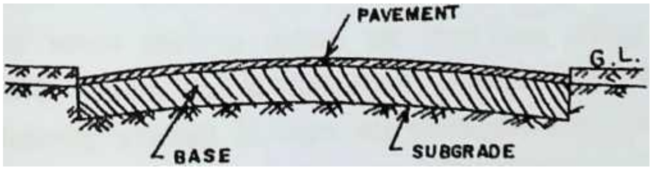


Fig. ^{141}

Pavement is the hard crust placed on the subgrade and serves the following purposes: (a) to distribute the traffic load uniformly over the subgrade (b) to protect the subgrade from the adverse effects of weather and (0 to prov.de a smooth riding surface.

Pavement again consists of the following: (i) *Soling* (lower most layer of the pavement) (ii) Base (Mid-layer of the pavement) and (iii) *Surfacing or carpeting* Uppermost layer of the pavement.

Soling Materials: The main function of the soling materials is to distribute uniformly the total traffic load and the dead load of the base and the surfacing materials over to subgrade. The materials used are well burnt bricks laid flat or on the edge in various forms of brick-bonds, big size stones rubbles and over-burnt brick bats (well rammed).

Base Materials: The base materials should be sufficiently strong to withstand the traffic load and to resist the adverse effects of the weather. The common materials used are the natural stones (gravels, pebbles etc.) artificial stones (brick khoa. machine made stones etc.) and synthetic aggregates.

Surfacing Materials: Surfacing materials are binding materials which act as binders for base materials to impart strength and stability to the road structure as a hole. The surfacing materials impart smooth and impervious coating which protects the main road structure from the abrasion due to traffic and from the action of rain water and other destructive agents. Surfacing is of mainly two types: bituminous *surfacing* (in case of flexible pavement) and concrete surfacing (in case of rigid pavement).

Of these various types of roads materials, the properties of natural stones, bricks, cement, steel, concrete and soils have been discussed in the preceding chapters. Here only the properties of bituminous materials and stone metal will he dealt with.

14.2 Bituminous Materials: Bituminous material may be generally defined as substances consisting primary of bitumen or containing a large percentage of bitumen. Bitumen in turn, may be said to be a complex organic material. This organic material may occur naturally or it may be artificially made during the distillation of petroleum. Bituminous materials are frequently divided on the basis of their consistency into liquid, semi liquid and solid materials.

Bituminous materials are principally of value to the road engineers because of their binding power and their waterproofing properties. They are now widely used in the construction of large number of different types of wearing surfaces & bases ranging in application from low-cost light- traffic roads to high type bituminous pavement intended to carry extremely heavy volume of traffic.

For the purpose of simplification, bituminous materials used in road construction may be divided as follows:

(1) Asphalts

(2) Tars

Asphalts are classed again as (a) Natural Asphalts and (b) Petroleum Asphalts.

Natural Asphalts: These asphalts occur in a pure or nearly pure state in nature. If associated with higher percentage of mineral matter they are termed as *rock asphalts or lake asphalts* extensive asphalts occur in nature.

Petroleum Asphalts: Petroleum asphalts are divided from the fractional distillation of asphaltic or semi asphaltic petroleum’s. These are further subdivided into the following categories:

(i) **Steam Refined Asphalts:** This is prepared by steam distillation of crude petroleum at 900°F, the more volatile constituents are distilled off and asphalt is left as residue of desired consistency.

(ii) **Straight, Run-Asphalt:** When the crude petroleum is distilled of at about 700°F. instead of 900°F. as done in case of steam refined asphalt the residue contains a certain quantity of volatile oils. The residue becomes solid when cooled and the product is called *straight-run asphalt* Trade names are *Mexphalt* 80/100 and *Spramex* 180/200.

(iii) **Air Blown Asphalt:** It is prepared by refining of the steam distillation residue by blowing air at a high temperature. The characteristics of asphalt are changed due to the occurrence of certain chemical changes. It is less susceptible to temperature change and claimed to be weather resistant that the steam refined asphalt. Air blown asphalt is also called as *Oxidized Asphalt.* Trade name is *Mexphalt* R115/15.

(iv) **Cut Back Asphalt:** This is asphalt dissolved in a volatile liquid such as naphtha, petroleum, benzo etc. Being in al liquid form it can be applied cold to the road surface. On exposure, the volatile solvent evaporates, leaving the asphalt residue on the surface. Cut back asphalts also used to floors and other surface for the prevention of damp or for filling up cracks.

(v) **Asphaltic Cement:** When air is blown through asphalt at high temperature the bitumen becomes partly oxidized and the thick plastic liquid thus formed is used as a cement paste. Asphaltic cement is highly resistant to atmospheric variations and is also very elastic. It is also used in the manufacture of certain paint enamels. This is also a very good waterproofing material and is often used for filling expansion joints in concrete works.

(vi) **Cracked Residue Asphalt:** It is obtained as residue from the cracking of petroleum. Cracking is accomplished by heating crude petroleum to a high temperature of about 1100°F under a pressure of 50 atmosphere. It is characterized by rapid fall in viscosity with increases in temperature. It is less weather resistant and durable. Trade name is *Mexphalt Dh* 70/75.

(vii) **Asphaltic Emulsions:** Asphalt is mixed with water in the presence of certain emulsifying agents (emulsifiers or stabilizers) like soap etc. If does not dissolve but its fine particles remain suspended in water in the form of an emulsion, the principal objective of emulsification its to liquid asphalt to allow its application at normal temperature without applying heat. The emulsion breaks down when mixed with aggregate the water evaporates and the asphalt remains as thin film on the surface of the aggregates. The water simply serves as a temporary transporting medium. Three principal classes of asphalt emulsions are used for road constructions. These are called *Quick Setting. Medium* Setting and *Slow Setting,* depending upon the speed at which the emulsion breaks down placed in contact with aggregates, asphaltic emulsions offer certain advantages that it can be used with moist aggregates or in wet weather.

Tars: May be defined as a substance obtained by the condensation of distillates resulting from the destructive distillation of organic materials. Many organic substances (coal, oil etc.) may be treated to yield tars. However, those tar product which are of significance in the road construction are the following:

(a) Gas-Works Coal Tar: This is a coal tar produced gas by product in the manufacture of illuminating gas from bituminous coal.

(b) Coke-Oven Coal Tar: This is a coal tar produced as a byproduct in the manufacturing process of coke from bituminous coal.

(c) Water Gas Tar: This is a tar produced by cracking oil vapor in the manufacture of carbureted water gas.

These various tars are further refined and may then be used alone or in combination with one another to produce the various grades of road tars which range in consistency from semi-liquid or very viscus liquid materials to very thin highly volatile liquids.

Pitch: The common type of pitch is the black or dark brown residue which is left behind during the distillation of tars. It is solid at ordinary^ temperatures and is used in roads as an inferior substitute for asphalt.

14.3 Comparison Between Asphalt and Tars: Asphalts and tars are somewhat similar in appearance and general composition they are produced by greatly dissimilar processes and differ sharply in certain properties which are of importance in road works. Generally speaking, tars are more susceptible to temperature change than asphalts of similar grade. Tars are toxic in nature and possess more free carbon than do asphalts and they harden more rapidly when exposed to the air aft^{er} being incorporated into a wearing surface or pavement. These and other differences in properties and behavior have lead the selective use of tars and asphalts in road construction other purposes.

14.4 Testing of Bituminous Materials: A large number of laboratory tests to determine specific gravity ductility, water content, viscosity. Hash point, solubility loss on heating and deducibility arc carried out on bituminous materials for the purpose of ascertaining is the suitability to use in road construction as per specifications. These tests are conducted in accordance with procedures established by the AASHO and ASTM and hence beyond the scope of this.

14.5 Stone Metal (Stone Aggregate): Stone metals are nothing but the building stones which have already been discussed in Chapter 2. here only those properties which are essential with respect of use them as road materials will be explained. In order to resist successfully weathering, abrasion and fracture due to stresses developed by the vehicular traffic, the stone metals should be tough, strong, hard and durable. They should also possess good cementation property[7] so that it may retain a well-locked surface lender the repeated shocks of traffic loads, the various types of stone metals are stone chips, boulders, gravels and pebbles.

14.6 Test on Stone Metals: Various laboratory tests are performed on stone metals to determine their suitability' to use as road metals. These are abrasion test, *attrition test, crushing test, absorption of water, cementation test and voids test.* All these tests are carried out by following the standard procedures specified by the AASHO and ASTM. In addition to these laboratory tests, the following field tests are performed on stone metals.

Appearance Test: Good stone metals should be clean bright, angular and crystalline in appearance. They should from earthy and organic matter.

Hardness Test: Hardness in tested by scratching stones with the sharp point of a pen-knife. If it produces a deep scratch, the stone is said to be soft and is not recommended to use it as a road material.

Brittleness Test: Brittleness is tested by strickling stones with a hammer of about halt pound in weight. If the stone breaks readily into several pieces, it is said to be brittle and is not suitable as a road material.

Questions

1. Discuss briefly the various materials used for a road structure with special reference to the properties and functions played by each.
2. What are bituminous materials? What purpose do they serve in road construction? What purpose do they serve in road construction? Name the various types of road materials.
3. Compare between the following:
   a) Natural asphalt and cut back asphalt
   b) Steam-refined asphalt and Air blown asphalt
   c) Asphaltic cements and Asphaltic emulsions
   d) Bitumen and Pitch

5. Compare between asphalt and tar as road materials.
   Explain the various types of tars.
6. Write explanatory notes on the following:
   (a) Subgrade (b) Petroleum asphalt (c) Stone metals (d) Test on bituminous materials (e) Field tests on stone metals.

CHAPTER-FEFTEEN

TIMBER

15,1 Introduction: Any wood which is used in engineering construction is termed as *timber.* Timber has been one of the primary materials of engineering constructions since the earliest times. Despite of the fact that it has been largely superseded by steel and concrete in certain classes of structures, the utilization of timber for structural and other commercial purposes is very large.

A part from its fuel value, its use is almost indispensable in engineering construction of structures temporarily during their construction and as permanent component parts of the completed structures.

Timber has several distinctive advantages over other materials of constructions. They are as follows:

1. Timber can be easily worked with tools of any size and can take good polish.
2. It is comparatively stronger than other materials common!} used when considered in proportion to weight.
3. It can be using both load bearing and non-load bearing members is structures and structural connections can be made Very easily.
4. Timber construction is very economic because even a small Piece can be utilized in one way or the other and therefore, minimizing waste.
5. Its use for making furniture, sport goods and other decorative and attractive articles of artistic design is quite important an is accepted universally without doubt.

6. Timber has low thermal conductivity, high electrical resistance and good sound proofing property. All these Timber have always contributed to its Importance as a very useful building material.

7. Timber structures are unquestionably durable it properly treated and carefully protected from direct exposure to weather and alternate wet and dry conditions by applying preservatives.
8. Various types of timber products, like plywood, veneers, laminated boards and other reconstructed woods are mostly used nowadays for their lightness and beauty.
9. Another important feature of timber which is worth mentioning is that it has a great resale value. The discarded timber can be utilized as fuel. Even saw dust can be utilized to make reconstructed woods like hard boards, light weight planks, partex boards etc.

Engineers are the principal users of timbers for structural purposes and in order that they may use it in the best possible ways it is necessary that the engineers should have some basic knowledge of the classes of their growth and structure in order to understand the fundamentals of the physical and mechanical properties of timbers.

Timber Trees. Growth and Structural Characteristics: -All trees are primarily divided into two botanical groups cording to their manner of growth. These are: (D Exogenous trees or Exogen’s and (b) Endogenous trees or Endogens. Exogenous trees or exogen’s increase in diameter by the annual formation between the old wood and the bark of a layer of new wood which envelops the entire living portion of

the tree. Practically all classes of commercially important timbers are derived from trees of this group.

Endogenous trees or endogens grow both diametrically and longitudinally, principally the latter by the addition of new wood fiber intermingling with the old. Most endogens are small plants like paddy, corn sugarcane, wheat, rye and Jute but others, like the bamboo, cane and the palms have some value as a source of engineering materials.

Exogenous Trees: They are mainly two types *(a)* Conifers (needle leaved trees) and (b) Board leaved trees, conifers form a portion of important timber trees, comprising principally the pines, fur, kail, cedar, chirr and deodar, they are usually light and soft, and hence, often called 'softwoods' and are for the most part 'evergreens' (trees which do not shed their leaves until new ones have grown). Timber from conifers (evergreen) is used mainly for sport goods, furniture, interior finishing and cabinet works.

Broad leaved trees comprise many verities o teak (segun) sal. gorjan, shisham, mahogany, chambel. telsu nageshwar and many other species of lesser commercial importance. They are usually heavy and hard, strong flexible and capable or resisting tensile, compressive and shear stresses quite well, hence often called 'hardwoods'. As a rule, they are deciduous (trees which shed their leaves each winter), although some of the broad-leaved trees are evergreen in certain climates. Most of the timber used by engineers in engineering constructions is derived from deciduous trees.

Endogenous Trees: This group is confined largel) to tiopical and semitropical regions like Bangladesh, India, Burma etc. The main endogens are palms, coconut, betel nut, date, bamboo and cane. The palms, coconut. betelnut and date trees are locally used for making piles, battens, posts etc. and also used as fuel but have practically no other commercial uses. The bamboo grows with extreme rapidity but requires years to harden after its growth is attained. The bamboo grows abundantly all over Bangladesh and also in Japan. Thailand and China. It is used structurally to a considerable extent.

Timber

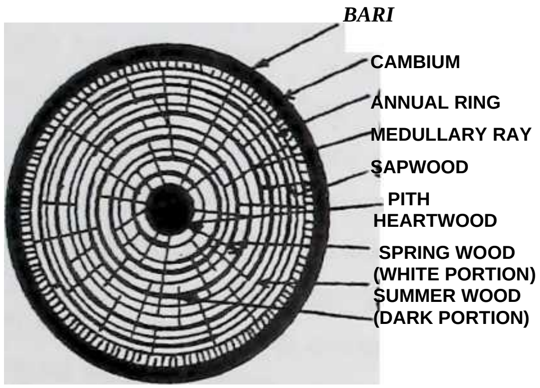


Fig. 15.1

15.3 Exogenous Growth of Wood: The section of any exogenous tree Exhibits a central portion called pith (Fig. 15.1). It is black, brown or gray in color, usually of small diameter and does not increase in size after the first few years.

Outside the pith the wood appears in concentric zones or rings of annual Growth. The demarcation between the rings, when evident, is because of The difference in structure

between the wood slowly formed towards the end of one season and that rapidly formed in the succeeding spring. The outer most portion or periphery of the section is formed by material of variable and very complex structure, called the *bark.*

Wood Structure: In the broadest interpretation, wood may be considered to be made up of two chief structural elements *cells* and *vessels.* The elemental cells are technically sub-divided as *tracheid's, wood fibers, medullary rays* and *parenchyma.* Although there is considerable difference in form and functions between these various subdivisions such distinctions are beyond the scope of this discussion and all these elements will be here referred to simply as cells. In cross section these cells are roughly polygonal and most commonly appear to be rectangular with rounded corners. The cells are formed of organic tissues with a cavity and a nucleus in it the nucleus forms the living part of cell and constitutes what is termed as *protoplasm.*

The cells perform the following functions:

1. To conduct the liquid food material from the root of the tree to the branches and leaves and vice-versa.
2. To store the materials and other substances like oils, Gus and resins.
3. To reproduce new cells in the living process, showing the growth of a tree.
4. To impart structural characteristics to wood in general by their mutual binding and interlocking nature of growth. In most timber a very large proportion of these cells will be formed with the longitudinal axes approximately parallel to the trunk of the tree. These are termed as *vertical cells or fiber*

cells. These vertical cells are crossed in a radial direction by a different class of cells called *radial cells or medullary rays* extending from the center of the trunk to the outside. The medullar}' rays maintain communication between the interior and the outside in transmission and storage of food and other materials. In addition, they bind the longitudinal fibers to gather and are mainly responsible for their combined strength. If these cells are cut during sawing of wood, the strength of timber is seriously affected. The cells which perform the functions of storage of food and other materials are termed as *parenchyma cells.*

There are other types of cells also which act as storages for gums and resins. In a combination they act as intercellular canals and ducts in which these substances are deposited. They run both vertically and radially Certain trees have latex canals. Such intra-cellular canals or ducts for gums resins and latex are principally present only in certain species of trees. Cell walls consist essentially of cellulose in the form of fibrils which are long spiral strands, some lignin is also present. The walls are an isotropic but are cemented together by a layer of isotropic substance essentially *lignin* called the *middle lamina.* The cell walls are perforated with recesses, called pits, whose function is to make possible the flow of sap between cells through the middle lamina. Mans of the pits occur in pairs, the recesses being opposite each other in adjacent cells.

The vessel is formed by the fusion of member of cells are in the form of open tubes often, extending the entire of tree. the vessels make the timber porous and hence reduce the strength.

Animal Growth Rings: Spring and Summer Wood: The growth of all exogenous trees is a process of formation of new wood fiber between the old wood add the inner bark This place of formation is a thin layer called the cambium, which in invisible without a microscope and in which all growth in thickness of the bark and wood takes place. Owing to the inability of trees to sustain their physiological activities indefinitely and the effect of the alteration of seasons in all temperate zones the growth is intermittent and the *zones* (rings) of growth in general correspond to the annual periods, known as annual rings. The succeeding rings of growth may easily be distinguished from one another in most species because of the different structure of wood formed rapidly in the spring and that more slowly in the summer. No wood is added during the winter months.

The rate of growth of trees is quite variable not only in different species, but even for different specimens of the same species. This means that the growth rings are of variable thickness of the ring is not uniform circumferentially because of unequal acceleration of the growth on different sides: thus, the section often becomes oval and even if circular, the pith is eccentric.

Sapwood and Heartwood: As the process of formation of annual rings of new wood adds layer after layer of vigorous healthy tissue over that previously formed, the old tissue gradually ceases to take, active part in the physiological activities of the trees, loses its protoplasmic contents and dies. Decay does not usually follow immediately, however, and the dead wood continues sound and provides mechanical support for the tree.

The living elements of the tree are called sapwood and the dead elements, "heartwood”. There is usually a sharp |line of demarcation between the sapwood and heart wood, although the vigor of living wood decreases progressively from the cambium layer inward, the proportion of sapwood varies considerably in different species and also between individuals of the same species. All young trees show' a higher percentage of sap wood then old trees of the same species. The proportion of sapwood in general varies from 20 to 60 percent of the total contents of wood.

The distinction in colour between sapwood and heart-wood, which is the characteristic of most woods, is due to the darkening of the dead wood by the presence of infiltrated pigments, gums, resins, tasins latex etc. Sap wood is iron in plant food material such as sugar, starch and albumen which is in a putrescible (decomposable) form and sets up decay in wood by the process of fermentation. It attracts fungus and insects which reduce the life of the timber. Sapwood contains proportionately higher percentage of moisture than heartwood and has an effect in reducing its strength and durability. Sapwood is lighter in colour than heartwood. Generally, heartwood is darker in colour, has more compact annual rings and is denser and closer grained in texture than sapwood. The cells of heartwood have stronger cell walls and contain substances like *tannins. resins, gums* and *latex* which are poisonous to fungus and other insects. These materials Impart natural immunity and durability of heartwood. Heartwood is heavier and less permeable to moisture than sapwood.

In general, the heartwood is more highly valued than the sapwood of the same variety. This is because the heartwood offers greater resistance to decay than the sapwood.

15.4 Felling of Timber Trees: To get timber, a living tree is cut and subsequently treated to impart durability and strength to green wood. The cutting of a tree is done in a systematic manner and the process is termed is termed as "Felling" Trees should be felled only' after they fully' matured, so that maximum wood would be obtained from a tree. Immature trees contain too large a proportion of sapwood which has less commercial value. Different trees have different periods when they attain their stage of maturity. Usually, it varies from 50 to 150 years depending upon the species of the tree. The proper season for felling trees is an important consideration. It can be recalled that in spring and in late summer, the wood cells are very active and the sapwood contains great amount of moisture and sap. The starches, sugars and albumen contents of sap bring about the decay of wood very quickly with fungal growth. During winter and early part of summer, the growth of tree is dull and the cambium layer is inactive. The sap and the moisture content are also less. Therefore, this pail of the year from October to March is favorable for felling trees.

In case of trees which contain a large proportion of water and in countries where there are no distinct climatic variations, sometimes the branches are cut and the bark is stiffed off one season earlier than actual felling operation. To avoid waste, trees should be felled as near as the ground as possible. They should be tied with the aid of anchor ropes and carefully brought to the ground after cutting by axes or saws. Trees standing on slopes should fall uphill. In case of trees like teak and other varieties oi the same species having natural resistance to fungi, the common practice is to cut a groove round the trunk of the trees to be felled 2 to 3 inch in size and at about 6 to 9 inches from the ground. This is done about 2 to 3 years before felling the tree and is known as *girdling*. By this, the moisture gradually evaporates and the shrinkage and warping at the time of seasoning is much less.

15.5 Conversion of Felled Timber Trees: The preparation of timber from felled trees by stimming off branches, removing the bark, cutting and sawing to convert it into marketable forms is called conversion. The principal market forms into which timber is converted are as follow.

1. LOG. A log is a trunk of a felled tree and the branches stimmed off.
2. LUMBER: Lumber is the general term applied to cut sections of a log manufactured by sawing.
3. BALK OR SQUARED TIMBER: This is obtained by roughly sugaring the log.
4. PLANK: A plank is a parallel sided piece of timber roughly 8 to 15 inch wide. 1 to 3 inch thick and 8 to 20 ft long
5. DEAL: A deal is a plank 2 to 3 inch thick and less than 9 inch wide.
6. BATTEN: A batten is a plank 1 $^1/_2$ to 2 inch thick and over 9 inch wide
7. BOARD: A board is a plank less than 2 inch thick and over 6 inch wide

SCANTLINGS: Scantlings are miscellaneous cut pieces of timber.

9, POLES: Poles arc long round logs from any defects (knots etc.) and greatest diameter not exceeding 8 inches.

15,6 Water Soaking and Storage of Logs: The bark of a timber tree affords natural protection. The felled trees after the removal of the bark (logs) is particularly liable tube attached by fungi. The logs are therefore, stored under water in log ponds (may be natural or artificial) out of contact with air. Water soaking dilutes the sap and partly eliminates it in solution.

It can be recalled that only a particular part of the year is suitable or felling timber trees and since saw mill works and other conversion processes are to run for all the year round, some sort of storage of the logs in essential. There are mainly two types of storage: (I) wet storage and (2) dry storage. The method of wet storage in log ponds has already been mentioned. The dry storage of logs is generally done on a specially prepared raised floor (well drained). Water is sprinkled with the aid of sprays from a pipe system to keep the logs in a wet condition. For the manufacture of matches and veneers, logs of uniform dryness are essential. They should be storied in wet conditions (in log ponds) for a long period to facilitate the process of peeling and slicing.

15.7 Sawing of Timber: The conversion of logs into various market forms of timber is generally done by sawing. The structure of wood gives rise to variations in the characteristics °F timber depending upon the angle which the plane sawing or cutting makes with the two systems of cells (vertical cells and medullary rays). The following are (he principal method of sawing logs:

1. **Ordinary Sawing or Cross Sawing:** When the sawing is done approximately perpendicular to the tree, it is said to be *ordinary sawing or cross sawing.* The surface of the planks sawn by this method is termed as *end grain cut (sawn) surface* (Fig. 15.2). This is most common method of sawing used tin our county. This is most economical and quickest method of swing logs. Planks sawn by this method are liable to warping and twisting due to shrinkage because the central portion of the plank is of heartwood and its ends are sap woods and the two portions of the plank shrink unequally.

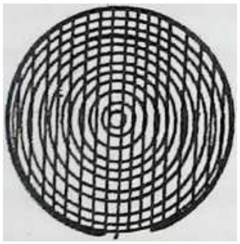


Fig. 15.2

2. Radial or Rift Sawing and Tangential or Slash Sawing: When the log is sawn parallel to medullary rays and perpendicular to the annual rings, the method is said to be *radial or rift* sawing. Radial or rift sawn lumber is known as *edge grain lumber (Fig.* 15.3)

When the log is sawn perpendicular to the medullary rays and more or less tangential to the annual rings, the method is said to be tangential or slash sawing tangential or slash sawn lumber is also called flat grain Lumber (Fig. 15.3).

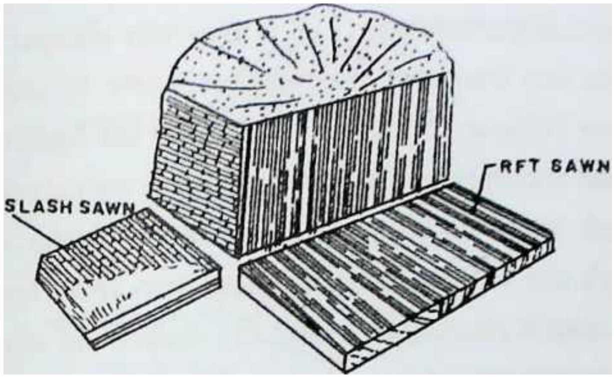


Fig. 15.3

Usually, rift cut lumber is not sawn strictly parallel with the medullary ras and often in slash sawn lumber, the material near the edges is from being tangent to the annual rings. It is a commercial practice to call lumber rift sawn with the annual rings from 45 to 90° with the surface is *called slash or tangential saw.*

The rift sawn lumber has the following principal advantages as compared with slash or tangential sawn lumber:

(1) it shrinks and swells less in width (2) it twists and cups less; (3) it does not split so badly in seasoning and in use (4) it wears more evenly (5) types of figures coming from pronounced rays, interlocked grain, and wavy grains are brought out conspicuously (6) Width of sapwood in a plank or board depends on width of sapwood in the log and (7) it holds paints, and varnishes better.

The slash or tangential sawn lumber, on the other hand, has the following advantages (1) it is generally cheaper because it requires less time and involves less waste in sawing (2) it does not collapse so easily in drying (3) the figure resulting from the annual rings brought out conspicuously (4) circular or oval knots occurring in slash sawn planks affect the strength and surface appearance less than spike knots which may occur in slash sawn planks (5) shakes and other defects when present extend through fewer boards.

All planks subject to surface wear as flooring should be rift sawn. Rift sawn boards may often be obtained most economically by resawing large dimension stock.

2. Quarter Sawing: Quarter sawing is the term generally applied to the method of sawing timber first sawing the logs in quadrants of circles. Quarter sawing are of the following types (a) simple or plain sawing (b) Radial or rift sawing.

In simple quarter sawing, the central portion is correctly radial sawn and the two side portions of the quarter piece are partly radial and partly tangential (Fig 15.4). This is the easier method but the planks sawn, except the central 2 to 3 planks are not very strong.

In radial or rift quarter sawing, the wood is sawn parallel the medullary rays and perpendicular to annual rings. The timber thus sawn shrinks and warps less. This is a costly method but produces timber which is better suited for high class works- The various types of rift quarter sawing are shown in 15.4. Wastage is greater in this method of rift quarter sawing.

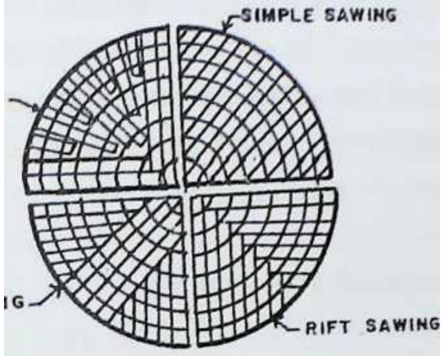
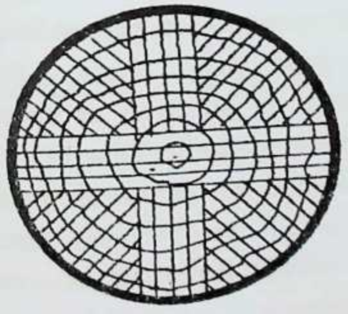
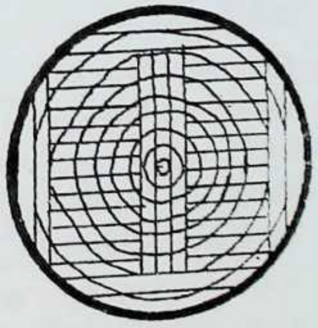


Fig. 15.4

3. Combination Sawing: In this method the central portion is sawn at right angles by the ordinary[7] sawing method to get the best advantage of the method while the outer quadrants are again sawn by the method of radial or rift sawing. Different types of combination sawing is shown in Fig. 15.5 The central slices yield timber of maximum strength because the medullary rays are not cut.



(a)



(a)

15.**Wastage of Timber is Sawing:** In the Conversion of timber by sawing there is a great wastage. In general, when a log is sawn only 50to 65 percent of its contents are actually converted into useful timber and the rest is waste. The waste of a lot due to sawing may approximately by estimated as follows:

Bark	5 percent
Side slabs and trimmings	18 percent
Saw dust	12 percent
Loss of moisture	5 Percent
	Total 40 Per cent

These figures vary to a great extent depending upon the types of sawing adopted and the quality of timber.

15.9 Moisture Content in Timber: Logs contain large amount of water in the form of moisture. As the strength, durability and other properties of timber depend upon the moisture content in it, it is necessary to know how much moisture is present in the timber.

The moisture content of a wood sample is determined from thin pieces, whose broad surfaces are perpendicular to the grain of the wood or from wood chips. After careful weighting, these are heated in an oven at approximately 100 C (212°F) until there is no further loss of weight. The sample is taken out, cooled at room temperature and weighted again. The loss of weight (moisture content) divided by the oven dry weight expressed as percentage is known as the *moisture content.*

$$\text{Moisture Content (percent} = \frac{\text{Loss of wt. of the sample}}{\text{wt. of oven dry sample}} \times 100 \quad (15.1)$$

15.10 Weight and Measurement of Timber: The specific gravity of the actual wood fiber of all species is about 1.5. so, it is apparent that no wood would float in water. Two factors chiefly influence the weight of wood formed a succeeding period of growth, first the proportion of summer wood formed and second the size and the number of pores present in the early wood. The first is the controlling factor in most conifers. The weight of wood is itself an important quality in many of structural uses. Weight is also closely related to strength.

The timber usually is measured in volume. The following are the various methods of measurement of timber:

(1) If $d_1$and d_2 are the two-end diameter of the log in inch and 1 is the length of the same in ft. the volume of the log is given by the following expression:

$$\text{Volume in cu ft} = 0.2618 \frac{(d_{\}}\, 2 + d_2 2 + d_1 d_2)}{144} \times 1 \quad (15.2),$$

(2) The volume also can be determined by measuring the quarter girth in ft at the middle (g_2) and at the two ends (g_1 and g_3) of the log as follows:

$$\text{Volume in cu ft} = {}^1/_3\,(g_1+g_2+g_3) \times 1 \qquad \textbf{(15.3)}$$

where I is the length of the log in ft.

(3) The volume can also be determined by the following formula:

$$\text{Volume in cu ft} = g^2 \times 1 \quad (15.4)$$

where, g is quarter girth at the mid-length of the login and is the length of the log in ft.

All these measurements are approximate, because e crossection of the log is not a regular geometrical figure.

Equilibrium Moisture Content: This is a stage of equilibrium when there is no interchange of moisture between the wood and the air, i.e., when the wood and the atmosphere become equally humid. 1 his is very important in case of seasoning timber. Because in the process of seasoning the wood is dried to a moisture content which is in equilibrium with the local atmospheric conditions.

11 Defects in Timber: A defect is any irregularity or imperfection in or on wood which may lower its strength, durability and utility. Defects are usually two types (1) Natural defects due to abnormal growth and rupture of tissues (2) Artificial defects arising due to conversion and uses.

Natural Defects: Natural defects are (a) knots (b) twisted fibers (c) shakes (d) upsets (e) rind galls (also known as burls or excrescences) (f) foxiness (g) compression wood (h) pitch pockets.

Knots: Knots constitute one the most common natural defects in ber: they originate in timber cut from the stem or branches of tree ause of the encasement of a limb, either living or dead, by the cessive annual layers of wood, hi most structural timber, limbs ginate at the pith of the stem and the knots found deep in a log are refore small, increasing in size towards the bark. Knots are of various es. If the knot retains its place in the piece on cutting and if it is as d as the wood itself, it is called a sound *knot*- An unsound knot is not ard as the wood in which it is situated

A pin *knot is a* sound knot less than $^{1}/_{2}$ inch in diameter. A

stander knot is a sound knot not over 1$^{1}/_{2}$-inch diameter.

Large knot are those having diameter more than 1$^{1}/_{2}$-inch.

In case of conifers, majority of the limbs die after a certain time and the portion of the dead limb is subsequently encased by the growing stem, there is no intimate connection between the new stem wood and dead wood of the limb and a plank cut so as in erpet this portion of the log will contain an encased *knot. \ Pith knot* is one which is located in the pith of the stem. A *spike knot* is one sawn in length wise direction. *K rotten knot* is one which has been decomposed.

Knots make sawing and planning more difficult. Timer generally splits when a nail or a spike is driven through a knot and hence it is considered to be a very serious defect in a railway sleeper, if found near rail seats where spikes are driven.

In structural beams the effect of knot on the bending strength largely depends upon their location. Knots in the tension side of the beam near the point of maximums tress will have a significant effect on the maximum load the beam will sustain, whereas knots on the compression side are somewhat less serious. Knots in any position have little effect on shear. Stiffness of beams is not greatly affected by knots.

In long columns in which stiffness is the controlling factor knot are not of importance. In short or intermediate columns, the reduction in strength caused by knots is approximately proportional to the size of the knot, although large knots hate a somewhat proportionately greater effect than small ones. Sound knots actually increase hardness and strength in compression perpendicular to grain and are objectional le regard to these properties only to the extent that they cause non-uniform wear or a non- uniform distribution of pressure at contact surfaces. Knots, however are harder to work will than the surrounding wood, may project from the surface when shrinkage occurs and arc a cause of twisting.

Knots found in timber are illustrated in fig. 15.6

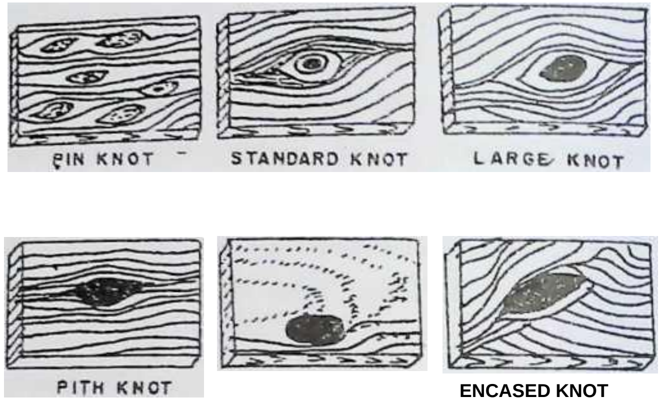


Fig. 15.6

(B) Twisted Fibers: This detect is developed in a living by the prevailing wind which tend to turn the free constantly in a particular direction causing its fibers to- get twisted longitudinally (fig. 15 7). In sawing planks from such a tree, the fibers are cut through which reduces the strength of the planks.

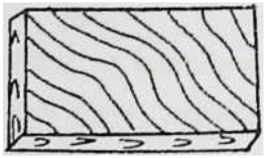


FIG. 15.7 TWISTED FIBRES

(C) Shakes: Shakes arc splits, or cracks in timber which the separation of the wood tissues, shakes are caused by the action of wind on trees and by the shrinkage when it dries, Shakes are of various types. When the separation occurs between the annual ring, it is termed as ring *shake.* Cracks extending between the two faces of a *prece* of a lumber are called *through shakes.* Shakes extending radially from the periphery towards the Centre are known as *radial shakes.* If the split is curved along annual rings, it is known as cup shakes. If a crack of spilt radiates from the Centre (pith) and extends in direction of the medullary rays it is called *heart shake.* If these are more than one such crack of split, radiating from the pith it is called a star *shake.* They are found mostly in trees past maturity but sometimes they may be caused by quick drying of the central pail of the tree if a tree is nearing maturity is felled and left unbraked for a long time *A check* is a lengthwise separation of the wood between two consecutive annual rings.

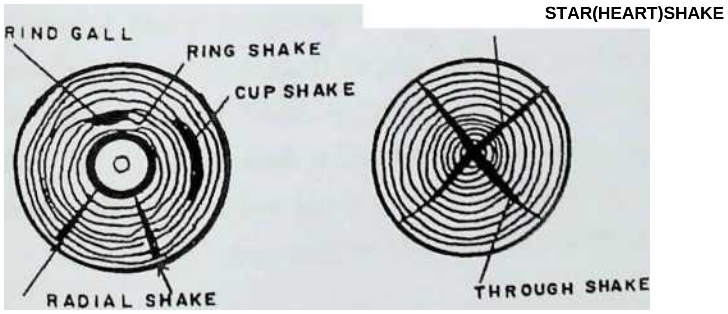
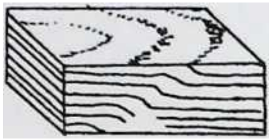


Fig. 15.8

Shakes found in wood are illustrated in Fig. 15.8

(D) Upsets: These defects are caused in limber trees in which the fibers have been injured by shock of crushing usually during their growth (fig. 15.9)



Hg. 15.9 UPSETS

(E) Rind Galls, **Burs or Excrescence:** Swellings are caused by the growth of layers over the remnant of an imperfectly cut branch which are termed as rind *galls, or burs or excrescence* (Fig. 15.8) They are particular} formed if a tree gets an injury when it is young. An injury to a young growing tree upsets its growth and leaves behind a shock which gradually swells and forms rind galls.

(F) Foxiness: This is a yellow or red stain which disfigures the wood. This is generally caused by the decay of the timber. These stains are usually found round the pith of the tree.

(G) Compression Wood: It is abnormal wood formed on the lower side of branches and of leaning trunks of softwood tree mainly which has relatively wide annual rings, a large amount of summer wood and a dark reddish to brown color. This type of timber is very weak and less durable, because it ends to shrink excessively lengthwise.

(H) Pitch Pockets: Pitch pockets are opening between the fibers of the wood extending, along the grain usually containing pitch or bark.

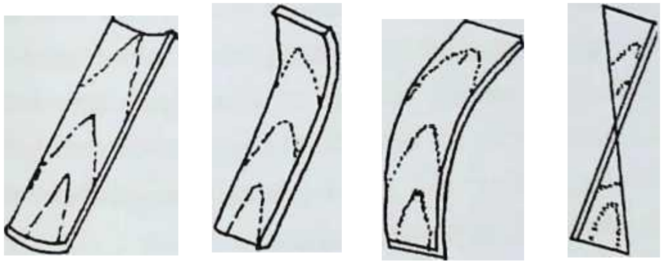
Other defects like resin and mineral streaks,

gum veins, latex canals are also found in some species of trees.

2, **Artificial Defects:** Artificial defects arc: (a) Warping (b) Splitting and cracking (c) Defects due to fungal action and (d) Defects due to insects.

(a) Warping: Warping is a variation or distortion from a true or plane surface of a plank due to unequal shrinkage and includes *bow, crook, cup and twist. Bow* is distortion of a plank or a board in which the face is convex of concave longitudinally: *crook* is similar distortion of the edge of a plank or of a board caused by turning of the edge tostha the four-corner a of a board are not in the same plane.

All these defects are mainly due to seasoning and drying of timbers. The Fig. 15.10 shows the various types of warping's.



a) BOW b) CUP (c) CROOK (d) TWIS

Fig. 15.10

(b) Splitting and Cracking: if the reasoning of the freshly felled logs of wood is not properly carried out several defects occur due to non-uniform drying of the exterior and interior section of the timber. Exterior dries: more quickly than the interior which remains comparative!) wet. Shakes of various types (Discussed already) may result.

(c) Defects due to fungal action: Fungi are microscopic plans. They attack and active on wood tissues and their cell contents. *Rotting* is the general term applied to the disintegration and destruction of wood by fungal action. The factors promoting fungal action arc moisture content, enough air. suitable temperature and sufficient food material. There are mainly two types of fungi, (i) Sap stain fungi and (ii) wood rotting fungi. The sapwood of both soft wood and hard wood are attacked by sap stain fungi. Minute holes are caused in timber by this group of fungal attack.

Wood rotting fungi are again two types, namely, *wet rot fungi and dry rot fungi.* Generally, 20 to 25 per cent moisture is essential for fungal activity, wet rot fungi require a higher percentage of moisture for their activity. Dry rot fungi require comparatively a lower percentage of moisture and does not require pump conditions to bring about disintegration and final decay of timbers reduced to almost powdery state from which the term dry rot is used. It is worth mentioning that wet rot is commonly found in living trees through their wounded parts into which water gains access.

(d) Defects due to insects and worms: Insects and worms which cause defects in wood are mainly of two classes. One classes of insects are termites (white ants) and beetles and the other class is marine borers. The action of insects is to make holes in wood in, various ways and then to reduce to powder and impart a honey-comb texture to it. Timber is discolored and loses its strength and finally falls in decay (Fig. 15.11)

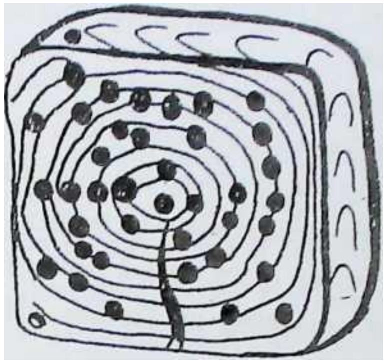


Fig. 15.11

lei mites and beetles attack timber by eating out the interior of the wood and leaven a shell of sound wood to conceal their activities, very few woods offer any marked degree of resistance to termite attack.

Damage to timber structures in sea water and even some times in fresh water may be caused by marine borers. Rapidly of attach depends on the local condition and the kinds of bores present, the principal marine borers and the teredo and limnoria. The fig. 15.11 shows the section of a timber attached by teredo borer.

15.12 Seasoning of Timber: The seasoning or drying of timber frequently precedes its application to structural purposes. The main purpose of seasoning is dry sap and to reduce the moisture content of timber. The following are the main objectives of seasoning timber.

1. To bring timber to a state of equilibrium moisture content which is essential for all subsequent conversion and use.
2. To reduce the weight of timber to facilitate transportation and handling.

3. To make timber durable and more resistant to decay due to fungal action.

4. To make timber strong, hard and stiff as unseasoned timber is weak and soft and more vulnerable to decay.

5. To dry the sap and to reduce the moisture content to certain degree to apply preservatives on timber.

6. To make timber more suited for polishing and painting.

Methods of seasoning of Timber: The following are the principal methods of seasoning of timber: (1) Natural or Air Seasoning (2) Artificial Seasoning (kiln seasoning. Chemical Seasoning. Electrical seasoning, Esteeming, Boiling. Smoke seasoning) and (3) water Seasoning.

1. Natural or Air Seasoning: This process of seasoning is also known as air drying. The natural seasoning is done by a long outdoor exposure of timber to the action of the air. *The timbers are stacked in a dry elevated platform which is covered by a temporary' shed to protect timbers from the action of rain. Sometimes, permanent shed is also erected for the same. Timber is generally turned frequently to ensure equal drying all round, because irregular drying causes splits and cracks. This is a very slow process and the time required from 2 to 3 years to remove the moisture by proration to the desired extent. This method is commonly employed all over Bangladesh.

official Seasoning: The drying of timber by exposure for a mited period to high temperatures in a closed chamber or by applying chemicals, steam and smoke is termed as artificial reasoning. The following are the various method of artificial seasoning.

(a) Kiln Seasoning: Two types of kilns arc available for artificial seasoning: (i) compartment kiln in which the conditions of temperature and humidity are changed as the drying progress, the timber being stacked in the compartment and (ii) progressive kiln in which a low temperature with high humidity condition is maintained at the entering end of the kiln and a high temperature with low humanity condition it the exit end. timber being moved periodically through the kiln. Both types of kilns may have either natural of forced air circulation. The advantages of forced circulation of air are accurate control of humidity and faster drying without any danger to the timber.

In kiln seasoning temperatures 70 to 82°C (158 to 180^{c}F) are usually employed soft woods generally require 4 to 6 days for 3 to 6 months to allow the first shrinkage to take place more gradually and are then exposed to above temperatures in the kiln require 6 to 12 days for 1-to-2%-inch boards. This method is used in Bangladesh.

(b) Chemical Seasoning: This is also known as salt *seasoning:* In this method, timber is first soaked in an aqueous solution of a suitable chemical salt (usually solution or urea) before it is passed through the process of kiln seasoning. The vapor pressure of the salt solution is less and therefore, the interior moisture of the timber is drawn out. The drying of timber from the center to the surface is at a uniform rate. The drying process is also accelerated. The most commonly used chemical is urea. It is a very good dehydrating agent and does not cause any harm to the seasoned timber. This method is not generally used in our country.

(c) Electrical Seasoning: In this process, high frequency alternating currents arc passed through timber in a closed chamber and the resistance caused by the passage of the currents produces heat which dries the limber. Electrical seasonings is generally preceded by air dicing.

This is a very quick process of seasoning but .is not used in this country.

(d) Steaming: This process, steam is passed through the stacked timber in a closed chamber and thereafter timber is dried gradually in natural air. The steam is usually passed for 4 to 6 hours.

This is a quick method but it reduces the elasticity and strength of timber. This method is used in certain parts of this country.

(e) Boiling: In this process the timber is immersed in boiling water for a certain period of time. Thereafter, the timber is dried slowly by natural air. This is also a quick process but it also reduces elasticity and strength of timber. This method is very rarely used in Bangladesh.

(f) Smoke Seasoning: This is a very old practice of drying timber in smoke heat over a fire of straw, sawdust and wood savings. This method is claimed to be efficient to make timber more durable and resistant to decaying agents, heat is gradually applied to prevent splitting and wrapping. This method is very frequently used in Bangladesh in boat making industries.

3. **Water Seasoning:** In this process, timbers and logs are immersed and allowed to remain in water for a couple of days, whereafter they are dried by in natural air. In process, the sap is diluted and is partly removed. This reduces

the possibilities of decay and increases the durability of timber. Water seasoning timber also dries more quickly. This process of seasoning is good for limber containing a lot of sap but it reduces the strength of timber to some extent. This method is commonly used all over Bangladesh.

Remarks. I amber shrinks when seasoned. But seasoned (dried) timber has the ability to reabsorb water from the atmosphere when in structure use. The amount of water than absorbed always exceeds the moisture content of the air but varies with the humanity. The consequent shrinking and swelling of the timber is a serious handicap if exact is desired. This phenomenon may be reduced but not limited entirely, by prolonged exposure to temperatures in the vicinity of 100°C (212°F). or by boiling, steaming, prolonged soaking and painting and varnishing.

15.13 Mechanical Properties of Timber: The intelligent use of wood for any structural purpose requires a general know ledge of the mechanical properties of different woods in order that the one selected may conform in its structural qualities to the requirement imposed and in order that a given purpose may be served at minimum expense. The mechanical properties of timber are extremely variable, not only between species and different trees of the same species but also specimens from different portions of the same tree. The following are the principal mechanical properties of timber. (1) Durability (2) Strength, (3) Elasticity. (4) Stiffness. (5) Toughness, Hardness and (7) Workability.

(0 Durability: Durability is the property of tun u to of sound condition for a long time when expose to the forces of nature in an exposed or underground condition. All timbers must be durable. For this the timber should be free from natural and artificial detects. The trunk of the tree should be thick long and straight. Timbers should be radially sawn; the annual rings should be regular and uniform and as dense as possible. The colour should be uniform and or lustrous. The timber should be well-seasoned. Hardness, density, specific gravity and strength seem to have direct influence on the durability of timber.

(2) Strength: Strength are of various types: (a) Tensile strength (b) Compressive strength (c) Flexural or Transverse strength.

(a) Tensile Strength: Timber in construction is practically never subjected to pure tensile stress. The type of specimen to be used for testing the tensile strength is rectangular piece, 2"x2"x8". The method of application of load is two types: (i) parallel to the grains and (ii) perpendicular to the gains.

(b) Compressive Strength: Timber in construction is mainly subjected to compressive strength. The compressive strength of wood in a direction normal to the grain is simply a matter of the resistance offered by the wood elements to being crushed or flattened. The cells with the thinnest walls collapse first and the action proceeds gradually.

The compressive strength of timber along the grain depends upon the anatomical structure and the moisture content of d^{ie} timber.

A rectangular specimen. 2”x2”x8” is used for this purpose and the load is applied along the grains.

(c) Flexural Strength: The flexural strength of timber is closely related to its tensile and compressive strength- ^{r} timber beams, whose resistance to shear parallel with the grain is comparatively low; the intensity of longitudinal shear also becomes a very vital factor. Flexural (bending) strength is tested on a rectangular beam section applying load at the center.

An attempt to predict the strength of a given piece of timber must take into account the various factors which may exert an influence upon this strength. The most important of these are

(i) species and variety (ii) locality from which content and defects and their location.

Moisture and Strength: All woods gain in strength when thoroughly seasoned. The relationship between the moisture content, compressive strength and modulus of elasticity of timber has been illustrated in Fig. 15.12

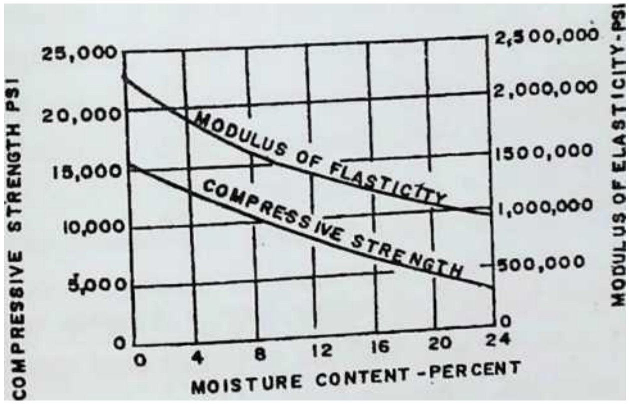


FIG. 15.12 EFFECT OF MOISTURE ON PROERTIES OF A TYPICAL TIMBER

Weight and Strength: The relation between strength and true (dry) density of timber can be expressed as follows:

Green timber: Modulus of Rupture= 18,500 (S) 1.25 (15.5)

Seasoned timber: Modulus of Rupture =26,200(s) 1.25 (15.6)

where S is the specific gravity.

The above noted formulae have been derived from tests on small clear, straight grained specimens. The actual data show that mean values for different species and variation in locality may deviate from the calculated value by 30 percent.

Rate of Growth and Strength: The average rate of growth of timber is readily computed by counting the annual rings along radial line and dividing by the length of the line. The indications are that for most species there is a rate of growth which, in a very general way. is associated with the greatest, strength. For species tested, this appears to be as tabulated as follows:

Name of the timber tree	Rings per inch
Fir	24
Teak	30
Sal	32
Garjan	31
Deodar	22
Chirr	20
Jarul	28

(3) Stiffness: Stiffness of timber largely depends upon the same factors as strength. Stiffness of timber used structurally is often quite an important factor. All wood gain stiffness when properly seasoned.

(4) Toughness: This is the property of timber to resist shocks. This property is desirable where the timber is subjected to vibrations or sudden blows.

(5) Hardness: Structural timber should be very hard- Hardness of timber depends upon the weight, uniformity in texture, closely spaced annual rings and freeness from defects

hardness is necessary for timbers to be used for flooring mallets tool hand less rollers, bearing shaft, spindles etc.

6. **Fissility:** It is the property of timber to spit in the direction of the fibers when a tensile force is exerted at right angles to the grain. Resistance to fissility of timber is required when it is used for spokes, shafts etc.

7. **Workability:** Timber should not offer any resistance when it is worked with tools for conversion, planning and polishing. A good workable timber should not split or crack when nail or spike is driven into it.

5.14 Elastic Properties of Timber: The ratio of compressive strength to modulus of elasticity which is a ratio of strength to stiffness is much greater for timber than for steel, iron, or concrete. Wood has no well-defined yield point, but the proportional limit or yield strength is determined as a measure of elastic strength. Timber has a high degree of resistance. Timber structural members have good resistance to shock. Timber can withstand a large deformation for comparatively low stress. A unit volume of steel has greater clastic resistance to shock than timber as measured by the area under the stress strain curve but since a much greater volume of timber is required to resist a given stress, timber members have better elastic shock resistance than steel. Timber members are much better in this respect than cast iron or concrete. Partly on account of these elastic shock-resisting Properties, timber is extensively used for railroad ties, fence posts, highway guardrail posts, wagon or cart wheels. Resistance to complete failure under shock is less tor Umber than steel but greater than for cast iron and concrete.

15.15. Characteristics of Good limber: The following are the characteristics ‘of good timber:

1. It should be strong, stiff, tough and durable.
2. It should be free from both natural and artificial defects
3. It should be radially sawn.
4. The annual growth rings should be regular, uniform and closely spaced.
5. The colour should be uniform and lustrous. There should not be any sudden change in colour as this would indicate a disease (defect) in timber. Dark uniform colour usually indicate strength and durability of timber.
6. When struck with a hammer, timber should give a clear sound. A dull sound usually indicates in timber.
7. It should be obtained from the heart to a fully grown tree with straight and regular girth.
8. The density of the timber should be high because heavier timbers are always stronger and durable:
9. It should have a good workability.
10. It should be elastic because this property is necessary in timber used for carriage shafts, bows, sport goods etc.
11. It should be resistant to compression because this property is needed when timber is used as struts, piles wheel spokes, posts, props, etc.
12. It should be fire resistant, i.e., it should have low combustibility. A dense timber offers greater resistance to Inc than light and porous one.
13. Timber should retain its shapes during the period of use. **15.16**

Uses of Timber: The following are the various uses of timber:

1. *Permanent structural works: T*imbers used in permanent structural works are mainly of two types: *(a)* Light structural members and (b) Heavy structural members.

(a) Light structural members: Beams, posts, roof trusses floor boards, door and window frames and battens, railway sleepers bridge Borings electric poles, fencing poles, poles for transmission lines, gates, railings etc.

(b) Heavy structural members: Piles, bridge piers, trestles foundation and superstructure, wood staves, stairs etc.

2. **Furniture works:** cots, beds, etc.
3. **Transportation works:** For making country boats launches speed boats, ships body frames of railway coaches, omnibuses and air crafts, for making jetties and landing platforms. Also used for making cart wheels.
4. **Temporary works during construction:** Scaffolding and general centering works (formworks) of all types in R.C.C. construction works, for providing shearing and strutting to support the sides of soft soil excavation. Timber is used or making packing boxes and pattern making in foundry castings.
5. **Commercial uses:** Timber is used for manufacturing sport goods, toys, and for making veneers which are used in manufacturing plywood batten boards, laminated boards, etc. and reconstructed wooden boards like insulating boards hardboard fiber boards particle boards, linoleum etc.
6. **Industrial uses:** Wood is used for the manufacture of matches, paper, newsprint, card boards, wall-papers, artificial synthetic fibers, roofing felt, preservatives etc.

7. **Ornamental and Decorative Works:** limber is used for ornamental and decorative purposes like table lamp holders, flower-vases, ashtrays, cabinet partition, interior decorative works, etc.
8. **Miscellaneous uses:** For making utensils, bows wheel spokes shafts mallets, tool handless rollers, spindles ploughs, tent pegs. weel, curbs, ladders. household fittings picture frames, combs, brushbacks. etc.

15.17 Decay of Timber: The decay of timber is not an inorganic process like rusting of iron or crumbling of stone but is mainly due to the action of wood destroying fungi. These wood-penetrating fungi consist of *hyphae,* which are branched threads or filaments of microscopic size. The masses *hyphae* are known as *micelle.* These fungi are mainly two types: Stain and *mold.* Blue stain is the most common in the stain group of fungi. These organisms depend on woody tissues for their food. They spread from cell to cell through the pits in the cell walls or bore through cell walls causing disintegration of mood which in advanced stages is easily recognized by changes in texture, continuity and colour. The wood becomes soft, friable, spongy and pitted depending upon the type of fungus. Mold is a wood staining fungus which forms a cottony growth on the surface of the timber most and worm conditions. Wood reduces the strength and durability of timber.

Wood destroying fungi may be further classed as *brown rot or white* rot. The former involves destruction principally of cellulose while the white rot destroys lignin gum, latex etc.

Five conditions are necessary for the development of decay in timber: (1) supply of food for wood destroying fungi (2)

presence of sap (3) A small amount of air (4) Suitable temperatures and (5) Sufficient moisture. If any one of these conditions does not exist, attack by fungi will be eliminated. Thus, timber subjected to very high or low temperatures will not be attacked by fungi. Timber immersed in water will not decay because of lack of air and timber kept continuously in a dry condition below a critical moisture content will decay. Insects and worms like beetles, termites (white ants) and borers also bring about decay in their own way.

15.18 Preservation of Timber: By far the best method of preventing the growth of wood destroying fungi is poisoning their food supply by injecting poisonous substance into the timber, so changing the organic food materials in powerful fungicides.

It is a widespread idea that the germs of decay are inherent in the wood, needing only an opportunity for development to bring about its destruction. On the contrary, all wood destroying agencies start from the outside and may even be eliminated by certain paints which merely coat the surface of the timber but which are poisonous enough to prevent the germination of fungal spores.

The deliberate attempts to preserve timber from decay date back may centuries, when wood was chaired to make it more resistant. Later came the period when wood was coated with preservative paints; then came attempts to inject pre into the wood. .

There are mainly three types of wood preservatives available in the market: (1) Preservative Tar oils (b) Water Soluble Preservative and (3) Organic compounds.

The most important and widely used tar-oil preservatives is creosote. Creosotes are of three types: (a) Coal-tar creosote (b) Water gas tar creosote and (c) Wood-tar creosote, depending upon their origin whether it is from coal petroleum or wood. Creosotes are obtained by the process of destructive distillation these substances. Out of the three creosotes. Coal tar creosote is the most important and efficient one Creosote has the advantage of insolubility in water so that it will not wash out of timber. It is the best preservative for general outdoor exposures and is preferred for piling, poles and general structural timbers. Creosoted timber, however, is discolored so that it cannot be painted and it has an objectionable odor.

Among the water-soluble chemical salts, zinc chloride is most widely used. Mercuric chloride, potassium dichromate copper sulphate, arsenic and sodium fluoride are the other types of water-soluble preservatives. Zinc chloride is soluble in water and hence it is utilized In comparatively dry situations. Its advantages are that the treated timber can be painted and is odorless.

Toxic organic compounds such as tetra chlorophenol, pentachlorophenol, copper nap enate and zinc naphthenate dissolved in non-aqueous, non -toxic volatile solvent such as naphtha, spirit, etc. have been recently developed for the treatment of door and window frames battens and other types of furniture. The wood is soaked into the preservative no heat being required. The volatile solvent escapes rapidly after treatment. The toxic agent remaining does not discolor the wood detrimentally nor cause swelling since the moisture content not affected. Treated wood is paintable and odorless.

Preservative treatments also prolong the life of timber and increases its durability to a great extent. A good preservative should have the following characteristics: (1) It should be safe in handling and safe to use *(2)* It should be non-injurious to the wood tissues and should not act chemically with the wood fibers (3) It should not get washed away and should preserve wood permanently (4) Its quality should be such that decorative colors and paints could be applied on timber very easily (5) It should be nonflammable and should penetrate the wood thoroughly.

15.19 Processes of Applying Preservatives on Timber: The following are the various processes of applying preservatives on timber:

(1) Pressure Processes
(2) Non-Pressure Processes
(3) Superficial processes
(4) Dipping Process.

(1) Pressure Processes: These are the most *efficient* processes of treatment of timber with preservatives and give reliable results. The pressure processes in general provide tor some preliminary treatment, after which the presentative introduced into the cellular spaces by pressure. According there are two types of pressure processes: (a) "Full cell'' process and (b) "Empty cell" process.

(a) Full Cell *Process:* In this process it is *intended that the* cells of the wood shall remain practically *filled with* Preservatives. The seasoned timber is loaded on trollies, (specially designed with ball bearings) and pushed them into long steel cylinders (known as autoclaves), doors of which can be closed completely airtight. After locking the door of the autoclave, a preliminary vacuum is applied to remove the air as much as possible from the wood cells. The preservative which is generally heated to about 210°f is then pumped into the autoclave and the desired pressure usually ranging between 125 to 200 psi is applied for a specified period of time. The pressure is then reduced to atmospheric and the preservative is then withdrawn from the autoclave. Then the cell cavities get filled up with preservative. After a short time, the door of the autoclave is opened and the trollies taken out. This method is most suitable to water soluble preservatives.

(b) Empty Cell Process: In this process, it is desired that the preservative shall merely form a thin film over the cells without filling the inside of the cells. The procedure is exactly same as that of the full cell process, except that prior to filling the autoclave with the preservative, an initial air pressure of about 50 to 75 psi is created in the autoclave which forces the air into the cells of the wood. The preservative is then admitted to the autoclave under a high pressure (about 200 psi) and is thus forced into the cells. Upon the removal of the external pressure, the imprisoned and compressed air within the cells expands and forces out a considerable portion of the preservative, which may be further removed by application pf

a partial vacuum. This process requires only $^1/_3$ to $^1/_2$ of the preservative that is required by the full cell process. This process is very economic and is often preferred for structural Timbers because the treated timber is cleaner to handle and less apt to bleed. This method is most suited for oily type preservatives like creosote.

(2) **Non-Pressure Process:** I his process is also known as the *hot and cold hath treatment.* The timber is immersed in the preservative in an open tank and the temperature is raised to about 93.3°C (200°F). The heat of the preservative expands the air within the cells. The cooling of the bath or the rapid removal of the wood to a cold bath causes a contraction of the air still remaining in the cells, which tends to produce an infiltration of the preservative. This process in not commonly used.

(3) **Superficial Process:** Less efficient but cheaper treatment can be secured by painting the surface of the timber with at least two coats of hot creosote or zinc chloride or some other similar preservative. This process also known as the brush method. The preservative will not penetrate to any great extent but as long as there remains an unbroken antiseptic layer around the surface of the timber, the spores of fungi cannot enter. Through seasoning is necessary before painting with preservatives, otherwise shakes may form and provide a means of access to the interior of the timber for the spores of fungi and also for termites and borers.

Sometimes, instead of brushing, the preservative is sprayed on the timber by machine. The spraying method is definitely better than the brush method and gives a uniformity of application. Superficial process is suitable when the preservative has to be applied at an interval of 2 to 3 years and also, when the timber is exposed to damp condition only for a short time.

(4) Dipping Process: A still less expensive treatment than the brush or spray treatment is the method of dipping the timber in an open tank or vat of the preservative. Usually, the timbers are carried through the bath on chain conveyors and remain submerged only for a few minutes at most. Dipping is not only more economical of time and labor but also gives better results than the superficial method.

Remarks: Timber members should be cut to final dimensions before treatment, with a preservative. If cutting is necessary after treatment the cut surfaces should be brushed or sprayed or dipped with the original preservative.

15.20 Bleeding. After treatment of timber, sometimes the creosote (Preservative) oozes out and this phenomenon is termed as bleeding. When the final vacuum is applied (in case of empty cell process) much free creosote is drained out as well as a lot of air under pressure which was imprisoned in the cell. But due to the viscosity of the preservative (creosote): a certain amount of air still remains blocked inside the capillaries of the timber. Timber is day when comes out autoclaves, but as the entrapped air gradually finds its j way out it pushes out the creosote and thus bleeding starts. Bleeding is found in the empty cell process of wood treatment.

15.21 Effect of Preservative Treatments on the Strength of Timber: Reduced strength timber after preservative treatment is due primary to the method of conditioning or process of impregnating rather than to the effects of preserved timber. Strength of treated timber is a function *of the* percentage of moisture remaining in the timber. Steaming during preliminary treatment may cause considerable reduction in strength a high degree of steaming is injurious since the amount of moisture in the timber is increased with consequent weakening of the fibers. Boiling under vacuum causes less weakening than steaming. High temperatures maintained for long periods during impregnation in order to obtain penetration of the preservative may cause considerable loss in strength. The presence of creosote in itself will not weaken wood since it does not reach chemically with wood and appear, not to enter the cell but only to coat them the presence of zinc chloride will not weaken wood except by the addition of water by the reason of the fact that it is itself a water solution. Subsequent seasoning will obviate this difficulty. A too concentrated preservative solution may cause chemical dissolution of some of the Woodfibre’s but this danger can easily be avoided.

15.22 Protection of Timber Structures against Termites and Beetles: Very few woods offer any marked degree of resistance to termites and beetles’ attack. Impregnation with an effective preservative increase’s resistance. The best protection against subterranean termites is to build a barrier so as to prevent their access to the building. The foundation should be of concrete or other solid material through which the termites and beetles cannot penetrate. Rich cement mortar should be used with bricks stones or concrete blocks because termites and beetles can work through wealk mortars. Termites and beetles' shields consisting of sheet of metals that extent out from the foundation at a angle of 45° for a horizontal distance of at least 2 inches should be placed between foundation add wood work in order to prevent termites and beetles. Metal shields should also be filled tightly around water and sewer pipes gas pipes and electrical conduits along which termites could build their tubes and gain entrance to wood work. Building infested with subterranean termites should have the infested timber replaced with treated once. The entrance galleries of the termites should be destroyed and chemical such as ortho di-chlorobenzene may be poured into a trench near the nests and then convert with earth so that the termites will be killed by fumes.

Paint is a good protection against the entrance of dry wood termites therefore all exposed timber should be kept painted.

15.23 Protection of Timber structure Against Borers: The best practical protection for piling in sea water against marine borers is the heavy treatment with creosote. The treatment should be through with deep penetration and high absorption of the creosote in order to obtain satisfactory results in heavily

infested walers. I he piles should be properly seasoned before the preservative treatment.

protection against borers may also be provided by surrounding the treated piles by a jacket of concrete or by cast iron pipe sections. The pipe section should extend from above high tide to below the mud line and space between the wood and the pipes should be filled with clay or concrete.

Paints and batten method of pile protection vary' as to details but consist of substantially in: (1) coating the untreated pile and other timber structures in contact with water with a thick viscous paint which may not contain poisonous materials (2) applying burlap, roofing felt or similar material over the paint

(3) applying a second coat of paint (4) nailing in a lace of a close-fitting layer of narrow battens, which are strips of sawn timber and (5) applying a final coat of paint of till the crevices between the battens and to coat the surface thoroughly.

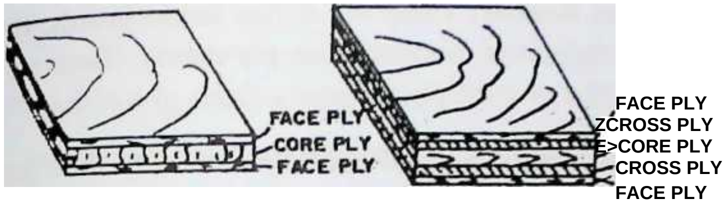
15.24 Fire Resistance of Timber: Timber can be never be mad fire proof, but it can be treated to slow down the action of fire. Timber may be impregnated with chemicals to increase fire resistance. The most common preservatives are monoammonium phosphate, diammonium phosphate, a Phosphoric acid arc effective in retarding glowing and flaming and do not have objectionable properties.

Timber may be coated with fire resistant paints to retard baring and to restrain the spreading of flames. Sodium silicate is an effective fire-resistant coating

15.25 Veneers: Veneers are thin layers of wood of $^{1}/_{16}$ to ¼ inch in thickness. These are used in construction were lightness, durability, stiffness. no shrinking, non-splitting and decorative properties are desired. Veneers are generally obtained only from those woods which have well shaped grains and which are pleasing in appearance. Slicing of veneers is done in the form of continuous sheets by rotating logs with the aid of a circular rotary saw. In our country, generally shisham and teak are considered to be suitable for making veneers. But in foreign countries, mahogany, walnut and waple are considered to be most for veneering. Veneers are principally used in the manufacture of plywood batten boards laminated boards and decorative facings.

15.26 Plywood: Plywood consists of number of thin sheets of wood (veneers) which are pressed and bonded together with some binding or cementing material like glue or synthetic alternately at right angles to the grains of adjoining sheet. Not less than three sheet are used, but more sheets can be added to increase the thickness. The inner sheet which forms the core is usually of a cheaper quality, while the top surface sheet or ply is of much superior quality of wood (Fig. 15,13). Cross bonding imports uniform strength in both direction and shrinkage is reduced to minimum. It also prevents splitting.

The veneers glued together as mentioned earlier are subjected io a hydraulic pressure is applied under temperatures ranging from 350 to 500°F.



PLAYWOOO WITH THREE VEHEERS tb) PLYWOOD WITH FIVE VENEERS

Fig. 15.13

Plywood is much stronger (roughly two to three times) than solid boards of equivalent thickness and therefore, it is lighter than planks of equivalent strength. It is available in all sizes and can be easily worked, especially when bending to a certain extent to suit the required shape is desired. It does not generally crack or split like solid boards due to the effect to atmospheric agents. Plywood is sometimes bonded with plastic sheets to provide a superior glossy appearance, low or nil water absorption, excellent abrasion resistance and better weathering properties.

Plywood is extensively used to partitions and panel works, exterior and interior walls decorations, rail cars, ornamental and engineering models. .

By ordinary plywood it is commonly meant that it consists of three plays or veneers. But if consists of 5 to 11 plays, it is known as multiply wood and its thickness ranges from 1/3 to $1^{1}/_{2}$ inch.

15.27 Laminated Boards: these ate called Lamin boards. These are also manufacture! similarly as plywood. They are of either three ply's or multiplies. These consist of a core of thick strips about ½-inch thick laid side by side with their grains reversed,

glued and compressed. These laminated are covered with veneers with their grains at right angles to the core (Fig.14, 15). The total thickness of the laminated boards usually varies from $^{1}/_{2}$ to 2 inch, but sometimes, thicker varieties are also made. Laminated boards are used as partitions, decorative works, furniture, etc.

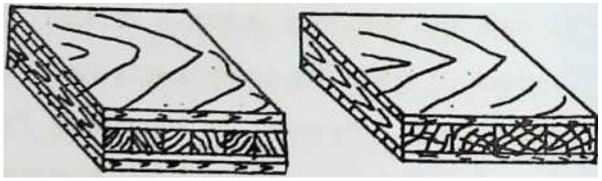


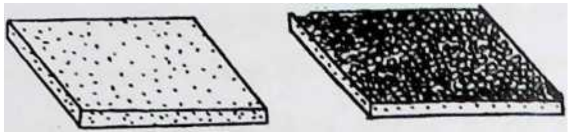
Fig. 15.14 Laminated Board **Fig. 15.15 Batten Coard**

Fig. 15.14 and 15.15

Fig. 15.14 Laminated Board Fig. 15.15 Batten Coard; Fig 15.14 and 15.15

Batten Boards: These are just like lamina boards except the middle thick panel is replaced by (wood battens of ¾ to 1 inch thickness battens of board is same as that of laminated boards (15.15) Batten broads are used for decorative works, furniture making partitions etc.

15.29 Reconstructed Wood: Good quality wood converted into chips (size about $^{1}/_{2}$ to 1 inch) which are cooked in as autoclave with super-heated steam to make them soft. This causes separation of the fibers from the wood gum (lignin) and the whole mass reduced to a plastic form. This cooked material is then transferred to a big steel cylindrical autoclave where it is further heated at a pressure of 800 to 1000 psi for a few minutes. The value provided at the bottom of the great force when the wood pulp comes out of the value the pressure is released suddenly and the fibers of wood separate from the wood gum (lignin). These fibers are collected, washed, refined and spread on wire screens to the required thickness and pressed between steel plates with necessary pressure to yield soft and hard broads as required (Fig: 15.16) The texture of reconstructed wood is quite different from that of natural wood and depends upon the size of the wood chips or particles. Sometimes, the surfaces are made corrugated or leather-grained for decorative purposes. Fine particles like sawdust generally yield a product of good quality (hard boards). Sometimes, coloring ingredients are added to the wood pulp to improve the original shades or for production color boards. The main varieties of reconstructed wooden boards are as follows; (1) insulating board (2) soft boards (3) hard boards (4) super-hard boards (5) laminated fiber building boards and (6) color boards.



(d) Fiber Board (d) Hard Board (Leather Gracing
Fig. 15.16 Reconstructed wood
Fig. 15.16

Reconstructed wooden boards are now-a-days widely used because they are strong durable, light and flexible, can be bent to any desired shapes. They do not crack or split. They can sawn drilled and punched easily and take almost any paint.

The most common use of these boards is for insulation against sounds and heat. The fiber boards are most suitable for insulting purposes. The harder varieties of boards are generally given a good finish and are used for penciling. Other uses include internal partition walls, interior finish furniture, flush doors, table-tops, railway coaches, notice boards, ship building and packing industries. Reconstructed wooden boards are available in the market under different trade names such as Lino felt, Torf oleum, fibro felt, Celotex, insulate, Masonite etc.

Partex: Partex is the trade name of the versatile chip boards manufactured from wood veneers, wood chips or jute sticks. Partex is a Bangladesh product, manufactured by the star particle board mills.

Partex in plain and veneered forms is constantly being recommended by good cabinet market for steam lined furniture in modem homes and office.

In veneered partex there is a choice of various types of boards of Burma teak, afromoisa (golden teak) and sapele.

Partex plain boards are ideal for surfacing with practically any material, viz, laminated sheets, Formica, aluminum sheets, plywood, wood veneers etc. Partex boards are available in wide range of densities and thickness.

Cork and Cork Board: Cork is a thick spongy' bark of the species of Oak trees: Cork has cellular structure and when dried, it is light, porous, very plastic and easily compressible.

It is one of the lightest solid materials having the specific gravity in the range of 0.15 to 0.2. Since it has low thermal conductivity, it is used as insulator in building, refrigerators and other machinery. It is also widely used for bottle stoppers, vibration pads and floats. Cork boards are manufactured by compressing cork chips (granulated cork particles) with some cementing material a subjecting them to high temperature so that the particles get cemented together. Cork boards are principally used as insulator tor insulating of ceilings and walls against heat and cold. They are also used as sound insulator.

15.30 Important Varieties of Timber available in Bangladesh

1. **Teak or Segun:** It is a very strong and durable timber with a beautiful golden yellow color. It is easy to season and easy to work. It takes good polish and maintains its shape very well. It is considered to be a very superior timber. It can resist fire attack to some extent. It is also not easily attacked by termites. It is very commonly used for all sorts of house construction and structural works, high class furniture, ship building, railway sleepers, flooring veneers and decorative structural works.

   It is found in Chittagong Hills and is generally imported from Burma.

2. **Sal:** It is a very strong hard, heavy and durable timber but difficult to work with. It is an all-purpose timber. It is extensively used for house construction, generally structural works, boat building, railway sleepers, rough furniture etc.

   It is found in Chittagong Hills and Sundarbans.

3. **Garjan:** It is very strong and durable timber. It is difficult to work with and does not take good polish. It is widely used for house building, railway sleepers and carriage floors, buildings general structural works rough furniture etc. It is liable to excessive shrinkage. It must be given a preservative treatment as it easily attacked by fungi.

   It is found in Chittagong Hills and Sundarbans.

4. **Gazari:** It is a strong hard and durable timber. H is extensively used as piles, posts and other structural members,

   house building flooring, rough furniture etc. It is found in Bhowal Garr in Dhaka District, Madhupur jungles in Tangail District, Chittagong I fill and Sundarbans abundantly.

5. **Jarul:** It is a light, hard and very durable timber. It can resist well the actions by salt water. It seasons well and takes a good polish. It is used for house construction, boat building, wheels of bullock carts etc.

   It is abundantly found in Chittagong Hill Tracts.

6. **Sundari:** It is a very strong, tough, hard and heavy timber. It is difficult to season and works It is used for all sorts of building works carts, wheel-spokes, furniture, well curbs tool handles, boat building etc.

   It is abundantly found in the Sundarbans.

7. **Shisham or Shisso:** It is **a** very tough strong, hard and durable timber. It seasons and works well. It is used to house building, high-class furniture, cart-frames, boat building and making good veneers and also used for general constructional purposes.

   It is found in small quantities all over Bangladesh.

8. **Shiris:** It is moderately strong hard and durable. It is a general-purpose timber, used for house construction agricultural implements, cart-wheels, heavy furniture sugarcane crushers etc.

   It is found in Chittagong Mills. Sylhet. Khulna Mymensingh and Dhaka.

9. **Simul:** It is a light and soil wood it is used for the manufacture of match boxes and sticks, packing boxes and as fuels. It is not generally used for structural purposes.

   It is abundantly found throughout Bangladesh.

10. **Babul:** It is a close grained, very durable, hard and tough wood. It is difficult to work with but takes a fine polish. Its colour is pale red tending to brown. It is commonly used for agricultural tools (ploughs etc.), car wheels, tent pegs, railway sleepers, boat building, well curbs etc. It yields valuable gum and its bark is used tanning hides.

    It is abundantly found In Northern parts of Bangladesh.

11. **Debdaro:** It is moderate hard wood, strongly scented and fairly durable. It is easy to season and work, takes good polish and retains its shape well. The strength of debadaro is considered to be 80 percent of good teak. It is one of the most important varieties of timber used in Bangladesh. It is in fact an all-purpose timber. It is principally used for railway sleepers and carriages planking general structural work and cheap furniture.

    It is found all over Bangladesh.

13. **Gamhari:** It is a strong, haul and moderately durable wood. It is difficult to sea cult and work. It is used for making furniture, musical instruments, form works and house building.

    It is abundantly found in Chittagong Hills.

14. **Chambal:** It is moderately strong, hard and not very durable. It is used lor furniture. door and window frames battens, posts etc. it is found in Chittagong Hill Tracts.

15. **Telsu:** It is strong and durable. It is generally used for furniture making, door and window framing, flooring etc.

    It is found throughout Bangladesh.

16. **Nageshwar:** It is a strong, hard and heavy wood is very hard to work with but very durable. It is not easily attacked by termites. It is requiring careful seasoning, otherwise liable to crack. It is used for furniture and cabinet making bridge posts and floors boat and launch, floors tent pegs etc.

    It is abundantly found in Sylhet, Mymensingh. Chittagong and Khulna.

17. **Bailum:** It is a strong, heavy and durable wood. It is generally used for furniture, door and window frames, flooring, frameworks etc.

    It is found throughout Bangladesh

18. **Tonn:** It is a light and soft wood. It takes a good polish. It is used for furniture, toys, models, musical instruments, packing boxes etc.

19. **Arjun:** Il is a dark brown, heavy and strong wood, it is used for masts, beams, rafters, purlins, furniture, scaffolding, frameworks etc.

    It is abundantly found in Chittagong Hill Tracks.

20. Bakul: It is a pink, heavy and close-grained wood. It is used for cabinet and furniture making, agricultural implements, planks scaffolding and frameworks.

It is found throughout Bangladesh.

21 Banyan: It is a brown wood. It is neither strong nor durable. It is easily attacked by fungi and termites. It is used for well curbs, tent poles, yokes, planks etc.

It is found all over Bangladesh.

22. Shilkarai: It is a strong, tough, hard and durable timber. It is easy to work with and takes a good polish. It is used for furniture, general structural works, house building, boat building etc.

It found throughout Bangladesh.

23. Chaplash: It is yellowish brown, moderately hard and even grained wood. It is used in ship building, canoes, masts, house building, well-curbs, furniture etc.

It is found in Chittagong Hill Tracts.

24. Guava: It is a hard, tough, light, moderately strong and fine-grained wood. It is used for wood engraving, toys, tool handless, ornamental works etc.,

It is found all over Bangladesh

25. Jackfruit (Kathal): It is a yellow darkening with ag^e compact hard and even-grained wood. It takes a good polish and can be easily seasoned. It is used for general puff^0 such as furniture, kitchen utensils, door and window frames, battens, planks, boat building, well-curbs, cabinet making etc.

It is found all over Bangladesh.

26. Mango: Il is a grey and moderately strong wood. It yields very fine planks. It is used for rough furniture, packing boxes, shoe hells toys, boats, door panels and tonga bodies.

It is found abundantly all over Bangladesh.

27. Neem: It is a hard, fibrous and durable wood. It is difficult to work and easily attacked by various insects. It is mainly used for local building purposes and as fuels.

It is found all over Bangladesh.

28. Tamarind or Tetul: It is a brown, knotty, cross-grained, very hard, strong and durable timber it is very difficult to work with and does not take good polish. It is used for tool handless, shaft wheels, axles, sugarcane crushers, oil presses, well-curbs and as fuels for brick burning.

It is commonly found throughout Bangladesh.

29. Barai: It is sufficiently strong and hardwood. It is used for making agricultural implements, toys and as fuel.

It is abundantly found all over Bangladesh.

30. Sandal or Chandan: It is a white or reddish wood. It is moderately strong and durable. It gives very good agreeable smell. It is very costly. It is mainly used for making valuable furniture, decorative and ornamental works.

It is found (in small quantities) in Chittagong Hills and the Sundarbans.

31. **Palms:** Outside wood is reddish brown; hard and strong Central wood is soft. It is used locally as house building and furniture making material. It is found almost all over Bangladesh.

32. **Red Ceder:** It is a brick red. soft and even grained wood. It is used for planks, door Pannels. furniture etc.

    Il is found (in small quantities) in Chittagong Hills.

33. **Aini:** It is yellowish brown, light, tough, closely grained elastic and durable wood. It is easy to work and takes good polish and also lasts well under water. It is used for boat and ship building, ploughs, small furniture and for general structural works.

    It is found in small quantities in Chittagong Hills and the Sundarbans.

34. **Gewa:** It is light and soft wood. It is mainly used for manufacturing the pulp for newsprint, soft boards etc.

    It is abundantly found in the Sundarbans.

35. **Bamboo or Bansh:** It is an endogenous tree. In fact, it is not a tree but a strong gigantic grass. It very often grows up to 60 ft in length. There are mainly three varieties: (a) Borak Bamboo (b) Jawa Bamboo (c) Muli Bamboo.

    Borak bamboo is generally 5to 8inch in diameter, jawa inch in diameter, Borak and jawa bamboos are very strong and extensively used for scaffolding, posts, rafters, beams- purlins, battens, ladder and other local structural works toys.

sticks hand bags, ornamental and decorative works and furniture.

Muli bamboos are weak and softened principally used Fortezza walls, mats, roofs, for paper pulp, fishing implements and as fuels.

Bamboo is an all-purpose engineering material in Bangladesh, it grows abundantly all over Bangladesh. It is extremely useful and all-purpose product used for all types of house construction and household utility purposes, verities of decorative articles, educational instruments like countian machines, side rules etc.

43. **Cane:** It is a species of endogenous tree. In fact, it is an elastic grass, having diameter ½ to 1½ inch and length exceeding 50 ft. It is a very useful product. It is used for making furniture, toys, ornamental and decorative works, household utility goods, house constructions etc.

It is found throughout Bangladesh hut abundantly in the District of Sylhet.

15.31. Important Foreign Timbers Imported in Bangladesh

1. **Burma Teak:** It is superior in quality to Chittagong teak, properties and uses have already been discussed. As the name indicates it is imported in large quantities from Bunna.

Iron Wood: It is reddish brown, extremely hard and very durable, not easily worked with and can resist nails and spikes. It is a costly timber. lt is imported mostly from

Burma. It is used for house connections (as beams, posts etc.) bridges, piles, posts, paving blocks, railway wagons, telegraph poles, agricultural implements and other structural works like ship building, Jetty construction etc.

3. **Pyinkado:** It is extremely strong, tough and hard wood. It is imported from Burma. It is used for house building bridge construction, telegraph poles, floors and railway sleepers etc.

4. **Mahogany:** It is reddish brown, hard, strong and a durable timber. It can be easily worked with and takes a fine polish; it is imported from Burma. U.S.A, and U.k. It is used mainly for furniture making.

5. **Douglas Fir:** It is a conifer group of wood. It is moderately strong but very durable. It is found in the U.S.A, and Canada.

   It is mainly used for dock works and for all constructional purposes sport goods, educational instruments etc.

6. **Pine:** It is also a conifer wood. It has several varieties. It is found abundantly in the U.S.A. Canada, Norway and U.K. It is light and soft and mainly used for sport goods, light furniture, decorative works, toys etc.

7. Ash: It is a strong, tough and durable wood, found in the USA. and European countries. It is mainly used for veneering, tool handles, and sport goods, toys and light furniture.

8. **Hickory:** It is strong and tough wood found in the U.S.A it has a great shock-resisting property. It is used for tool handles

and structural members where toughness and shock resisting properties are desired.

I. **Oak:** It is strong and durable wood, usually found in the U.S.A. Canada. New Zealand and Europe. It is mainly of two varieties red and white. It is mainly used in making furniture and toys and for generally construction works.

15.32 Structural Properties of Some Bangladesh and Foreign Timber:

Type of Timber	Unit Weight in lb per Cu ft	maximum crushing strength parallel to grain, psi	compressive strength perpendicular to grain, psi	Maximum shearing strength parallel to grain, psi	Modulus of elastic city. 1000 psi
Hardwood (Broakleaved)					
Teak	45	9,000	1500	1480	1500
Sal	55	10,000	1800	1810	1800
Sundari	60	7500	1400	1850	1600
Ash	48	7,280	860	1920	1,700
Oak	64	7,000	1260	1830	1,800
Garjan	46	8000	1500	1560	1600
Walnut	58	7,580	1250	1370	1600
Hickory	63	8.900 _	2300	2100	2200
Softwoods (Conifers)					
Pine	52	7,000	1,000	1300	1,700
Kali	32	5,500	720	1100	1,600
Debdaru	36	5,800	550	850	1,500
Douglas Fir	38	7,400	872	1,1160	2,000

Question

1 What is timber? Explain the importance of timber in engineering constructions.

2. Identify the following terms relating to the growth and structural characteristics of timber with a neat sketch (a) Pith (b) Bark (c) Medullary Ray (cl) Cambium and (e) Annual Ring.

3. Name at least eight varieties each of hardwoods and of softwoods. Distinguish between springwood and summerwood and heartwood.

4. Distinguish between slash sawn and rift-sawn lumber and state the advantages of each. Should planks for flooring be rift sawn or slash-sawn?

5. What is meant by conversion of timber? Discuss the various market forms of timber.

6. Explain, the various methods of sawing timber with neat sketches.

7. Give an analysis of moisture content in green timber. How the quantity of moisture content in a piece of green timber is determined? What is equilibrium moisture content? Explain the importance of moisture in its effects on the properties of structural timber.

8. What is meant by the defect in timber? Describe the following defects in timber with neat sketches:

(a) Encased knot (b) Shakes (c) Rind Galls (d) Foxiness

(e) Warping.

9 Discuss the effect of shrinkage on deterioration of timber. Is shrinkage tangential to the annual rings greater or less than radial shrinkage? Explain why?

10. What is meant by felling of timber? What are the advantages of felling timber in winter? What is girdling?

11. What are the objectives of seasoning of timber? Explain only one method of seasoning timber which is commonly used in Bangladesh.

12. What are mechanical properties of timber? Why are timber members ordinarily used in tension?

13. Explain why stiffness of structural timber beams may be of importance? Why is the determination of longitudinal shear important in designing structural timber beams.

14. Compare the shock-resistance property of timber with that of steel, cast iron and concrete.

15. What are the characteristics of good timber?

16. Enumerate the uses of timber in engineering constructions.

17. What causes the decay of timber? Name four antiseptics used for preserving timber and describe the pressure proc injection of preservatives in timber.

18. Discuss the effects of preservative treatments on the strength of timber.

19. Describe the action of termites in destroying timber in buildings.

20. How would you protect a new timber building from the destructive action of termites? What corrective measures would you employ for a house infested with termites?
21. What methods are employed to protect timber piles against attack by marine borers?
22. What is veneer? Explain the process of manufacture of plywood. Enumerate the engineering applications of plywood.
23. Write explanatory notes on (with neat sketches wherever possible) of the following:

    (a) Laminated Boards (b) Reconstructed Woods (c) Partex (d) Cork Boards (e) Kxugenous Tree (f) Ring Shake and heart shake (g) Water Seasoning of Timber (h) Facility and Workability of Timber (i) Empty Cell Method of application of preservatives in timber (j) Bleeding of timber.
24. Name the common timber tress of Bangladesh. Discuss any ten of them with respect to the following: Availability, properties and uses.
25. State typical values of maximum compressive and shearing strength parallel to the grain and density of the following dry timber: Chittagong Teak, Sal, Garjan, Hickory, Fir, Pine, Kail, Debdarou.

PROTECTTIVE COATING MATERIALS

16.1 Introduction: Many materials of construction need to be protected front deterioration. A large number of organic compositions are available in the market for this purpose. Organic protective coating materials may conveniently be grouped *as paints, enamels, varnishes and lacquers.*

16.2 **Paints:** The purposes of paints are fourfold: (1) Preserve the materials coated (2) Produce a pleasing appearance (3) Improve sanitary conditions and (4) Obtain better distribution of light.

Paints essentially consist of (1) a base (2) a vehicle (3) a pigment (4) a drier and (5) a thinner.

1.Bases: The base of a paint is its principal constituent forming its body. The materials commonly used to form the base of paints are white-lead, zinc white, lead, iron oxide, graphite, lithophone, antimony white and titanium oxide. The base forms an opaque layer to obscure the surface of the materials to be painted. White lead is a carbonate of lead. It is most commonly used base for building works. It is available both as a powder and in the form of a stiff paste containing about per cent linseed oil. The great advantage of using white lead is that cheap and can be easily applied and it has the property of obscuring the surface to which it is applied it Produces an elastic film which reduces the possibility of cracks in the covering film applied to the surface. Its disadvantages are that it darkens on contact with air containing sulphuretted hydrogen and therefore, it cannot he used for the top coats. It is very poisonous and proper care should be taken in mixing.

Zinc white is an oxide zine. It is becoming now-a-days more commonly used. Is non-poisonous and is unaffected by weathering actions but it is very costly. It retains its colour well and takes a fine polish. It is more commonly used for interior decorations.

Red lead is a higher oxide of lead which is available as a rust-colored powder. It retains his colour permanently. It is very heavy and very[7] often used for the first coat on wood work and as a base coat to iron and steel works to prevent the information of rust.

Oxide of iron (this is the red oxide of iron) is used a base for paints to be applied to iron and steel works. The use of white lead and zinc white is considered to cause a certain amount of galvanic action between the base of the paint and the metal covered and therefore, oxide of iron is often preferred as it also prevents the formation of rust. It is comparatively cheap. Graphite is also used as a base but it is rarely used in our country. For interior works, lithophone is largely used as a white paint. Lithophone is an intimate compound of zinc sulphide and barium sulphate. It is cheap, non-poisonous and has the same appearance as zinc white. It is largely used as a white paint for interior works. It becomes yellow when exposed to bright daylight. It is inferior to zinc white for exterior works and its film rapidly disintegrates. It is not used on iron surfaces or surfaces which come in contact with water.

Antimony while and titanium dioxide are sold under the trade name of *Tumoonox* and *Titanox* respectively. Antimony white becomes yellow while titanium paints remain unaffected due to weathering actions.

2, Vehicles: The function of a vehicle is to contain ail the materials of a paint and to allow them to be applied on the surfaces to be painted. Linseed oil of various grades is the main vehicle used in our country in making of paints. It is obtained from flax-seed. Linseed oil contains acids which react readily with oxygen and harden by forming a thin film. Raw linseed oil does not dry very quickly and therefore is not fit for external works. Boiled linseed oil dries more quickly than the raw linseed oil. It is also thicker, darker and more durable and is considered more suitable for external works.

For superior works, refined and double boiled linseed oils are used. Linseed oil becomes thicker on boiling and therefore the double boiled oil requires the addition of a thinning material which is usually turpentine.

Other oils which can be used as vehicle are wood oil. nut oil. dehydrated castor oil, soyabean oil cotton seed oil. tung oil and fish oil.

8. Pigments: A pigment is a colouring in gradient which gives desired colour to the paints. Pigments are available in the form of fine powders. The particles of pigments should be in completely wetted condition and duly dispersed in the vehicle. The best pigments are those that do not change their colour when exposed to weathering actions. The pigments are given in the Table.

Table 16. 1 Various Pigments for Desired Colom s Colour desired Name of pigment

White : White lead, zinc oxide, lithophone, titanium oxide. Blue Iron blue, ultramarine, cobalt blue, sublimed blue lead, indigo, Prussian blue.

Green : Chrome green. Paris green, copper sulphate emerald green. cobalt green, hydrated chromium oxide.

Yellow : Chrome yellow (lead chromate) zinc yellow, cadmium yellow, ochre (Chinese yellow), raw sienna.

Orange : Mixture of chrome yellow and red pigments of basic lend chromate.

Brown : Umber, sienna, copper oxide.

Red :Red lead cadmium red. Iron oxides, mercuric oxide, hematite ochres (Indian red and Venetian red), carmine, vermilion.

Black Lamp black, carbon black, drop black, graphite, alimony.

sulphide, suit and charcoal, black, ivory black.

4. Dryers: The function of a dryer is to absorb oxygen from the air and to supply it to the vehicle to dry and harden through the process of oxidation. Therefore, all compounds used as iryers are such as can absorb oxygen from the air and impart it to the vehicle which in turn sets hard on the surface it is applied. Driers are generally of three types (a) Soluble dryers which are dissolved in linseed oil (b) paste dryers, which are dryers mixed with certain inert fillers (termed as extenders) such as barytes whiting etc. ground to a paste in linseed oil, and (c) liquid dryers which are dryers dissolved either in tin seed oil or in turpentine or in both.

Litharge is the commonest form of dryer. It is lead monoxide. It is used generally for lead paints Lead acetate, manganese dioxide, zinc sulphate and manganese sulphate are the other types of dryers.

5: **Thinners:** A thinner is a solvent added to paints to obtain a product of desired consistency. It helps the paints to be spread uniformly on the surfaces. The thinner evaporates and dries die pa.nl consequently, the common thinners are turpentine, solvent naphtha and various petroleum thinners of low boiling range.

Various Types of paints:

(1) Oil Paints: These are not ready mixed paints. These paints are to be prepared with all the ingredients discussed already. The base should be thoroughly ground in oil and thinned by the addition of oil and turpentine. The pigments are separately ground with oil until thoroughly mixed and tendered blind by the addition of turpentine. The two mixtures of the base and pigments are then mixed together and full quantity of turpentine and oil is added to make the paint workable.

(2) Water Paints: Water paints include those paints of which the medium is water. They are prepared with a medium containing both oil and paint to which a certain amount of glue is added to form the emulsion of oil in water. They are used only for interior works or for the decoration of exterior surfaces.

(3) Aluminum Paints: These consists of very *finely ground* aluminum suspended in a medium of slow, *drying oil varnish or spirit varnish. These are expensive white paints, usually- used for decorative works. It protects iron and steel from* corrosion far better than any other paints. It can resist heat to great extent. It is, therefore, *especially used for painting* marine piers, oil tanks, gas tanks radiations and hot water pipes.

(3)

(4) Cellulose Paints: Cellulose paints differ from other paints in the process of drying which is timely affected by evaporation of the solvent without any chemical change being involved such paints are used mainly Jpr motor cars, aero planes and also for the decoration of prefabricated fittings. They are commonly termed as *spray paints.* They are made from nitrocotton, celluloid sheets, photographic films, etc. These paints pose great hardness, smoothness and can stand extremes to temperature. They can be easily washed and cleaned.

(5) Water-Repellent Cement Paints: These paints are used for providing a water-proof coat to external as well as internal walls of buildings. They can be applied on any surface. They generally consist of white cement incorporated with some water proofing agents (soaps, heavy mineral oils, fluosilicate- tea lime and petroleum jelly) antifungals agents (mycol complex emulsions etc.) and some binding agents. They available in v.u ions colour.

(6) Distempers: It is a form of water paint which contains water and oil as its thinning agents. Glue, starch of resin is used as base together with a pigment to suit the desired colour. Distempers arc used in all interior surface of buildings for decorative purposes.

Distempers are of two types mainly: (a) *oil hound distempers* which are generally available in the form of pastes and they are thinned before use by the addition of water (b) *ordinary distempers* (not containing oil) which are available in the form of power and they are to be mixed with water before use according to the instructions of the manufacturer. Distempers arc easily washable.

(7) **Miscellaneous Paints:** In addition to those paints already discussed, there are other paints available in the market. They are enamel paints, paints, lead paints etc. Their method of mixing and application are clearly written on the manufacturer's instruction sheets.

16.3 Enamels: An enamel is made by suspending pigments in a varnish. An enamel is characterized by and ability to form an especially smooth film. The amount of pigment in enamels is usually much less than in paints. A much higher degree of dispersion of the pigment in the vehicle is required in camels than is generally necessary with paints.

The enamels contain the same ingredients as those of paints but in different proportions. Enamels and paints serve the same purposes.

16.4 Varnishes: Varnishes do not contain any pigment. They are Lique’s composition which may be converted to transparent or translucent solid film after application in a thin layer. Varnishes consist of melted resin dissolved in hot linseed oil, turpentine or alcohol. Varnishes give brilliance to which they are applied. Varnishes dry quickly and tough coating or film which protects the surface of materials to be protected. Varnishes are also used to brighten painted surfaces and protected them from the atmospheric action. They are most commonly used for brightening the plain surfaces of timber in furniture and other building works.

Varnishes are two different types; (1) Oil Varnishes and (2) Spirit Varnishes. Oil varnishes dry as the result of chemical reactions induced by oxidation (air drying). Spirit varnishes dry solely through the evaporation of volatile solvents from the film. Oil varnishes contain resins, oils, dryers and thinners (Table 16.2).

Table 16.2 composition of Oil Varnishes

Resins Natural	Oils	Dryers	Thinners
Congo copal	Turpentine	Linseed	Active dryers
Kauri conpal	China wood Mineral spirits		Cobalt
Boea copal	Tail	Manganese	Naphtha
Pontiana copal	Benzine	Dehydrated	Auxiliary dryers
	castor	Lead, zinc	Coal-tar Manila
	copal	Perilla Higher alcohols	calcium and
Dammar	Oticicia	iron	
Sandarac	Soya bean		
Rosin	Fish		

Shellac

Synthetic Resins

Alkyd, phenolic,

urea formaldehyde,

vinyl, acrylic,

polystyrene, maleic, silicone etc.

Oil varnishes are prepared by combining oil with resins. The resin is melted and beated oil is added to it together with

necessary dryers. Turpentine and oil are added to bring it to a required consistency. Oil varnishes are generally applied to exposed works. Among the oil varnishes for common works, copal varnish is considered to be the best. This varnish is suitable for protecting exposed surface of timber, iron and steel works. It can made in number of ways as follows:

(I) Resin	2parts	(2) Copal 3 parts
Linseed oil	2 "	Linseed oil 3 "
Turpentine	I "	Turpentine 5 "

(3) Double boiled

linseed oil	3 "
Copal	2 "
Turpentine	1 "
Bees-wax	1 "

Spirit varnishes are solutions of one or more resins in volatile liquids. These varnishes are commonly used in our country and are prepared by dissolving gums and resins in methylated spirit. *French polish or shellac varnish* are also classified under this category of spirit varnishes. Varnishes composed of alcohol are sometimes classed as *alcoholic varnishes.*

Frenches Polish: This varnish is prepared by dissolving shellac in spirit. It is general used for brightening surface furniture articles. The following is the common recipe for.

French polish in our country:

Methylated spirit	3 gal
Black-shellac	3 lb.
Copal	½ lb.

Gum	½ lb.

Types of Varnishes: A convenient method is to divide varnishes into two classes: (I) Architectural varnishes and

(2) Industrial varnishes. The first group includes cabinet or rubbing varnishes, varnishes tor floors, doors and windows; exterior or interior varnishes, marine varnishes and decorative varnishes. The second group comprises of an even wider variety of compositions which may be applied to different surfaces by one of several methods, such as rushing, dipping, tumbling and spraying. Of interest is the term "oil length' which is defined as the number of gallons of drying sills to 100 pounds of resin in the manufacture of varnish. In general, a greater flexibility of the films and more resistance to weathering whereas arguer percentages of rising give finishes which are harder and capable of being sanded and polished.

Resins: A resint is an amorphous, vitreous of semisolid organic substance, which is insoluble in water but soluble in organic liquid or drying oils or after being heated gives a which is soluble in hot drying oils resins may be as *natural resins or as synthetic resins.*

Natural Resins: Copals are natural resins obtained from the hardened sap of fossil deposit of trees. The congo copals are the hardest natural resins. Other copals are the kauri, Boea. Pontiansk and Manila copals. All these copals require heating to produce and oil soluble gum, Dammar and Sandarac are natural resins obtained from the sap to living trees and are soluble in oil without the necessity of heating. Resin is a natural resin that is obtained as a bye-product from the manufacture of turpentine. The liquid resin is obtained

from pine trees by cutting a vertical slice in the bark of the tree and alloying the liquid to flow into containers Turpentine is removed from the liquid resin by distillation leaving resin as residue. Rosin is translucent, inflammable and relatively cheap. Resin is soluble in alcohol, turpentine and alkalis. It is used in varnishes and dryers.

Shellac is the only natural resin derived from animal life. Shellac is derived from lac which is the term applied to the resinous products of the scale insect *laccifer lacca kerr.* Shellac is soluble in ethyl-alcohol and methylated spirits and is partly soluble in turpentine, ether and chloroform. It is insoluble in oils and petroleum solvents. Shellac is used mainly in spirit varnishes and to some extent in cellulose nitrate lacquers. Commercial shellac is orange in colour. By bleaching with sodium hypochlorite, white shellac is produced which is called *bleached shellac.*

Synthetic *Resins: Synthetic resins comprise a heterogenous group of materials that have been developed extensive!} during recent years. Most of the advances in the technology of paint and varnish manufacture have been in connection with synthetic resins. The following are the various types of synthetic resin:

Alkyd Resins: They are manufactured by condensation reactions between glycerin and phthalic a hydride or modifications of these materials. These are important resin for organic protective contains.

Phenolic *Resins*: *These resins are utilized where durable* protection is important, particularly in deleterious atmosphere and in the presence of moisture. These resins are produced by condensation when formaldehyde solution (formalin) and phenol is heated together with a catalyst such as a trace of alkali or acid.

Other synthetic resins are vinyl resins (harder, less soluble and less compatible with oils than other synthetic resins) acrylic resins (white in colour even at higher temperatures resistant to acid alcohol, oils and chemical fumes) silicon resins (highly resistant to heat-and chemical and moisture attack), ester gun (made from resin and glycerin, highly resistant to alkaline waters), chlorinated rubber (made by chlorination of natural rubber used for painting concrete plaster and stucco surfaces and asbestos cement boards) maleic resin (made from natural resin and maleic acid, used to increase the hardness of the painted and varnished surfaces), polystyrene resins urea formaldehyde resins and melamine-formaldehyde resins.

Lacquers: Lacquer is the term used to designate an organic coating dries by the evaporation of solvents and thinners, leaving a film of material which was present originally in fully polymerized form. A lacquer is composed of nonvolatile portion which produce the form contains resin, film- former and plasticizer and in some cases pigment. The volatile materials or thinners comprise active solvents, latent solvents, diluents (See Table 16.3)

Table 16.3 **Composition of Lacquers**

Resins *Film-Formers* *Plasticizer* *Thinners*

Natural Cellulose nitrate *Solvent type:* *solvents:*

Shellac Cellulose acetate Dibutyl phthalate Amyl, butyl

Dammar Cellulose acetate- Tricrsyl phosphate and ethyl

butyrate. *Ethyl non-solvent Type:* acetates,

cellulose Castor oil Latent *solvents:*

Synthetic: Linseed oil Ampl, butyl and

Alkyd ethyl

alcohol’s

phenolic diluents:

Vinyl Toluene,

xylene

Acrylic- and

petroleum

Silicon naphtha

Ester gum Maleic

Resins are incorporated in lacquers to give gloss, hardness, brilliance, adhesion and polishing characteristics. Alkyd resins are extensively used in lacquers: they contribute to durability.

Plasticizers are softeners that are added to lacquers to impart flexibility. They improve the flowing properties of wet lacquers and retard the action of the solvents. Plasticizers also intensify the luster of lacquer coatings.

Thinners serve as solvents for the other ingredients and make possible the attainment of liquid lacquer of suitable viscosity for application.

Lacquer coatings are durable, waterproof, tough, and quick drying. They possess attributes of eye-appealing beauty easy touch up and easy application. Lacquers are however, much more expensive than oil (old resinous) varnishes.

16.6 Special Coatings: The following arc a tew special coatings:

(1) **Fire Retardant Coatings:** Ordinary paint films are highly flammable. They give of toxic gases including carbon monoxide: under confined conditions these gases may be given off in such quantities as to cause explosions, fire- retardant coatings can also be applied to unpainted wood to reduce the rate of combustion. Chemicals incorporated in flame-retardant paints include ammonium chloride, ammonium phosphate and borax. The coating of fire-retardant paint can be covered with applications of enamel of lacquers to produce a surface of high glass. Fire retardant are also available for metal surfaces.

(2) **Luminescent Coatings:** Luminescent coatings contain pigments that emit light following the absorption of radiant energy and the transmutation of this energy to a longer wave length. Generally, two types of pigments are used in luminescent coatings (a) fluorescent pigments, such as synthetic dyes (eosin, flavin etc.), rhodamine dyes, zinc sulphide or mixtures of zinc and cadmium sulphides, and (b) Phosphorescent pigments such as calcium sulphide and strontium sulphide.

Applications of fluorescent coatings are for aero plane and automobile instrument dials, radio and television dials and decorations in homes, stores and heaters. Florescent coatings are used in safety installations in buildings such as exit lights and markers for alarm systems.

(3)**Wax Polish:** This is an inferior type of polish consisting of bees wax mixed with turpentine. Generally, 2 lbs. of wax are melted with 1 lb of turpentine. The hot mixture is shirred and allowed to cool. It is rubbed into the pores of wood

surfaces for polishing, allowed to remain overnight and then wiped off and finally rubbed with a smooth Hunnel It is superior to and more durable than French polish. It is mainly used for polishing wooden floors, rails etc.

(4) **Knotting;** The term "knotting" is a process of killing. This is done before the application of paint or varnishes. The material used for knotting is a mixture or 1 pint of vegetable naphtha, I tea-spoonful of red lead, 5 oz orange shellac and some size. The most common material used for knotting is pure shellac dissolved in methylated spirit.

(5) **Size:** A size is a liquid-coating composition, usually transparent, for sealing a porous surface preparatory[7] to application of finishing coats. It is made from superior glues and is used with earthy colouring matter to make it adhere to surfaces.

Glue: Glue is made from waste pieces of skins, horns, hoofs and other animal wastes. A good quality glue is transparent. It swells considerably when mixed with water, but does not dissolve into it. Glue is used as a coating material.

(6) **Putty-** This is made with chalk (whiting reduced to fine powder and mixed with a little linseed oil to make it a stiff paste. It is generally applied after the priming coal of paint and not before, as otherwise the timber absorbs the oil present in the putty. Putty is also used for fixing glass panes to doors windows. It can also be made colored by adding some colouring ingredient io give the required colour.

16.7 Preparation and Painting of Surfaces

Preparation of Surfaces: Surfaces should be properly prepared before protective coatings are applied. Cleaning of metal surfaces prior to paintings in fully as important as the selection and application of protective coatings.

Structural Steel Members: Structural steel members should be cleaned free from mill scale and rust while in the shop & given a prime coat before shipping to the field. Weathering of unpainted structural steel followed by wire brushing in field usually results in partial removal of only mill scale & rust and old paint coats is accomplished by several methods including brushing with hand or power-driven wire brushes, hand scraping, chipping by flat chisels, sand blasting and cleaning with oxyacetylene flame. A priming coat should be applied to the surface promptly after cleaning. Second and third coats should be applied at intervals of several days.

Sheet Steel: Sheet steel pressed into shapes for automobile bodies should have loose, scale, rust, grease, oil and dirt removed before being given a protective coating. Treatments should produce a clean, stable and less reactive surface that provides good adhesion for coatings. Generally phosphoric acid is applied to remove grease and oil and acid pickling is used to remove scale and rust and to each the metal surface, providing roughened surface for mechanical bonding of the providing the metal. Phosphate coatings can be used to inhibit corrosion and improve the paint retention characteristics of the metal surfaces.

Wood *Surfaces:* Wood should be thoroughly dry, before paint is applied, Knots should be given an application of shellac before painting so as to prevent resin in the knots from

breeding into the paint. All glue spots should be removed. Wood surfaces of cabinets and interior woodwork should be planned to remove factory marks, scrapes with a hand scraper and sanded and rubbed with sandpaper before finishing materials are applied.

Plastered Surfaces*:* Plastered surface should be brushed with a zinc sulphate solution before painting. Prior to repainting, grease should be removed by benzine and the walls should be washed with soap.

Concrete Surface: Cement and concrete surface should be treated with benzine to remove grease and oil and then a zinc sulphate solution should be applied to neutralize the lime in the concrete.

16.8 Method of Application: Protective coatings for structures and houses are applied by brushing and spraying on both exterior and interior works. Emulsion paints and water paints are applied to interior walls by means of cloth or felt rollers. Spraying is used in coating automobile bodies steel furniture etc. Manufactured, articles are coated by roller coating is well adapted to flat metal sheets and composition boards. In machine dip coating, objects are attached to a moving conveyor chain which dips them into tanks of paint, varnish or enamel. Flow coating is used for large pieces that are suspended over a tank of desired protective coating materials.

16.9 Standard Tests: Numerous tests for determining physical and chemical properties of organic protective coating materials have been standardized by the ASTM.

Paints and Enamels: Tests For paints and enamels include consistency of exterior house paints and enamel type paints, relative drying power and measurement of dry film thickness.

Varnishes: Tests tor varnishes include specific gravity appearance, colour viscosity, flash point, non-volatile matter elasticity (toughness), reactivity between paint liquids and zinc oxide and resistance of dried films to water and to alkali. *Lacquered:* The tests include density, drying time, gloss, outdoor exposure, non-volatile matter and consistency.

Questions

1. List the different types of components of each of the following: (a) Ordinary paint (b) Oil Varnish (c) Spirit Varnish (d) Enamel.
2. What is meant by each of the following terms: (a) a resin (b) a pigment (c) a thinner (d) a dryer (e) a plasticizer (f) a size.
3. For what purposes is paint? Give examples.
4. What are the different general types of pigment several examples of each type.
5. Name the different types of vehicles. What are the principal drying oils?
6. Describe the properties of the following resins with respect to their use in protective coatings: Shellac, Resin, Alkyd, Vinyl, Dammar.
7. Distinguish between fluorescent and phosphorescent pigments. Give examples of each.
8. How should a structural steel bridge (old) be prepared for repainting?
9. Describe the process of preparation of surfaces and application of paints on timber furniture.
10. Write explanatory notes on the following:

(a) Litharge (b) Aluminum paints (c) Distemper (d) French polish (e) Fire retardant coatings (f) Wax polish (g) Knotting (h) Putty (i) Oil lengths.

CHAPTER-SEVENTEEN
MISCELLANEOUS ENGINEERING MATERIALS

17.1 Coal: Coal is the final stage reached by the decayed and compressed former forest and vegetation. Partly decomposed forest and vegetation is known as *peat.* Through countless ages, chemical changes have taken place, so that the coal is now mines as a brittle, black which may contain any thing between 70 percent and 90 percent of carbon. A large proportion of the hydrogen and oxygen which present in the original wood has gone roughly speaking coal can be divided into two kinds: (1) Soft of Bituminous Coal and *(2)* Hard or Anthracite Coal.

Bituminous coals burn easily with a flame and produce an amount of smoke which varies considerably with the various grades of coal. Anthracite coal actually contain hardly bitumen and for this reason gives off little smoke. The heating value of a coal depends on the amount of carbon it contains and since anthracite coal has a high proportion of carbon, it has a high heating value. For this reason, it is much used on ships and in boiler plants.

Coal is still the material best known and most used for fuel but making in the search for materials from which energy can be obtained has used wood, peat, coal, oil, even harnessed the power of wined, tide and water.

There seems to be no end to the products made from coal.

The Fig. 171 shows the coal, its bye-products and the irrespective uses.

In Bangladesh coal of good quality was hit at a depth of over 3,600 ft and the' drilling revealed a total thickness of 1,212 ft. The composite thickness of 108 ft of Gondwana bituminous coal has been improved. The latest estimates place the reserves as high as 600 million tons in Bogra and Jamalgonj areas. The reserves of coal in Sylhet district are estimated to be about 3 million tons.

17.2 Glass: The name 'glass' comes from the latin word *glavcies* meaning ice. others from the Gallic word glassum meaning amber while some authorities claim the word comes the Anglo-Saxon *glisnian* meaning to shine.

Glass has been defined as a hard, brittle, transparent, nanocrystalline solid consisting of a mixture of silicates of metals. Roughly the composition of different glasses most commonly used is as follows.

Material	Ordinary or bottle glass	Window glass	Plate glass	Flint or Cut glass	Fusible glass for chemical apparatus	Infusible glass for cornbustion tubes.
Silica	60-70%	70-75%.	74-78%	50%	70%	73%
Potash	2-3	-	17	12	2	10-12
Lime	15	13	6	-	8	10
Soda	5	13	-	-	16	3
Lead oxide	-	-	-	30	-	-
Alumina	5-7	4	1	1	1	1

Silica is the principal raw material for all types of glasses. It fuses at a very high temperature and requires the addition of an alkaline material (sodium or potassium carbonate) to reduce its melting point and to impart sufficient viscosity to make il workable. Soda causes the glass to fuse but an excess is harmful. Potash imparts infusibility and adds fire resisting properties to glass. Lime gives sparkling brightness. Sometimes, borax or boric acid is added to silica which acts as flux and reduces the melting point and gives a physically stable product having a low thermal expansion.

Manufacture of glass: The raw materials are properly ground mixed in required proportions and melted in furnace. Sometimes broken glass or scrap glass (usually known as cullet) is added to the raw materials before meltine in the furnace. After the glass mixture has been melted in the furnace. It is given the required shapes and finish by various process.

Properties of glasses: *Glass is brittle,* amorphous *and very ductile at high temperature. Glasse varies in weight, but generally* is about two and a half times as heavy as water, so that one cubic foot of *glass weight roughly 160 lbs, Glass has* low thermal *coefficient of expansion (800x106 to 900x 106 per deg C). Glass is comparatively chemically stable and resistant to acid attack Glass* possesses very *excellent optical properties. Ordinary glass rods (1/2-inch diameter) have an ultimate tensile strength of about 10.000 psi and the strength varies inversely with the area. Glass fibers (0,00005 inch* Dia-meter) may have an ultimate tensile strength of about 3.500.000 psi.

Types of Glass: The following are the various types of glasses:

Sheet Glass: It is generally used for door and window glazing.

Plate Glass: It is used mainly for glass curtain wall ring, long ranges of windows and partitions.

Wired glass; This type of glass contains a wire mesh introduce into the center while casting. It is mainly used in skylights, windows etc.

Safety glass (laminated Glass): This glass is manufactured by placing a sheet of transparent celluloid or resinoid bet - ween two sheets of plate glass and the whole is moulded together. This is mainly used for car windshield and doors and windows.

Soda-lime Glass: It is generally used for manufacturing hollow glasses, such as bottles, hurricane chimneys drinking glasses etc.

Borosilicate Glass: This type of glass is very stable both physically and chemically. Chemical apparatus, Pyrex dining wares and lenses are manufactured from this type of glass.

Fiber Glass: This is a very important variety of glass. It is used mainly for sound and thermal insulation in walls floor, ceilings, covering of hot water pipes and cylinders and also in the form of cloth tape etc. for electrical insulation purposes, It is available in the form of sheets, mattresses.

It weights approximately 3 lbs. per eft. The glass fibers are made in seven standard diameters varying from 0.0002 to 0.008 inch, resistant to attack by fire, acid, oil and sea water.

Since it can resist high temperature (2760°C or 5000°F) it is now a days used in jet aircrafts and guided missiles The strength of fiber glass varies from 10 to 14 x 10^6psi.

Glass wool: Glass can also be made into a fluffy material known as glass wool and this has very good acoustical and insulating properties.

Lead Glass: This type of glass has an average composition of 72% silica. 17% soda and 12% lead oxide. Lead glass is very' heavy the specific gravity being 45 to 6.33, Lead glass is used for cut glassware, optical glasses and for ornamental purposes.

Foam Glass: It is a lightweight cellular glass used in cold storage chambers.

Pyro Ceram: This is a special type of glass which is lighter, stronger and more heat resistant. It is mainly used in some functional pearls of automobile engines:

Plastic Glass: This type of glass is manufactured from plastics which have a high transparency. Perspex is a special variety of plastic glass. Perspex is used widely in making laboratory apparatus like flume, simulated channel, wind tunnel etc.

Opaque Glass: Glass is rendered opaque by the following methods.

(a) ***Frosting:*** In this process the glass surface is ground by the help of sand blast giving frosted appearance. Sometimes acids are also used for this purpose:

(b) **Grinding:** The glass surface is subject to a grinding machine which while grinding produces waves and thus opaque surface is obtained:

(c) **Ribbing:** the glass surface is ribbed in triangular fashion thus obstructing direct vision and

(d) **Using Colored Plastic Sheet:** By placing colored plastic sheets between two sheets of glass.

Opaque glass is generally used for wall linings and shelving.

Coloured Glass: Glass wares can be given various-colours. The colour may be of two types:

(a)**Pot Colour:** With pot colour the shade is uniform throughout the thickness of the glass which may be rolled or drawn. This type of coloured can be manufactured as both transparent and opaque with the desired colours:

(b) **Flash Colour:** Flash colour is used only in case of blown glass and the colour consists of thin flash on the surface.

The following substance are used for various colours in glasses:

Colour Desired	***Colouring substances***
Black	Cobalt, Nickel. Manganese. oxide, Ferric oxide
Red	Gold, Selenium sulphide. Cuprous oxide.
Yellow	Selenium, Cadmium sulphide. Carbon and Sulphates.
Green	Chromic oxide.
Violet	Manganese oxide.
Blue	Cobalt oxide, Cupric oxide.
Amber	Sulphur and Iron oxide.

Mirror: Mirrors are made by silvering one side of a sheet glass. Silvering is done by precepting a film of nitrate of silver on the surface of the glass and protecting this film with shellac or with some other suitable mirror paint.

17.3Rubber: Rubber is an important engineering material. It is used for the manufacture of tires and tubes for cars, trucks, buses, tractors, cycles, aero planes, etc. Rubber absorbs shock and is elastic in nature. These qualities recommend the rubber to be used in engineering works, especially when it is associated with asbestos and other such materials. Other uses of rubber include belts, pipes, sheets, gaskets, toys etc.

Rubber is of two types: (1) Natural Rubber and (2) Synthetic Rubber.

Natural: The chief source of natural rubber is the milky juice known as *latex* which is obtained from the bark of rub grow abundantly in Bangladesh (Chittagong Hills). Ceylon. Malaya, Singapore, Burma, Mexico, Peru, Venezuela and in North Africa.
Latex is obtained from rubber trees by cutting vertical grooves, about 2 ft long in the bark in the cambium layer starting from a point 2 to 3 ft from the ground upwards. Rubber in its crude form is obtained by coagulating latex and washing it in hot water. During the process of coagulation, the rubber settles down like curd and water is liberated which

is drained off. The materials used coagulating latex are alcohol, acetic acid, alum etc. The coagulated latex is torn into small pieces in a special machine through which water is constantly circulated and rubber pieces thus obtained are dried, squeezed through rollers, flattened into thin sheets. The next process consists of mixing the rubber with certain fillers which are cheaper substances used for hardening, colouring cheapening its physical and chemical properties. Cheapening (also known as compounding) is usually done by employing materials such as Sulphur, tar, oil, asphalt etc. Necessary pigments are added to give the desired colour.

Vulcanization: Vulcanization is the process of manufacturing metrical rubber. Almost all rubber to-day is vulcanized. Charles Goodyear developed this process of manufacturing rubber in 1839 which gave a real acceleration to the rubber industry. This process consists in mixing Sulphur with pure or crude rubber and heating the mixture to a temperature (about 300°F) above the melting point of sulfur when it combines with rubber. The chemistry of vulcanization is not yet fully understood. As the mixture of rubber and Sulphur is beated in a steel vessel, the Sulphur first melts and combines chemically with rubber. The effects of vulcanization are: *(a)* increase in tensile strength (b) increase in resistance to weathering (less affected by temperature changes than pure rubber) (c) more elastic (d) good flexibility
(e) improved resistance to solvents and (f) good dimensional stability for longer period. All these properties are entirely dependent on the degree of vulcanizing temperature, curing period, and the Sulphur content. Sulphur is added in a proportion of about 2 to 5% depending on the work for which

the rubber is to be used. A higher percentage of Sulphur is used for rubber required for belt is etc. and a lower percentage is suitable for rubber to be used for rubber shoes and other ordinary rubber goods. As the Sulphur content goes on increasing vulcanized rubber becomes hard and brittle. Rubber containing large percentages of Sulphur, about 35 to 40 per cent and vulcanized at high temperature is termed is termed as *chonite.*

Physical Properties of Natural Rubber: It is very strong in tension Very clastic, insoluble in water and a bad conductor of heat. When melted it becomes soft; when placed in boiling water, it loses most of its elasticity but on cooling it regains its elasticity and hardness. The melting point of natural rubber is about I2°C and after melting it does not harden again, rubber goods require protection against the deter mental action of oils, grease and fats, so, they are kept dusted with French chalk. The specific gravity rubber varies between 0. 93 to 0. 97.

Uses of Natural Rubbers: Rubber is a very important engineering material. It is used for the manufacture of types and tubes for cars, trucks, buses, tractors cycles, aero planes etc. about 70 percent of the world production of natural rubber is consumed by the automobile tire and tube industries. Other uses include belts, pipes, rubber flooring, sheets, gaskets, toys etc.

Synthetic Rubber: Nowadays rubber is manufactured artificially from acetylene gas. It is sold under the trade names buty, Neoprene, Chloroprene etc. Synthetic rubber possesses certain properties which are impossible with the is drained off. The materials used coagulating latex arc alcohol, acetic acid, alum etc. The coagulated latex is torn into small pieces in a special machine through which water is constantly circulated and rubber pieces thus obtained are dried, squeezed through rollers, flattened into thin sheets. The next process consists of mixing the rubber with certain fillers which are cheaper substances used for hardening, colouring cheapening its physical and chemical properties. Cheapening (also known as compounding) is usually done by employing materials such as Sulphur, tar. oil. asphalt etc. Necessary pigments are added to give the desired colour.

Vulcanization: Vulcanization is the process of manufacturing metrical rubber. Almost all rubber to-day is vulcanized. Charles Goodyear developed this process of manufacturing rubber in 1839 which gave a real acceleration to the rubber industry[7]. This process consists in mixing Sulphur with pure or crude rubber and heating the mixture to a temperature (about 300°F) above the melting point of sulfur when it combines with rubber. The chemistry of vulcanization is not yet fully understood. As the mixture of rubber and Sulphur is beated in a steel vessel, the Sulphur first melts and combines chemically with rubber. The effects of vulcanization are: (a) increase in tensile strength (b) increase in resistance to weathering (less affected by temperature changes than pure rubber) (c) more elastic (d) good flexibility (e) improved resistance to solvents and (f) good dimensional stability for longer period. All these properties are entirely dependent on the degree of vulcanizing temperature, curing period, and the Sulphur content. Sulphur is added in ^{a} proportion of about 2 to 5% depending on the work for which

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Physical Properties of Natural Rubber: *It is very strong in* tension Very elastic, insoluble in water and a bad conductor of heat. When melted it becomes soft; when placed in boiling water, it loses most of its elasticity but on cooling it regains its elasticity and hardness. The melting point of natural rubber is about 12°C and after melting it does not harden again, rubber goods require protection *against the deter mental* action of oils, grease and fats, so, they are kept dusted with French chalk. The specific gravity rubber varies between 0. 9 3 to 0. 97.

Uses of Natural Rubbers: Rubber is a very important engineering material. It is used for the manufacture of types and tubes for cars, trucks, buses, tractors cycles, aero plane etc. about 70 percent of the world production of natural rubber is consumed by the automobile tyre and industries. Other uses include belts, pipes, rubber flooring, sheets, gaskets, toys etc. ,

Synthetic Rubber: Nowadays rubber is manufactured artificially from acetylene gas. It is sold under the trade names buty, Neoprene, Chloroprene etc. Synthetic rubber possesses certain properties which are impossible with the natural rubber. These properties are: (a) resistance to acids, grease, kerosene and petroleum, (b) highly resistant to sunlight, heat and deterioration by oils etc.

Synthetic rubbers are of the following types:

Butadiene: They resemble natural rubber in many respects. They are highly resistant to oils and heat and can be used in combination with natural rubber. They can also be vulcanized.

Polysulphides: They resemble less to natural rubber. Some of them cannot be Vulcanized. They are best oil-resistant.

Polyacrylates: They are best heat-resistant some of them resemble less to natural rubber. They are used for high temperature gaskets in gas-turbines and jet aircrafts.

Silicone: Silicone rubber is produced by polymerizing silicone liquids. Its production cost is higher than the other synthetic rubbers. It shows little change for a wide variation of temperature. It also possesses excellent water and oxidation resistance. It is mainly used for electrical insulation, wire and cable coverings, high temperature gaskets in gas turbines and jet aircrafts etc.

Buna-S: This is another variety of synthetic rubber made wholly from petroleum. It is dark brown. It can resist heat, the action of petroleum, grease and oils better than natural rubber. But it is not so elastic as natural rubber and there manufacturing motor tyres.

Due to special qualities, the synthetic rubbers are mainly used for petrol pumps, packing for oil-working machinery, gaskets, nose pipes for carrying petrol and kerosene oil insulator tor high resin wires, tyres, tubes, toys etc.

17.4Plastics: Plastics include a wide range of organic materials manufactured from natural or synthetic resins. Accordingly. Plastics are of two types; natural plastics and synthetic plastics. Natural plastics are manufactured from natural resins, such as shellac, wax, tar etc. The properties of natural resins cannot be controlled easily and therefore, natural plastics are not much importance to the engineers. Synthetic plastics are manufactured from the synthetic resins. This type of plastics is most commonly used by the engineers and therefore, in this text only synthetic plastics will be dealt with.

Actually, plastics age started from 1909 when Dr. Bakland first produced the phenol formaldehyde resin. The chemists developed the science of plastics and the engineers' applied plastics in engineering constructions for its many fold properties. The wide range of colours, simplicity in fabrication light weight, excellent insulating properties, resistance to wear, corrosive chemicals and oxidant agents and moderate strength properties make plastics an industry. The following are some of the uses of plastics: a) used to make paints, varnishes and lacquers (b) used as resins, glues and adhesives. (c) used as laminated safety glasses (d) used as photographic films (e) used for paneling, gears, couplings and other similar purposes (f) used in making lenses & prisms (g) used as decorative articles, fabrics, packing and lining materials.

Basic Materials for Manufacturing Plastics: The following are some of the basic materials for manufacturing plastics:

Formaldehydes: It is pungent gas produced by the oxidation of methyl alcohol or by the oxidation of ethylene in the presence of a catalyst like copper, silver, etc. Its boiling point is 21 °C. It is a very important raw materials for manufacturing plastics. Plastics are manufactured by reacting formaldehyde with phenols, urea and melamine.

Phenol: It is a colorless and hydroscopic organic acid (carbolic acid). It has strong disinfectant properties. Its melting and boiling points are 43°and 183°C respectively.

It is mainly used for manufacturing phenol-formaldehyde resins, detergents, preservatives and food staffs.

Urea: It is soluble in water but insoluble in either. It is the main constituent of urine of both human beings and animals. It is mainly used for the manufacturer of urea-formaldehyde resins.

Vinyl Chloride*:* It is a gas which can be liquidities in a freezing mixture. When dry hydrogen chloride is reacted by passing over acetylene gas, the product is known as vinyl chloride from which polyvinyl chloride from which polyvinyl chloride is derived.

Vinyl Acetate; When acetylene gas is passed over acetic acid, vinyl acetate is formed. This is a monomer from which polyvinyl acetate is derived. Vinyl acetate is liquid at room temperature.

Cellulose: Cellulose is substance which forms the cell walls in all plants. Wood, cotton and other fibrous materials are the chief sources of cellulose. Paper pulp is also used for producing cellulose. It is a raw material for manufacturing of paper, artificial silk, plastics (cellphone).

Styrene: Styrene is constituent of essential oils and coal tars. It is soluble in alcohol and other. Its boiling point is 145°C. It is largely used for the manufacture of synthetic rubber and polystyrene (a plastic product).

Propylene: It is a colourless gas. Its boiling point is I85°C. It is melting point is 48°C. It is mainly used for the manufacture of acetone detergents, lubricating additives & plastics.

Ethylene: It is a colourless gas manufactured from ethane or propane. Its boiling point is 170°C and milling point 104. It is mainly used for the manufacture or polyethylene plastics.

Melamine: It is the chief raw materials for manufacturing thermosetting plastics (Urea formaldehyde. Alkyd, Casein. Polyester etc.), Melamine is derived from calcium carbide.

Types of Plastics: Plastics are generally grouped into two classes: (a) thermoplastics and (b) thermosetting, depending upon their behavior on heating.

Thermo-plastics: These can be softened upon heating to a plastics mass and can be shaped as desire on cooling, they harden. If reheated they will again soften and then harden on cooling as before will still retain essentially all their original properties and the process can be repeated any number of times. The softening is due to the loss of strength of mechanical bond and thus the material becomes flexible scrap and discarded thermoplastic materials can reheated and moulded to any desired shape. During the process of moulding the process of moulding the materials must be kept in their moulds until hardened. The use of thermoplastics at temperatures over 150F and below 40 F is not generally recommended. The famous thermoplastics are: Nylone, Acrylics Polystyrene Polyvinyl chloride (P.V. C. Polytene, Polyvinyl Formal Polyvinyl Butyral, Polytetrafluoroethylene Cellulose Acetate-Cellulose-Acetate-Butyrate, cellulose Nitrate).

Thermosetting Plastics: These consist of substances such as phenol formaldehyde, urea-formaldehyde phenol formaldehyde resins etc. which fuse or melt upon heating and then harden permanently which cannot be remelted. The behavior of thermosetting plastics is similar to that of setting concrete. The chemical action which once harden, the material cannot be reversed. The material once broken or scrapped cannot be remitted of reshaped. This is the main disadvantage or all thermosetting plastics. These plastic materials can be taken out from the moulds after hardening more quickly than thermoplastic materials. Thermosetting plastics are more suitable for engineering applications. The well-known there, Mo setting plastics are: Phenol Formaldehyde, Phenol-furfuraldehyde, Urea-Furaldehyde. Cast Phenolics, Epoxy resins Polyester, Melamine Formaldehyde, Alkyd and Casein.

Manufacture of Plastics: AH plastics are manufactured by the chemical reaction known as *polymerization:* I^{n} polymerization several simple molecules (monomers) of an

organic substance arc combined with to form a more complex molecule without altering the original empirical formula of the simple molecule. Due to polymerization a large complex molecule is developed with higher molecular weight when the process is accompanied by the elimination of water, it is known as *condensation polymerization* and when there is no loss of other materials, the process is said to be *addition polymerization.* A co-polymer is formed when two different substances (for example vinyl chloride and vinyl acetate) are polymerized. For the manufacture of plastics, the desired quantity of powdered resins is mixed with fillers, plasticizers and solvent in different proportions.

Fillers: Fillers are used to increase in bulk and to reduce cost. Common Fillers include wood powder, paper, asbestos, shredded cloth, mica, graphite, iron filings etc. The choice of a particular type depends upon the finished products. Fillers also impart greater tensile strength and shock resistance to thermosetting plastics.

Plasticizers: They are non-volatile oily organic liquids.

Dibutyl phthalate and tricresol phosphate are the most widely used plasticizers. Plasticizers are added to impart softness flexibility, toughness, elasticity, noninflammability and low temperature resistance. Plasticizers are also used to improve the flow property of thermosetting plastics.

Solvents: solvents are volatile materials. Common solvents are alcohols, petroleum and coal-tar spirits. Solvents give fluidity for casting and forming.

In addition to the above materials, the following materials are also used to serve specific purposes:

Dyes and pigments*:* To impart desired colours to the plastic dyes and pigments are used. These materials should not affect the desired properties of the finished products.

Lubricants: Lubricants are used to assist removal of the product from the mould. These materials should be such that they should not react with plastics while forming, common lubricants are oils, waxes, soaps and tatty acids.

Catalysts: Catalysts are used to accelerate the chemical reaction (polymerization) of the ingredients of plastics. Catalysts are of various types: acid catalysts (sulphuric acid etc.) alkali catalysts (ammonia etc.), metallic catalysts oxides of silver, copper zinc. etchant salt catalysts (neutral salts, lead salts and ammonium salts etc.).

Hardness: These materials impart hardness and help in solidification of plastics.

Compression Moulding: It is simple and slow process of moulding plastics. In the method the moulds are made in the form of plates which are heated first: the raw' materials are placed between them and the required pressure is applied. The heat causes the resinous materials to be in plastic state and the pressure forces them to fill up the moulds. The excess material is squeezed out and is removed. The moulding time various from 30 seconds to 1 hour.

Colour effects in layers easily be given by varying the temperature in the mould after purring in the differently coloured raw materials. Colour effects can also be produced pouring in different coloured liquids in the moulds at the same time. The moulds of castings are usually made of zinc blocks, wood plaster of Paris and steel (in case to withstand

high pressure). In case of thermosetting plastics, cooling of mould is not necessary but in thermoplastic moulding the moulds must be cooled before removing the plastics.

In compression moulding usually two types of moulds are used: *Positive Mould* and *Hash Mould.* In a positive mould the exact weight of the raw materials required for moulding is used but in Hash mould an excess of raw materials than required for moulding is used and the excess material is finally squeezed out after casting.

Injection Moulding: This is a much quicker process and is generally used for moulding thermoplastic materials. In this process the raw materials are first softened by heating them in a chamber and then forced (injected) them by a ram through a nozzle into cold moulds where plastics becomes hard. This is a fully automatic process.

Extrusion Moulding: This process is adopted for the manufacture of thermoplastic materials; this is not a very costly method. This is similar to injection moulding. The raw materials are first softened by heating and then forced out by a screw through a die of desired shape. It is a continuous process of manufacturing materials like plastic sheets, reds. tubes etc.

Plow Moulding: This process is adopted when articles like bottles, jars and similar hollow types are to be moulded. The principle of this process is same to that of glass blowing

Lamination: The principle of this process is same to that of binding veneers into plywood. Sheets of wood, asbestos paper, cotton, glass fabrics, metal foils etc. are spread with trendsetting materials which are heated in the desired number of layers and subjected to heated plates under liydnillc pressure. The sheets are pressed and the resin hardens joining the sheets permanently. Due to lamination the strength of the finished products increases. These laminations are used in aero planes, automobiles, railcars door and window glazing and for decorative and architectural purposes.

Thermoplastic Materials: The following are some important thermoplastic materials with their manufacturing process, properties and specific uses:

Polystyrene Plastic: It is prepared by catalytic polymerization from styrene. It is highly resistant to chemicals and crystal clear like glass. It is very light and transparent and is highly resistant to water penetration. It has good dimensional stability and excellent electrical properties.

It is mainly used as electrical insulators, fancy decorative articles, packaging, toys tank linings and making floats.

Nylone: It is also known as Polyamide plastic. It is manufactured by condensing acetic acid with hexamethylene diamine. It has excellent mechanical strength. It is highly resistant to abrasion, most corrosive acids and solvents, it is primarily used for bearings, gears, and other parts spectacle frames, door knobs packaging, bottles, pipes, fabric, cord belts, toys etc.

Polyvinyl Chloride Plastic: This derived through polymerization of monomers (vinyl chloride etc.) It is hard, rigid but slightly flexible. It has good chemical resistance, good insulating properties. It is highly resistant to abrasion and corrosion.

Main uses include pipes, acid containers, raincoats, shower curtains, fabrics, electrical insulations floor coverings recording tapes toys etc.

Polyvinyl Formal Plastic: It is tough and hard. It is resistant to water and abrasion. It has good electrical properties. It is used as waterproof cloth, electrical insulating material, insulating enamel, surface, coatings, interlayer in safety glass, adhesives and laquears.

Polyvinyl Butyral Plastic: It has good mechanical properties. It is highly resistant to water. It is mainly used for upholstery adhesives lacquers, waterproof cloth, insulating materials etc.

Polythene: It is a tough, flexible waxy and lightest plastic material. It is highly inert to solvents and corrosive chemicals.

It has excellent electrical properties. It has low water absorption capacity and good dimensional stability-'. It is widely used as insulating material, wire covering, corrosion proofing lining, chemical apparatus, food packages, bags, containers, cloth etc. **Polyvinyl Chloride Acetate Plastic**: It is strong, hard and durable material. It is a rubber substitute and used mainly for manufacturing tyres, tubes, fabrics etc.

Polytetrafluorethylene Plastic: It has very good chemical resistance and electrical properties. It is resistant to high temperature. It is very costly. It is mainly used as insulators
chemical equipment’s bearings, valve seats, etc.

Cellulose Acetate Plastic: For the preparation of cellulose acetate, acetic acid is used. It is a tough, durable and strong.) It has high moisture absorption capacity and phases high insulating properties. Its main uses include photographic films, spools toys, costume jewelry. spectacle frames, packaging, handles, knobs etc.

Cellulose Nitrate Plastic: Nitric acid is used for the preparation of cellulose nitrate. It is tough and highly inflammable. It has high impact strength and low water absorption. It is used for the manufacture of photographic films, tool handles. lacquers etc.

Cellulose Acetate Butyrate Plastic*:* It is tough, strong and durable. It is highly resistant to heat and weathering action. It is mainly used for tool handles, knobs oil and gas lines Instrument housing signs and display.

Acrylics: First hydrocyanic acid is added to acetone and the product is reacted with sulphuric acid, followed by a further series of chemical processes until methyl methacrylate is produced, which is finally polymerized by heat to produce polymethyl-methacrylate. They are more transparent than glass. They have got perfect clarity. They are highly resistant to sunlight and weathering. They have good flexibility and rigidity. They are semi brittle and have low water absorption •capacity.

They are used as decorative articles, large transparent sheets (used in aircrafts, motor cars and other building industries), instrument cases, lamp holders and shades window sheets and reflectors.

Thermosetting Materials*:* I he following are some of the important thermosetting materials with their manufacturing process, properties and uses:

Phenol Formaldehyde Plastic*:* This type of plastic is manufactured from phenol formaldehyde resins combined with various percentages different fillers. It is very heavy, hard rigid and resistant to heat, organic solvents, weak acids and alkalis. It has low water absorption capacity and good electrical properties.

It is used as electrical fittings, mechanical and thermal appliances of all kinds, decorative articles housing for radios television, cameras and electrical goods.

Phenol Furfuraldehyde Plastic: It is dark in colour. It can be fabricated in a wide variety of ways including both hot and cold moulding. It is strong and durable. It is mainly used for making decorative articles, lighting fittings, toys, etc.

Urea-Formaldehyde Plastic: It is a light-colored plastic. It has good mechanical and electrical properties. It is resistant to organic solvents but has high water absorption capacity. It is mainly used for decorative articles, electrical fitting. kitchen equipment, etc.

Melamine-Formaldehyde Plastic: It is highly resistant to heat, organic solvents, greases, weak acids and alkalis and water. It is mainly used for decorative articles, housing for radios, cameras etc., glass fabrics and glass reinforced plastics.

Alkyd Plastic: It is resistant to water, heat and organic solvents. It has good dimensional stability and electrical properties. It is used as insulating material electrical fittings etc.

Casein Plastic: Casein is a product of skimmed milk which react with formaldehyde to produce a plastic material. It is resistant to weak acids but affected by weak alkalis and water. It is used for the manufacture of buttons buckles decorative wears, furniture, handles, fountain pen. barrels, umbrella handles etc.

Polyester Plastic: It is thermosetting and is available both as surface coatings and as moulded and cast products. It is highly resistant to heat and impact. It is unaffected by weak acids. It is used for making laminated objects, reinforced plastics fiberglass etc.

Cast Phenolic Plastic: It has very good colour stability. It is available in various shakes and colour. It is used for manufacturing costume jewelry, decorative articles, hardwires, instrument handles etc.

Epoxy Resin Plastic: It is highly resistant to chemicals thermal and mechanical shocks. It has excellent adhesive properties. Its uses include the production of reinforce plastic insulation material and lacquers for electronic equipment.

In addition to those plastic products mentioned already, the following are some of the well-known plastic products.

Celluloid: It was invented in 1911 by W John and I.S. Hyatt. It is manufactured by mixing nitrocellulose (40%) with powdered camphor *(20%),* sprinkling alcohol on the mixture, kneading it at low temperature (35°C) for couple of hours, then heating it and finally pressing it into the form of desired

manufacturing sheets, blocks etc. Pigments are added during kneading lor desired colour add shade. Urea is added as a stabilizer lor making transparent plastic. Celluloid plastics possess high insulting properties, but they are inflammable.

Celluloid has given the engineer materials for the construction of models which he can use for studying the distribution of stresses under different actual loadings. It is also used for the manufacture of laminated safety glasses, sheets and rolls of transparent films, toys, decorative articles etc.

Bakelite: It was first invented by Dr. L.H. Baekeland in 1908. It is the trade name of plastic produced by a reaction of phenol and formaldehyde. Phenol-Formaldehyde is used as a base and is mixed with fillers along with colouring pigments in the proportion of 50% resin (Phenol-Formaldehyde resin). 40 to 45% filler and 5 to 10% mineral matter.

Bakelite is fixable and tough over *a* wide range of temperature. It is highly resistant to not water, chemicals and weathering. It was non-toxic and has good dimensional stability and excelled electrical properties.

Bakelite is mainly used for imitation jewelry, handles of domestic utensils, in electrical components, cable and wire coverings, insulation, and seats for paneling. Bakelite as also used in aircraft industries for propeller hubs, tad where is, fairleads, cable pulleys and bearings. It is further-used or safety insulated lamp holders, switches, telephone handsets, car ignition and lighting equipment etc.

Synthetic Adhesives: Ordinary natural adhesives (glues) derived from animal and plant sources are liable to be affected by fungi, moisture and other climatic conditions. Synthetic adhesives (glues) are not affected by fungi and can very well resist the action of water. Moreover, synthetic adhesives set quicker!)' and produce stronger joints. They are also comparatively cheap. Most of the synthetic resins used for manufacturing plastic are also used for making synthetic adhesive. Phenol formaldehyde and urea formaldehyde resin adhesives are commonly used in plywood industries. Resorcinol-formaldehyde resin adhesives have characteristics similar to those of phenol-formaldehyde resin adhesives but possess an advantage in that assembly and curing operations may be performed at room temperature. These are well suited for structures for Prefabricated houses and for laminated timbers and boat construction. Acroleic and vinyl adhesives are used in the manufacture of safety glasses as the interlayer. These adhesives are more transparent than glass and no sealing of the edges of laminated glasses necessary because of the use of those glues. Melamine formaldehyde resin adhesives, cellulose nitrate and cellulose acetate adhesives and resistant to fungus growth. They adhere well to various materials including metals, glass rubber, plastics, leather, and paper.

Perspex: *It is* a synthetic plastic product. It is highly resistant to heat, acids and alkalis, organic solvents and weathering actions. It has less water absorption capacity. It has very good dimensional stability it is tough, strong and durable. It is mainly used in research works for making chemical apparatus decorative articles, toys etc.

17.5 *Asbestos:* Asbestos is a fibrous mineral which is composed of the following: Silica-40%, magnesia-40%, alumina-l to 25%, Iron oxid-1 to3% and water-12 to 15%. Its melting temperature is about 1300°C. Asbestos can resist combustion, retains its strength at high temperatures and has low thermal and electrical properties. It is commonly used as asbestos sheets (both plain and corrugated) and as heat insulator. For commercial purposes it is supplied in the form of rope, wool and flakes.

Asbestos is very important engineering material. It is used to manufacture asbestos-cement. Asbestos fibers, (usually 15 to 20%) and ordinary Portland Cement (usually 80 to 85%) are mixed with water to form a slurry which is so processed by machinery as to form wet sheet of rubber-like consistency. The sheet is then molded into desired shapes and when set. forms a homogeneous mass. It is said that the asbestos fibers act in the same way as the steel in the reinforced cement concrete. Asbestos-cement products are strong, durable. fireproof of good weight/strength ratio and have resistance to transverse and tensile strength. Asbestos-cement *products* include plain and corrugated sheet pipes for carriage of water and sewage. Asbestos-cement pipes are comparatively cheap and also non-corrodible and require no preservative coating.

17.6 **Leather:** Leather is an important engineering material. It is used in two forms in engineering constructions: as raw hides and us tanned leather. Raw hide (suited hide) is tough, strong and durable with little capacity for stretch. It is used for gears, belts and belt lacing (when dried). Dried raw hides are also used for gaskets. hand bags, linings, coverings etc.

Tanned leather is prepared by treating the salted raw hides with tanning chemicals. Colour pigments are added to impart desired colour to the tanned leather. Leather weighs about 4000 psi (for a good quality leather). Tanned leather is used for belts, washers, non-friction lining material, gaskets, shoes, suitcases, hand briefcases, moneybags, decorative works, garments etc.

17.7 **Gutta Percha:** It resembles rubber in many of its properties but it is stronger, more soluble and less elastic. It is greyish white. It is obtained by boiling the milky juice (sap) of certain tress (Palaqulum Gutta) grown in Malaya. Borneo. Java and other Islands of the same area. It is not vulcanized with Sulphur like rubber but used alone in its pure state. But sometimes it is vulcanized with Sulphur to form hard substances. When pure it is brownish in colour and at low temperature it is as hard as wood and excessively tough. With the increase of heat, it becomes more flexible until at about 120°, it becomes pasty, when it can be molded into all varieties of forms which it retains on cooling.

It is widely used for various purposes as a substitute for leather and rubber, as an insulating coating for copper wire and submarine telegraph cables, as an ingredient in mastics and cement for the manufacture of flexible hoses, tubes, bottles etc. It is also used for impregnating driving belts, washers, valve seats and in adhesives. It is further used for golf balls and dental fillings for its high resistant to water.

17.8 **Linoleum:** It is manufactured from Sulphur chloride with linseed oil. When rolled into sheet, it is used as a substitute for rubber or gutta-percha. When dissolved, it is used as

varnish. It can also be made in the forms of table covers felt carpets. It can he given beautiful colour and shades with desired colour pigments. When ground cork or sawdust and pressed upon canvas, it forms good floor cloth

17.9 **Jutex:** It is a special variety of board prepared from, powder jute-sticks. It is mainly used for making light furniture, partition walls, cabinet making, false ceiling etc.

17.10 **Silicones:** Silicone resins, called *silicones*, introduced in 1945 have an inorganic structure with an organic exterior. The basic materials are silicon, alkyl, silicon dichloride, methyl chlorides and water. The materials are hydrolyzed in order to obtain silicones. Silicones are manufactured in the form of liquids, greases and solids. The liquids are used for heat transfer media, damping fluids and high temperature lubricants. The greases are employed as high-temperature lubricants for bearings and valves. The solids are used as gasketing materials for service at higher temperature. Silicones are resistant to water, weathering, acids, alkalis, ultraviolet rays, ozone and aging. They have good bonding properties and fair dielectric properties. They show very little change in viscosity over a wide range of temperature. Usually, silicones are chemically inert.

Silicones are also used as protective coatings, as bonding agent in laminates, as electrical insulation. They ar. also used in manufacturing waterproof insulation products tor high frequency equipment and high-tension ignition systems and products which are used as rubber substitute.

17.11 **Expanded Metal:** This is a cast iron product. Expanded metal is the term applied to a wide variety of lattice and diamond shaped mesh structures. The cutting or stamping with dies and stretching out of the diagonal strands by machine are done operation. Expanded metal is made in sheet of different sizes with various mashies which are distinguished by the dimension across the short way of the mesh which is usually 1'/4".

3" /8", 3'/4".$1^{1}/_{2}$-3 ". or 6".

Expanded metal is used as partition walls, fencings and other engineering works.

17.12 **Abrasives:** *This* consist of both natural and artificial material used for cutting and polishing wood, metals and stones. The most commonly used natural abrasives are carborundum, emery, sand, garnets, pumice and other different types or grinding and polishing stones. Artificial abrasives are carborundum, crushed, iron, steel and rouge. Crushed steel and steel emery are made by heating a good grade of steel to a high temperature and cooling it. quickly in water then reducing the cold steel to a powder by means of crushing machines of heavy hammers. This is then mixed with glue and applied to belts and wheels in the same manner as emery or sand.

Emery: It is chiefly consisting of alumina add quartz. It is a very ward material which is not acted upon by heat or acids when ground to powder, it is used for making emery wheels, emery cloth and emery paper for polishing. All these are used for polishing purposes.

Corundum: It is a compound of aluminum and oxygen. H^{s} hardness is next to diamond. There are several varieties, the

amethyst, ruby, sapphire etc., to a coarse variety known as emery. It is used for griding rough surfaces of stones marble mosaic and other such materials.

Carborundum: This is made by mixing in proper proportions of coke, sand, sawdust and a small quantity of salt and smelting the same at a very instance heat for 36 to 40 hours in hours in an electric furnace and the mixture is converted into carborundum. It is the hardest possible synthetic abrasive and has replaced corundum and emery to a great extent.

Sandpaper: This is a common name given to various types of abrasive paper. It is generally consisting of a strong and stout paper coated with sand embedded in glue. Sandpaper for hand use may use glass or garnet powder and depending on the nature of the abrasive material glued to paper. It is called *glass paper, flint paper or garnet paper*.

17.13 **Diamond:** This is the hardest possible natural substance known and one of the most precious gems, which is chemically the purest form of carbon. It used for cutting, glasses mainly. Other engineering uses include making of abrasive materials, wire drawing dies, rock drills etc.

17.14 **Felts:** Felts are materials composed of wool alone, mainly to eliminate noise and vibrations and to serve a covering for resisting heat. Felt washers and packings air used in automobiles for the prevention of leakages from engine bearings, gearboxes etc.

In addition to those felts mentioned above the following are the other varieties of felts.

air used in
from engine

Bituminous Felt: This is made by applying bitumen’s io paper, hides canvas woolen felt. Bitumen is either impregnated or is applied to the surface sometimes sand and crushed stones are sprinkled on the surface of the tells before applying the bonding tar or asphalt. It is used as damp-proof course

Reinforced Bituminous Felts: These are impregnated sheets on which bitumen is spread and then hessian or jute fabric is laid on top and the sheets rolled. Sometimes talc or mica powder is doted on to give the desired finish to the surface. These felts are more resistant to wearing and have better insulating power.

17.15 **Ropes:** Jute. hemp, coir and cotton are the plant fibers used for making ropes. Cotton ropes are the strongest but very expensive and therefore not used in engineering constructions. Coir ropes are cheaper and used in ordinary works where high strength is not required. Jute and hemp ropes are very strong and used mainly in engineering purposes.

There are other varieties of ropes also available in the market: Wire ropes are made of a large number of steels of any other metal twisted together. They are mainly used for cables and other purpose requiring very high strength. Various synthetic ropes are used nowadays but they are not very strong.

17.16 **Nails, Screws and Spikes**: These are the products of cast iron, wrought iron and steel. They are of various sizes and shapes for various engineering purposes and the choice of a particular type depends entirely upon the nature of works.

I hey have got wide applications in the various fields of engineering constructions.

17.18 **Graphite:** Graphite is the well-known crystalline form of Carbon. It is naturally found in marbles, gneisses, schists and granite with impurities such as clay, iron oxide and other minerals. It has black to grey colour, greasy touch, very soft and is a good conductor of electricity. Graphite is also manufactured artificially by heating a mixture of powdered carbon and a suitable binder.

Graphite is mainly used in mechanical chemical, electrical and metallurgical fields as electrodes, lining for furnaces and crucibles. It is also used as a lubricant and in paint and pencil industries.

17.19 **water:** Water is an important engineering material. Since we get it free, we do not any importance to it. In any engineering connection, water is needed. The importance of water in concrete construction and its quality' have already been mentioned in the Concrete Chapter. Industry uses large volumes of water in its manufacturing processes and in supporting operations. Indeed, the production of steam, foodstuffs, metals, chemicals, synthetics, concretes and other basic commodities and engineering enterprises call for a tonnage of water that far exceeds the combined tonnage of other raw materials.

Questions

1. What is coal and how is it formed? Enumerate the byproducts of coal and their specific uses.

2. Name the places where s2eable deposits of coal are known to exist in Bangladesh.
3. What is glass? What materials are used for glass manufacturing? Give the engineering applications of glasses.
4. Distinguish between:

(a) Laminated glass and sheet glass (b) Lead glass and soda lime glass (c) Pot Colour and Flash Colour.

5. What is safety glass? Why lead is used for glass making?
6. Discuss rubber as and engineering material. What the different varieties of rubber and how are they manufactured?
7. What is vulcanization? Why is vulcanization of rubber essential for its use under industrial conditions? Name some physical properties of rubber which are utilized in industries and engineering constructions and state these uses.
8. Describe what is meant by plastics a filler, a plasticizer a thermoplastic, a thermosetting resin and polymerization.
9. What are the important properties of plastics which contribute

their use as materials for construction?

10. Name the important groups of plastics. What are some of their advantages?
11. What are some of ten different types of phenolic plastics? How do they differ?
12. Name and briefly describe five types of thermoplastics.
13. What is nylon? Name some of its properties and applications.

14. What are silicones? What are their properties? Name several applications of silicones.
15. Name the properties of natural rubber and compare them with those of synthetic rubber.
16. Write short notes on any five of the following: Polystyrene plastic, Polythene, Acrylics, Alkyd. Casein Plastic, Epoxy resin plastic, Cast phenolic plastic.
17. Distinguish between:

(a) Injection moulding and Extrusion moulding (b) Poly vinyl chloride and polyvinyl formal (c) Cellulose nitrate and cellulose acetate (d) Phenol-formaldehyde and melamine formaldehyde plastics.

18. What is celluloid? Critically examine its properties and write some of its uses.
19. What is Bakelite? Why is it so called? Give the engineering applications of Bakelite?
20. What is asbestos? Why is it considered to be important engineering material?
21. Distinguish between Gutta Percha and Perspex: Give the engineering applications of leather.
22. Write explanatory notes on any five of the following.

Linoleum, Jutex, Expanded metal. Abrasives, Felts, Ropes, synthetic adhesives, Hardeners, Polyethylene, Silicon resins. Buna-s, Latex.

23. Name the basic raw materials for manufacturing plastics.

24. Do you consider water as an engineering material? Justify your answer.

--- The End ---

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