A TEXT BOOK

OF

ENGINEERING MATERIALS

(WITH NUMEROUS ILLUSTRATIONS)

A TEXT-BOOK
OF
ENGINEERING MATERIALS

(*With numerous illustration*)

BY

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PREFACE

It has been the aim of the author, ever-since he underook the teaching of the subject, to prepare a concise text ook on Engineering Materials, covering all its aspects, which will meet the demands of students undergoing engineering A. M. education in colleges and Technical Institutions, and also be of some service to those who want to know something about the fundamentals of materials used in the field of construction.

With due appologies to the existing books on the subject matter, it is claimed that this text is specially written for those who are new to the subject and also be of use to the practicing engineers. Sequential treatment of the common materials of constuction, from their raw stage to the finished roduct, with reference to their properties and uses, is a speciality of this book.

Elaborate descriptions of the various manufacturing rocesses have been avoided by illustrating them with the aid self-explanatory sketches specially drawn for the purpose. n the openion of the author, no description however detail t may be, is complete unless it is supplimented by such ketches.

It is suggested that the class-room study of a subject of this type should be supplimented by occasional observations of the various processes, in the manufacturing concerns, concrete depots, quarries, factories and brick kilns, etc.

College of Engineering,
Poona. 1–6–1950,

G. J. Kulkarni

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ENGINEERING MATERIALS

CHAPTER I

Building Stones — General

Introductory.

Necessity of a thorough knowledge of Engineering materials. Requirements of good building stones — strength and durability, cost and appearance.

Properties and tests of building stones.

Structure and texture; porosity; specific gravity; strength, hardness and toughness; fire- resistance; electrical conductivity; seasoning qualities, appearance; facility of working.

Durability of building stones.

Decomposition, disintegration and weathering. Atmospheric agencies. Action of rain water — physical and chemical. Effects of temperature variation. Frost. Influence of vegetable life and organisms. Position of stone in structures.

Preservation of stone work.

Precautions to preserve building stones. Use of preservatives for building stones. Choice of preservatives. Preservatives commonly used.

Classification of stones.

Geological classification — Igneous, sedimentary and metamorphic. Physical and chemical classifications. Silicious, Calcarious and Argillaceous stones.

Building Stones

Art. 1. Introductory—Building stones are derived from the rocks in the crust of the earth. They are natural products and are used directly, except for their rough sizing and dressing before being put in a structure. An attempt to describe their geological and minerological aspect will be beyond the scope of this volume. For such information reference should be made to text books on geology.

The abundance of stones and their easy availability at or near the surface has led to their common employment from very early days for structural works such as, foundations, walls, floors, roads, dams, bridges, etc. The broken and crushed varieties of stones are used on an extensive scale in the making of concrete and artificial stones. Different types of stones are found in different parts of our globe. Practically every region produces its own building stone which is used locally. But when a special class of work is in demand, as in the case of ornamental or decorative structures or when strength and durability are the primary factors, suitable stones have to be imported from outside, if not available from the local quarries.

Therefore, to enable an engineer to select with precautions, a suitable stone for any particular work, it is necessary for him to be acquainted with the different varieties of building stones and their characteristic properties.

Art. 2. Requirements of Good Building Stones—The essential requirements of stones used for structural work are ***strength*** and ***durability***. Ordinarily, the strength of a stone is not of primary importance, since very often the loads to which it is subjected in a structure are below its crushing strength. But for heavy work and where the intensity of loading is very great, the strength of a stone should be determined by experiments.

Stones should possess *natural durability* to withstand the distructive actions of the various agencies which are continuously operating on them from the time they are placed in a structure. In fact, the life of a structure is governed by the durability of the materials with which it is built. The durability of a stone depends upon the relations between its chemical composition and those of the atmospheric surroundings. The texture of a stone also bears an influence on this property. Crystalline or homogeneous and close-grained varieties of stones with dense structure should be selected for good work. The surface of a freshly broken stone should represent a uniformity of texture, colour and hardness. A dull chalky appearance is not a sign of good stone. Porous stones or those containing patches of soft materials are liable to decay readily.

The next important consideration in the selection of a stone is its *cheapness*. The weight of a stone usually prohibits its conveyance over a long distance. Other things being equal, its cost depends upon the ease with which it could be quarried out, the proximity of the querry to the place of use, and the transport facilities available. The subsequent cost of dressing a stone, before it is placed directly into a structure, should be also low.

In the case of stones used for face work where appearance is a primary factor, their *colour* and *ability to receive polish*, play an important part.

The various properties will now be considered in detail in the following articles.

Properties and Tests for Requirements of Building Stones

Art. 3. Properties and Tests of Building Stones—The following are the characteristic properties of building stones in relation to their structural requirements :—

(i) Structure of a stone.
(ii) Texture of a stone.
(iii) Porosity and absorption.
(iv) Specific gravity.
(v) Strength, hardness and toughness.
(vi) Heat and fire resistance.
(vii) Electrical conductivity.
(viii) Seasoning qualities.
(ix) Appearance, colour and polish.
(x) Facility of working.

These will now be described in detail.

Art. 4. Structure of a Stone—This relates to the manner or mode in which the particles and the mass which go to form a stone, ate arranged. Principally there are three structures corresponding to those of the rocks from which the stones are obtained, - *unstratified, stratified* and *foliated structures*.

The unstratified structure relates to the stones obtained from the rocks of the igneous origin. They are formed by the process of cooling of the molton rock magma and depending upon the time taken to cool down, they are either crystalline or amorphous varieties. They yield strong building stones in general.

Stratified Structure is a characteristic feature of sedimentary rocks, indicating the manner in which they are formed, viz., by the deposition of the materials produced by weathering of originally formed rocks, as described later. Layer after layer of these materials is deposited and give rise to statified structure. These rocks also have thin laminae interposed between their layers of stratification and thus give rise to laminated structure and " planes of cleavage " along which they split very easily.

Metamorphic rocks have a *foliated structure* in general' They also represent layers of stratification but they are not uniform. They are not formed by the process of deposition, but are developed in the existing rocks as a result of metamosphic action of heat and pressure.

Art. 5. Texture of a Stone—The texture of a stone is indicated by the arrangement, size and shape of its constituent mineral grains. Stones with *crystalline* or *homogeneous* texture are *close grained* and *compact*. They exhibit better weather resisting qualities than those of the *open-textured* variety. In the latter case atmospheric agencies gain access into their interior and readily decay them. Generally igneous rocks and metamorphic rocks, such as granites, traps, gneisses and shists are practically impervious.

Sandstones and limestones belonging to the sedimentary rocks are *Porous*. These stones are also examined for the nature of their binding material. Their texture could be described as *granular crystalline*. Some of the metamorphic rocks also have the same texture.

It is important that stones should manifest a *uniformity of texture* and should be composed of minerals of almost equal hardness and possessing similar weather resisting properties. The presence of softer minerals and weak patches, sets up unequal weathering and in the course of time imparts open texture to the stones for rain water to enter. This hastens decay and reduces the life of a building stone.

Amorphos rocks represent a glassy or fused texture. They have no grains or crystals, viz., flints, glass, etc. They are hard and compact.

The fractured surface of a stone generally indicates its texture. The fracture may be *even*, *uneven* or *concoidal*. Crystalline and compact varieties always indicate an even broken surface. Good building stones should always represent an even fracture. But for the construction of road surfaces and for concrete work, an uneven or concoidal fracture indicated by sharp and angular, bulging or hollow faces, is desirable to secure proper interlocking and solidity of work. The fracture of a stone should be bright, clean, and sharp, with grains well cemented together. A dull, chalky and earthy appearance clearly indicates sure signs of early future decay.

Art. 6. Porosity and Absorption—Stones can hold water in two ways:—one depending on its absorption and the other on its porosity. Of these two, *absorption* is the characteristic property of its mineral constituents whereas *porosity* is governed by the void space between the component minerals and the manner in which they are grouped into a stone-mass. But the possibility of the outside moisture or rain water travelling into the interior of a stone depends on the *permeability* of a stone. For a given void space in a stone, the sizes of the voids are a measure of its permeability. Smaller the size of the voids or pores, greater is the resistence offered for the moisture to travel and therefore smaller is the permeability.

Effect on stones — Porous stones give a free action to the movement of water through them. Therefore while considering this physical property of stones, the decaying effects of rain water will have to be studied. The action of rain water is given separately in Art. 17. To have these effects the least, the texture of stones should be dense and compact so that they will absorb the smallest quantity of water. Secondly, stones used in aqueous foundations and in dams should be least porous and non-absorbant, to avoid heavy leakage and uplift on them.

It may be noted that stones exposed to alternate wet and dry conditions lose their strength in the course of time. In cold countries, the effect of frost and the consequent freezing of the water held in pours of the stones, is very severe. Finally the dampness created in a building due to stones holding water gives rise to unhealthy conditions.

Porosity Test is carried out for porous stones in particular. The stone is weighed in the air and then after immersion in water for 24 hours, it is again weighed. The difference in the two weights indicates the porosity of the stone. Porosity is expressed as the percentage absorption of water with the dry weight of stone. To have an idea about the void space inside the stone, it is also expressed as percentage of volume. Compact stones have a negligible porosity whereas porous and clayey varieties have a porosity as much as 5 to 7 percent of their weight. The saturation coefficient of stones also could be determined, but this is more important for bricks. See Art. 77. The best stone, as a rule, absorbs the smallest amount of water.

Art. 7. Specific Gravity—This indicates the weight of a stone and varies but slightly between any two varieties. Dense and compact stones have a specific gravity of 2.7 to 2.8 and porous or open-textured sand stones have about 2.4 specific gravity.

To determine the specific gravity of stone, the sample is weighed in the air and its weight is compared with the weight of an equal volume of water. In the latter case, the stone should be saturated before weighing it in suspension in water.

Heavier stones should be selected for massive structures, such as dams, quay walls, retaining walls, etc. Igneous rocks and gneisses are heavier than the sedimentary rocks.

Art. 8. Strength, Hardness and Toughness—The next property of importance for building stones is their strength. Stones are usually subjected to direct compressive loads in structures and as such their compressive resistance or crushing strength is determined. Sometimes stones are also subjected to transverse loads as in the case of beams, lintels and corbels, when their transverse strength to resist bending stresses is also important.

Stones used for road metal, paving blocks, floor slabs and railway ballast have to withstand mainly abrassion or wear and tear where hardness and toughness are essential requirements. Stones for walls subjected to vibrations of mechinery and moving loads should necessarily possess toughness.

Art. 9. Factors affecting Strength, Hardness and Toughness—These physical properties depend on various factors such as;—

(a) Hardness or softness of the component minerals.

(b) Proportions of the hard and soft minerals in the same stone.

(c) The size and shape of the minerals.

(d) The manner in which the minerals are interlocked collectively, e.g. uniform, homogeneous, mottled or seggregated.

(e) The cohesion between the component minerals.

(f) The quality of the cementing material binding the grains or minerals.

Considering the factor detailed above regarding the fitness of a stone to resist the external forces, it can be said that, igneous and metamorphic rocks, owing to the interlocked condition of their minerals, are naturally hard and strong than the sedimentary rocks whose strength depends on the cementing matrix binding their grains together and also on the hardness of the grains themselves. A sandstone with hard grains of quartz but without the necessary binding material is brittle and fragile and therefore weak.

Effect of moisture on Crushing Strength— Stones in wet condition show a lower crushing strength than when they are dry. It has been already remarked under porosity and absorption that alternate wetting and drying of stones has a marked effect on the reduction of their crushing strength, which may even extend to 30 or 40 percent of their strength when dry. Particularly sandstones and limestones lose much of their strength due to this effect.

Effect of Impact and Intermittent loads on crushing Strength—The strength of stones is greatly reduced when they are subjected to impact and intermittent loads, as in the case of piers and abutments of highway and railway bridges, in walls subjected to vibrations of machinery as in the cace of workshops and industrial buildings. Under the effect of such loads failure of stones occurs considerably below the load which will cause crushing when normally applied.

Art. 10. Strength and Abrasion Tests on Stones--

(*a*) *Test for strength* To determine the strength of a stone to crushing, test blocks 4″ × 4″ × 4″ size are cut with plane faces and tested for compression failures in a testing machine. Usually 12 to 16 samples of the same variety of stone to be tested are taken and an average value is worked out. The crushing strength of stone is expressed in terms of tons per sq. ft. Good quality of granite can stand a crushing load of about 1250 tons per sq.ft. while weaker stones like sandstones and limestones show signs of crushing even at 500 tons per sq. ft. Considering the stone as a natural product and also depending on the nature of stresses to which it is subjected, a suitable factor of safety is applied to the above values of ultimate crushing strength to obtain the safe permissible loads on these stones.

Since stones are used as individual units to form masonry, the strength of masonry work has to be ascertained by building pillars and subjecting them to compressive loads. Very often the strength of mortar used, determines the strength of masonry work.

(b) *The Abrasion Test*--This test is carried out with the aid of a cast iron or steel barrel closed at both ends and attached to a horizontal spindle at a slight angle. The stone to be tested is broken into small angular pieces of varying sizes which are all weighed dry before being put into the barrel. Cast iron balls are also put along with the stone pieces. The barrel is then revolved for one hour at about 2000 times. The stone pieces are then taken out and after *rejecting the dust and the smallest particle, the loss in weight* is determined. The loss in weight is the least in the case of stones which wear well.

Resistance to abrasion is also tested by grinding a 3-in cube stone against an emery wheel under a constant pressure of 180 lbs. After five minutes or so, the stone is re-weighed. The loss in weight indicates the abrasive resistance of the sample.

(c) *Test for Hardness*—Hardness of a stone, as already pointed out, depends upon the hardness of the constituent minerals. This is determined with the aid of the Moh's scale of hardness, as explained later. If a pocket knife makes a mark on a fresh surface of a stone e. g. say on a limestone, the hardness of that limestone may be taken as H = 3. A scratch with the aid of a finger nail indicates a hardness of H = 2. Hard silicious rocks which could not be scratched by a knife represent a hardness of H = 7. However, hardness also depends on the texture and structure of the stone.

Art. 11. Fire Resistance—Fire brings about rapid distruction of stone structures by disintegration. This is due to the following reasons:—

(a) Unequal coefficient of expansion of different rock forming minerals.

(b) Bad conductivity of stone in general.

(c) Rapid rise in temperature of the exposed faces of stone due to fire.

(d) Sudden cooling of the surfaces of stone by the application of a stream of cold water.

The last two causes bear relation to the durability of stones, since they are the problems actually met with in practice, after any particular variety of stone has been selected for a structure.

Crystalline varieties of igneous and metamorphic rocks such as granites and gneissis, disintegrate quickly under the effect of fire. Trap stones are better resistants. Free quartz expands and splinters suddenly at about 1200° F. Limestone loses its gaseous constituents when heated to about 1400° F. These are the temperatures which are usually reached when a building is under configeration. Limestone gets converted into quick–lime which swells and crumbles to powder in combination with water. Argillaceous stones are better resistants to fire.

Art. 12. Electrical Conductivity—Stones are bad conductors of electricity. They offer a very high resistance, which normally exceeds 10^5 ohms. per cubic foot in their dry condition. But when stones become wet, their resistance falls greatly. Thus dense stones having a low percentage of porosity and absorption should be selected for panels, in electric instalations. For switch board panels, etc., marbles are the most suited ones, since in addition to their dense texture, they could be easily cut into panels and polished. They also represent a clean appearance. Sometimes slates are also used for the same purpose and they possess a higher ohmic resistance than marble. But this higher resistance is limited owing to the presence of veinlets of metallic minerals in them, which cause short circuiting of the current,

Art. 13. Seasoning Qualities of Stones—Stones contain water when they are freshly taken out by quarrying from the crust of the earth. This water usually contains mineral matter in solution and is termed as quarry sap or quarry water. when it dries on exposure to atmospheric conditions, its mineral constituents are deposited in its pores, and after certain chemical reactions with the mineral constituents of stones, they help to bind their ingredients more compactly. The filling in of the pores in this manner makes the stone more dense and hard, and better resistant to the weathering action. Therefore stones should be seasoned by exposure to the air before they are put in a structure. These seasoning qualities are exhibited particularly by sandstones, limestones and laterite.

Stones should not be dried suddenly after quarrying by carelessly leaving them in the Sun. Otherwise, the quarry sap will dry away on the surface leaving the interior of the stone in a damp condition.

Art. 14. Appearance, Colour and Polish—These properties mainly indicate the fitness of a stone to produce the necessary architectural effect on the face work of a structure. In the case of high class buildings, many a time, importance is attached for the selection of stones of suitable colours to match with the surrounding for asthetical reasons. But it is equally important that stones used for such specific purpose, should not be discoloured due to weathering. This would be easily ascertained from their minerological composition. Particularly in the case of iron, if present in stone, rusting will take place and will impart an unsightly appearance. An examination of the behaviour of stones in the older buildings in the neighbourhood, or an inspection of the stone at its outcrop near the quarry, often gives an idea about its weathering qualities. Stones showing flaw, clay-holes and mottled colour should not be used for face work.

Harder varieties of crystalline stones having a dense texture receive a good polish. Granites, marbles, slates and compact varieties of limestones could be polished well. polished stones are specially used for pillars, balusters, cornice, pedestals of columns and statues, paving stones, door and window sills, etc.

Art. 15. Facility of Working—Stones have to be shaped by dressing before they are set in a wall. The harder the stone, the greater will be the cost of dressing it. Softer stones with a uniform texture, even-grained and free from flaws, offer better facilities for cutting and working into the requird shapes. But it is necessary in any case, that the stone should possess a soundness of texture also. This factor has an importance from the economical point of view.

Durability of Building Stones.

Art. 16. Durability of Stones — weathering— Stones used on exposed faces of structures are continuosly acted upon by atmospheric agencies such as, wind, rain, frost and sun, and also by plant life and organisms. These agencies set up disintegration and decay and subsequent separation of the particles of stones. This action is known as *weathering*. The process of weathering is associated with the transportion of the separated particles, usually from a higher region to the lower ones. So powerful are these agents that even the hardest varieties of stones are worn down and crumble to pieces and also to powder under favourable conditions, by the continuous action of weathering. A stone which has an ability to resist this distructive action is said to weather well. This weathering ability of stones depends upon their chemical and minerological composition, and also upon their physical structure, as explained later. Freedom from flaws is an essential requirement. Stones containing silica and silicates are the most resistant ones.

The life of a building stone is counted upto the period when it starts showing signs of disintegration and decay. But some stones develop seasoning qualities on exposure to atmosphere and last for many years e. g. laterite stone. The estimated life of granite, gneiss and sandstone buildings is well over 200 years normally; while limestone and weaker types of sandstone buildings hardly last for 50 years.

Atmospheric agencies bring about physical and chemical changes in a building stone. As mentioned above, they mainly act in breaking down a stone, and we shall now consider how they operate. Though the various atmospheric agencies are described individually in their action, it is but rare that any one of them acts alone. Very often two or more agencies act together and when their action is extended to regions, they are capable of wearing away mountain renges during geological periods.

Art. 17. Action of Rain Water on Stones—Rain water acts both (a) *Physically;* and (b) *Chemically,* as an agent in the weathering and decay of stones. The former action is due to its erosive and transportation powers and the later mainly due to its solvant capacity, decomposition, oxidation, and hydration.

Art. 18 (a) Physical Action of Rain Water — The alternate soaking of stones in rain water and subsequent drying in sunshine, causes disintegration and loosening of their particles. When next showers of rain strike on such disintegrated exposed faces of stones, the force is often enough to wash away the loosened particles. This action of weathering is purely a mechanical one and if there are structural defects, like open joints, cracks in stones, it reaches their interior section also. Again if a stone is porous, moisture will travel to its interior and the decaying process is rapid. It may be noted here that wet conditions are more favourable to set up decay in stones.

Art. 19. (b) Chemical action of Rain Water— *Pure waters attaining chemical activity*—the solvant action of pure water upon the mineral constituents of building stones is very slow. But rain water is hardly pure. Very often it is contaminated with gaseous impurities such as oxygen, nitrogen and carbon di-oxide. When it passes through the acid laiden atmosphere of industrial localities, it gets charged with other gases and particles of acids such as sulphurous, sulphuric and carbonic acids and soot etc. As the water passes through regions covered by decaying vegitation, it gets charged with various types of organic acids and renders itself chemically active.

Such rain water rendered chemically active has a greater solvant action, and brings about chemical reactions on the ingredients of stones, producing deleterious effects.

Alkaline materials like lime, magnesia, soda, potash and iron are readily dissolved and carried away in solution by waters containing carbon-di-oxide.

Decomposition—The disintegration of alkaline silicates of alumina in stones is mainly due to this solvant action of chemically active water. The alkaline materials in their carbonate form and the hydrated silica are very soluble and are removed in solution, leaving behind a hydrated silicate of alumina known as *Kaolinite*.

The decomposition of a typical predominent mineral of igneous rocks, namely felspar, could be represented as follows :

$$\underset{\text{(Orthoclase)}}{K_2.\ Al_2\ O_3.\ 6\ SiO_2} + \underset{\text{(Chemically formed)}}{CO_2 + xH_2O} = \underset{\text{(Alkaline Carbonate)}}{K_2\,CO_3}$$

$$+ \underset{\text{(Kaolinite)}}{Al_2O_3.\ 2SiO_2.\ 2H_2O} + \underset{\text{(Hydrated Silica)}}{4\ SiO_2.\ xH_2O}$$

The kaolinite on further hydration yields the deposits of clay known as *kaolin,* which is a basic material in the manufacture of various clay products, as explained later. The richness or otherwise of kaolin deposits depends upon the extent to which the carbonate of alkaline materials and the hydrated silica are removed in solution subsequently. This weathering of felspar family of minerals into clay is an important process in the decay of stones. Particularly granites and other crystalline varieties of stones are influenced by this action. Similarly, when the *silicates of lime* decompose, the lime is converted into calcium carbonate which is carried away by the solvant action of waters containing CO_2.

Oxidation and Hydration— In addition to the solvant action and decomposition effects of aciduated rain waters, the chemical reactions which disintegrate stones by the same agency are mainly oxidation and hydration. This is due to the oxygen and water entering into chemical combination with the rock minerals. Iron is present in almost all rocks in one form or the other. Rocks containing iron compounds either in the petroxide, sulphide, or carbonate form, are readily oxidised and hydrated. Thus petroxide- FeO is converted into ferric oxide- Fe_2O_3 which combines with water to form Fe_2O_3. $\times H_2O$. This chemical combination is accompanied by an increase in volume and results in a physical change manifested by the liberation of the neighbouring minerals composing the rock. Similarly iron sulphide readily oxidises to lemonite and liberates sulphur which on its turn unites with oxygen and water to form sulphuric acid and finally to sulphates. Similarly iron from iron carbonate or siderite, is also oxidised to lemonite.

Art. 20. Some Durability Tests—*Brard's Test*—Some times stones are subjected to severe acid tests to determine the presence of alkaline salts. A sample of stone measuring 4 × 4 × 4 cms. is put in a solution of Na_2SO_4– glouber salt, for 2 hours at 68° F. It is then hung up in hot air for drying at 212° F. This process is repeated about 12 times and each time the difference in weights before immersion and after drying is noted. A stone with good weathering properties indicates but a very small difference in the initial and final weights.

Acid Test—The following test is carried out to ascertain whether a stone could stand the town atmosphere in industrial localities. A sample of stone is immersed in a weak solution of sulphuric and hydrochloric acids, containing usually one percent of the acids. After a weak or so, the stone is closely examined for the acid reaction, such as the rounding of the edges and the deposition of loose particles on surface. This gives a rough idea, along with the effervescense if observed, he presence of $CaCO_3$ or Mg CO_3, or both.

Smith's Test--This is a very simple test and is carried out to determine earthy matter or soluble mineral matter in stone. Though primarily intended for magnesian stones, it is applicable to any stone in general. The sample of stone is broken into small pieces which are put in a test tube containing clean water. After an hour or so, the test tube is vigorously shaken. The water will remain clear if the stone does not contain any soluble or argillaceous matter. Otherwise the water will represent a turbid or milky appearance.

Art 21. Effect of Temperature Variation on stones.—Stones under exposed conditions disintegrate and decompose readily due to temperature variations. Alternate heating and cooling due to temperature changes of the atmosphere, causes them to expand and contract. It is only when these expansions and contractions occur repeatedly, a weakening effect is produced on stones. In addition, stones are bad conductors of heat so that the inner parts of the same stone remain cool when the outer parts are heated. This sets up unequal expansion and contraction and consequent breaking up of a stone.

Again, when it is remembered that stones are aggregates of minerals which have different coefficients of thermal expansion, it will be realised that the above temperature variations have an increased effect on their disintegration. They set up internal strains resulting in the formation of cracks on the surfaces of stones and breaking up into their compound minerals.

The separated and dislodged minerals are further carried away by the erosive and transportation power of the following showers of rain and wind movements.

Art. 22. Action of Wind and Frost—*Wind acts* as a mear agent of conveyance of the separated particles of the disintegrated portions of exposed rock surfaces. But wherever the wind is strong and carries dust and sand particles in it, its abrasive effect on the exposed faces cannot be neglected. On the other hand, a gentle breeze has an effect of drying away the moisture from a stone face and helps to increase its durability.

Sometimes building stones have to resist the *action of frost.* In cold seasons when the atmosphere reaches the dew point temperature, the moisture present in it is deposited on stones and fills in their pores. On reaching the freezing point temperature this water expands and causes internal stresses which are practically irresistible. Porous stones break up and disintegrate very easily by this method. The action of frost is naturally limited to very cold countries.

Art. 23. Influence of Vegetable Life and Organisms on Stones—The decaying of stones due to these agencies occurs but to a very less extent in buildings. However their influence in promoting rock disintegration and decomposition may be mentioned here.

Action of Vegetable life –When the lower form of vegetable life such as lichens and mosses grows on the surfaces of stones and in the open joints or cracks in buildings, their rootlets penetrate the interstices to secure a foothold and in search of food. They are known to secrete organic acids which bring about chemical decomposition of rock minerals. The mineral salts of the decomposing rocks also provide the necessary food for their growth. Moreover, the vegetable matter attracts moisture and keeps the stone under damp condition which is favourable to augment decay.

Action of Living Organisms—Living organisms like worms and bacteria play their own part in promoting rock disintegration. Some class of worms bore holes in stones and weaken them. But generally all organisms secrete organic acids which have a corrosive action on stone minerals as already stated.

Art. 24. Position of a Stone in Structure—*Influence on Durability*—The position occupied by a stone in a structure affects its durability. Though this is not an independent agent of decay and distruction, yet it could regulate the rate of action of various agencies hitherto described.

Stones used on that side of a building which is exposed to the direct action of rain and sun are liable to be decomposed readily. Free circulation of air to keep the stones dry, particularly in damp climates, is also essential to increase their life.

Natural Bed—The natural bed of a stone is expressed by the original position occupied by it during its formation. Apparently a stone may occur with its natural bed titled in a quarry. Thus the natural bed of a stone belonging to the sedimentary rocks is along its plane of stratification. For a metamorphic rock, the plane of foliation or the cleavage plane is treated as a natural bed. But in igneous rocks, natural bed is difficult to be traced and is of less importance.

Stones should be placed in a building with their natural bed at right angles to the direction of the load or pressure they are called upon to bear. A stone thus placed on its natural bed is capable of bearing more load. Again, if stones are placed on edge with their natural bed vertical so that the lines of stratification or cleavage are parallel to the face of the wall, disintegration starts very easily and layer after layer falls into decay in a short period.

In arches, the bedding plane should be radial and at right angles to the face of the arch, so that they will be at right angles to the line of thrust of the arch. In string courses and cornices the natural bed has to be kept vertical.

Preservation of Stone Work.

Art. 25. Precautions to Preserve Building Stones in Structures—The decaying of building stones through various agencies has been stated in the previous articles. Many methods have been deviced and adopted to retard their action, and to preserve the stones from gradual distruction. preservation is specially needed in the highly polluted atmosphere of big towns and cities. The following are the various precautions taken to secure this object.

(a) *Selection of Stones*—To minimise the efforts to be taken for preservation, subsequent to construction, it is necessary that proper precautions should be taken in selecting good varieties of stones possessing natural durability to a greater extent. For ordinary building purposes, any kind of stone available from the quarries in the locality may be used. But for capital and national structures, a selection of the right type of stones has to be made. Silicious rocks with a dense crystalline texture should be used for external stone finishings. If sandstones are used, they should be compact having their grains cemented with silicious matter. The use of limestones or calcareous sandstones with open texture, should be avoided for external finishings in industrial towns.

(b) *Seasoning of Stones*—The seasoning of freshly quarried stones in some cases, by exposing them to atmospheric conditions before using them, as already explained, increases their durability. It is necessary that sufficient time should be allowed to pass for the quarry sap to dry out completely.

(c) *Size of Stones*—It is clear that ordinarily, large blocks of stones are more strong and durable and therefore should be adopted for massive structures. There should be as few joints as possible and the stones should be cubical in size. Joints always indicate the weakness of a structure in general.

(d) *Surface Finish*—Well-dressed, smoothly finished and polished surfaces are more durable than rough and rugged ones, when imparted to stones. This always involves extra expenditure.

(e) *External Renderings* — This is specially provided with a continuous coat of plaster of a specified thikness and the materials used for the purpose should also be well selected for their durability. Usually cement plastered renderings are recommended and the sand used should be pure silica sand.

The joints of masonry, when a continuous rendering coat is not provided, should be specially treated by pointing in one of the standard methods, so that the rain water does not penetrate into the interior but is thrown off readily from the face of the wall.

(f) *Natural Bedding*—The importance of placing a stone on its natural bed as a precautionary measure to increase the life of a building stone in a structure has been mentioned already in the previous article.

(g) *Workmanship*—Much of the work in the direction of preservation of stones could be done in good workmanship while building a masonry. All joints should be properly filled in and no hollows or cavities should be left inside. It should be the aim to produce a solid structure with weather resisting properties.

(h) *Maintenance of Buildings and Structures*—The maintenance of exposed stone surfaces in a clean condition, is very effective in increasing the life of a building. This is done by washing down the surface with clean water or steam, at least once in three years. It prevents the adhesion of deliterious substances to stone faces, and in fact, may be considered better in many cases, to any of the artificial methods mentioned below. A thorough washing with clean water is essential.

Art. 26. Use of Preservatives for Building Stones—There are many methods in use for increasing the weathering qualities and for preserving the stones. Their action depends upon—

(a) The filling of the pores in the body of the stone.

(b) The provision of a coating to the stone surfaces to prevent the access of moisture into their interior.

(c) The reactions with the constituents of stones to form a hardened surface.

These methods incur great expenditure and since there are possibilities for the solutions themselves to be acted upon by the destroying agents, their repeated applications would therefore, be necessary. This again adds to their cost.

Choice of a Preservative.

Art. 27. Preservatives for Building Stones—Many proprietory solutions such as oils, paints and paraffins, both of organic and inorganic types, are in the market. But the choice of a preservative depends on the chemical composition and physical properties of the stone and the nature of the surroundings. Whichever preservative may be used it is necessary that,—

(i) The surface of stone work to be preserved should be thoroughly cleaned by a wire brush to liberate and to remove all foreign coating and dust, as far as possible.

(ii) The stone surface should then be washed with a jet of clean water.

(iii) When the preservative treatment is applied, the surface of stone should be dry. Otherwise the preservative is slightly warmed.

Raw and Boiled Linseed Oil are applied to the exposed stone face. They afford a greezy surface for the rain water to drain off quickly. They do not cover nor affect the original colour of the stone. But in hot weather they readily evaporate.

Paints and preservatives containing soluble silica and alkaline silicates are employed. The desired tints could be applied to these solutions to improve the apperance if necessary. The anticipated reaction is that, in the course of time the silica combines with lime and yields an insoluble silicate of lime which covers the stone surface and fills in the pores. If a deep penetration is desired, the preservative could be applied under pressure.

Coal Tar—An application of one or two coats of coal tar and bituminous preservatives very often produces the desired effects. But they are usually objectionable for their colour and black shade.

Praffin or paraffin dissolved in naphtha is also applied to stone surfaces. But they discolour the stones.

Alum-Soap Solution—Sometimes soft soap, containing 3/4 lb. of soap and 1/2 lb. of alun per gallon is also frequently employed as a stone preservative. These are only surface coatings and therefore require occasional applications.

Solution of Baryta—Under particular conditions ofl atmosphere in industrial towns, there is usually a charge of SO_2 in the air as a production of combustion of coal. It dissolves in rain water to form a weak acid and reacts on the calcium contents of limestones and sandstones and other rocks to form $CaSO_4$. Soot and dust firmly adhere to $CaSO_4$ and form a hard skin. The calcium sulphate flakes off in the course of time to expose fresh stone surface for further action. This is known as sulphate action and is prevented by an application of a preservative solution of baryta, $Ba(OH)_2$ - Baruim hydrate. This helps to preserve the stone by stopping the decaying process. Baryta, with calcium sulphate, forms barium sulphate which is insoluble. The resulting calcium hydroxide absorbs CO_2 from the air to form calcium carbonate.

Szerelmey's Stone Liquid—This contains silicates of sodium and potassium with chlorides of calcium and barium. The wall must be made perfectly clean and dry and the stone liquid is applied in two or three coats. A wash of this is generally preceeded by a wash of some bituminous liquid.

Classification of Stones.

Art. 28. Geological classification of Building Stones—According to the accepted theory of their mode of origin, rocks from which our building stones are derived, are classified into three main groups, - Igneous, Sedimentary and Metamorphic rocks.

Igneous Rocks—These are formed by cooling and solidifying of the rock masses from their molton magmatic condition, either in the interior of the earth's crust or upon its surface. They represent different structural features varying on the conditions of solidification and composition. Thus we have massive, crystalline, or glassy forms of igneous rocks. Generally igneous rocks are strong and durable. The rocks belonging to this class are :- *granites, trap* and *basalt*. Granite indicates the formation of large crystals due to the extremely slow cooling of the lava. This slow cooling has been mainly due to a thick covering on the top. Trap and basalt were formed by the sudden cooling of the lava as it forced to the surface; and this gave them a noncrystalline or amorphous and glassy texture. The appearance of granites at or near the

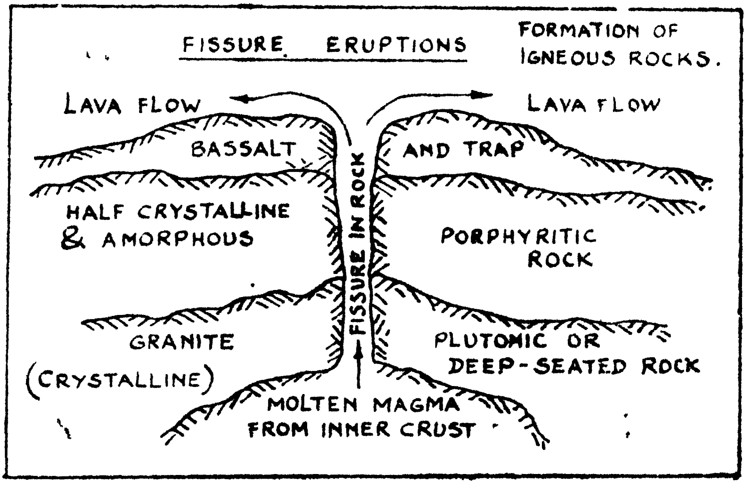


Fig 1. Formation of Igneous rocks.

surface is due to the subsequent weathering and erosion of the protective coating under which they were once formed.

Fig. 1 explains the mode of formation of igneous or primary rocks of the crystalline, porpheritic and glassy varieties, with respect to their position from the surface of earth's crust.

Art. 29. Sedimentary Rocks—These are secondary rocks formed by *denudation* and *deposition* of the previously existing rocks exposed to weathering action. Rocks formed through the agency of plant and animal life and also from bacterial and chemical action may be included in this class. Water is the most powerful and the principal natural agent of transportation. Most of our sedimentary rocks used for buildings are formed by water depositing the materials, which

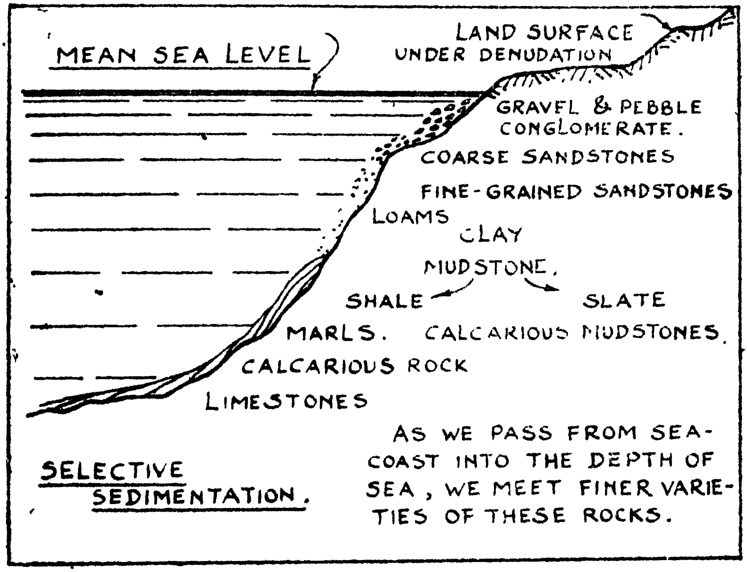


Fig. 2 Formation of sedimentary rocks

it once conveyed in suspension and in solution. Sometimes the sedimentary rocks themselves are eroded and as a result of this secondary erosion, followed by a secondary sedimentation, a new type of sedimentary rocks are formed. These rocks are more uniform, fine grained and compact in their texture, than the previous ones from which they are derived.

The mode in which the sedimentary rocks are formed from the products of denudation of primary and secondary rocks, through the process of selective sedimentation is illustrated in fig. 2.

The *consolidation* of the deposited materials, which is generally considered as the secondary stage in the formation of these rocks, has taken place either under pressure, accompanied by heat, or by deposition into their voids, of the cementing materials like silica, lime or iron, carried by water percolating through them. The cementing material is taken up by the chemically active waters as they passed through the regions where decomposition and disintegration of the rock masses is taking place.

Characteristics of Sedimentary rocks--They represent a bedded or stratified structure in general. They may be either granular or fragmental, close grained, compact or open textured. It is apparent that the strength and durability of sedimentary rocks vary greatly, - the strength and durability depending upon the quality of the grains and the extent and the quality of the cementing material; and durability depending upon the mode of formation in addition. Sandstones, limestones, mudstones, etc. belong to this class of rocks.

Art. 30. Metamorphic Rocks—These are formed by the metamorphic action of pressure or internal heat or by both due to crust movement on the previously formed igneous and sedimentary rocks. Rocks formed due to chemical changes and not due to weathering may also be included in this class. Due to intense pressure and heat, the original minerals are crushed and a compact dense mass is produced. Sometimes new minerals are formed altogether. Thus the mode of formation of these rocks may be due to any one or more of the " thermo " - " dynamo " - or " hydro " metamorphism forces.

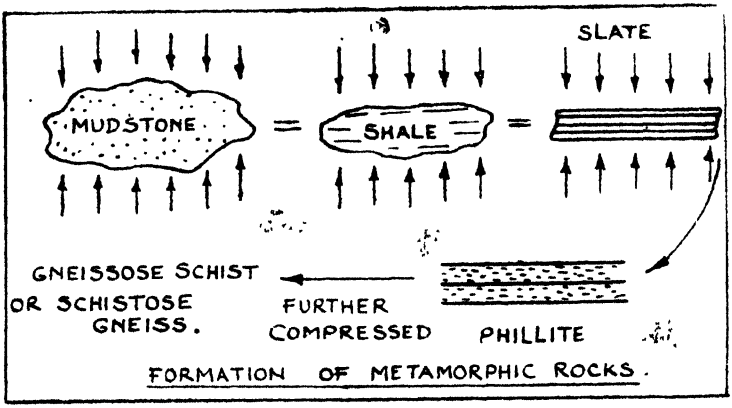


Fig. 3. Formation of Metamorphic rocks.

Metamorphic rocks represent either bedded, shistose, foliated or crystalline structure. They are generally hard and durable.

The simple effect of metamorphic action on mudstone is given in fig. 3. All the original signs of stratification have been obliterated due to compression giving rise to new planes of clearage, and the formation of new minerals.

As a result of metamorphic action, granites become gneisses, trap and basalt change into shists and laterite, limestones and marl change into marble. Similarly sandstones become quartzite and mudstone and shale become slate.

Art. 31. Physical Classification of Stones—According to their physical characteristics, stones are also divided into the following classes :—

Crystalline Variety--Rocks belonging to this class are generally hard and durable and yield very good building stones commonly known as granites, quartzite and marble.

Grannular Variety—If the grains are crystalline, arranged either in a banded or foliated manner as in the case of gneiss stones, the texture is termed as granular crystalline. But when the grains are rounded and held together by some cementing material as in the case of sandstones and limestones, the texture is termed as compact granular. Stones belonging to these two granular varieties are accompanied by strength and durability. If the grains are not well packed into a compact stone, the texture becomes porous granular, which indicates weakness in stones.

Slaty Texture—Stones indicating this texture could be split easily into thin layers along their cleavage planes. They are usually compact, dense and durable, e.g. clay slates, hornblend slates, etc. Compact limestones, containing some proportions of silica and clay, are also capable of yielding thin slabs and paving sets, along cleavage planes.

Art. 32. Chemical Classification of Stones—Stones are also classified by their chemical composition. Thus there are silicious stones, calcareous stones and argillacious stones, depending upon their chief constituent rock forming minerals.

Silicious Stones—These stones have silica or silicious matter as their principal constituent. Silica is a very common mineral, generally found as quartz, sand and flint. It is very hard and durable, and is unaffected by weathering agencies. But in its combined form and when present with weaker minerals, it disintegrates very quickly. Therefore, silicious rocks should contain free silica to a maximum degree for their hardness and durability. Granites, syenites, and traps with their varieties, like gneisses, quartzites and sandstones are the chief types of ofsilicions stones.

Calcareous Stones—This group includes the rocks mainly composed of calcarious material in its carbonate form $CaCO_3$. They are acted upon by dilute hydrochloric acid, HCl, and are soluble in meteoric waters. The durability of these rocks depends upon the conditions and the constituents of the atmospheric surroundings, and also upon their texture. The crystalline and compact types are hard and durable than the porous ones. These rocks are very often found with certain proportions of silicious and clayey matter. Sometimes iron is also present in them as a bilnding material. The principal varieties of these rocks are, marbles and limestones of various grades.

Argillacious Stones—Rocks of the clayey type are included in this group. They are more or less composed of alumina, mixed with small proportions of silicious, calcarious and carbonecious matter. Clay slates belong to the more compact and dense varieties of these rocks. They are hard and durable but not elastic as they are brittle and do not absorb shock. The softer varieties comprise clay and kaolinitic rocks which become soft and plastic when wet. Calcarious or silicious shales, laterites, also form an important group of argillacious rocks.

Choice of Building Stone

Keeping in veiw the requirements to be served by the stones for any purpose when used as a member in a structure, and with the help of an idea about the properties and behaviour of different stones as detailed in the previous articles, it is possible to make a choice of a particular type of stone which would serve a specific purpose. The samples of stones available and to be used, should be examined and tested, and their crushing strength, resistance to abrasion, toughness to resist impact, hardness, weather resisting qualities, aesthetical properties, etc., should be determined.

CHAPTER II.

Common Building Stones.

Common uses of Building stones.

Use of stone in their original or physical form – as independent units, and broken and crushed form. Use in their converted form. Industrial uses.

Principal Rock-forming Minerals.

Silica and its varieties. Silicates – alumino-alkaline and ferro-magnesian. Oxides and other minerals. Secondary minerals. The outer crust of the earth. Average composition.

Common Building Stones.

Granites, Traps and Basalts. Sandstones. Limestones, Gneisses and Schists. Laterite. Quartzites. Marbles. Slates.

Quarrying of Building Stones.

Quarry and quarrying. Site for quarrying. Preliminary considerations. Methods of quarrying. Quarrying in soft rock. Quarrying with machines, channelling, lifting, cutting, dressing, planning and polishing. Breaking and crushing,. Transporting. Drilling machines.

Quarrying by blasting.

Boring hole in the block. Charging with explosive. Explosives used. Tamping. Firing. Secondary blasting. Line of least resistance. Quarry dressing. Tools used.

Uses of Stone.

Art. 33. Common Uses of Building Stones—(A) Stones are used for various purposes by a constructional engineer. The most common ones are the following :–

(i) For walls in general, for foundation and superstructure.

(ii) For parts of buildings such as lintels, arches, cornice and coping, sills, bed blocks, quoins, slabs of granite and marble, etc.

(iii) For face–work of monumental and capital structures where massive appearance, solidity of construction and ornamental features are primary requirements.

(iv) For paving work in general, in buildings, roads, side–walks, etc.

(v) For dams, bridges, quary–walls and such other heavy structures. For retaining walls.

(vi) As a water–proof material in damp proof courses and roofing slates.

(vii) As macadam of broken stone for road metal in combination with argillacious, calcarious or carbonecious building material.

(viii) In the making of concrete, plain and reinforced, which has almost an unlimited application in the construction field, as an aggregate with sand and cement.

(ix) In its crushed form, as an artificial substitute for natural sand.

(x) In the making of artificial stones, hollow and solid blocks,

(xi) Ballast or broken stone for the permanent way elastic material for railways.

(B) In its converted form stone is used on a very large scale as detailed below :–

(i) As a basic material in the manufacture of calcarious cements.

(ii) In its disintegrated form, stone is used as murum for roads, floor and floor filling in buildings.

(iii) As limestone for burning, to manufacture lime which is so largely used for making mortar.

(iv) Limestone is used as a flux in the manufacture of iron.

(v) Clays or the products of rock disintegration, are used for making bricks and clay products in the ceramic industry.

It may be noted that limestone or $CaCO_3$, which is not a desirable constituent in stones used for buildings under certain circumstances, is very extensively used in the various manufacturing processes, agriculture, and industries such as chemical, textile and glass making. Its use in metallurgy and pottery manufacture and in the making of fertilizers, is not uncommon.

Principal Rock Minerals.

Art. 34. Principal Rock-forming Minerals—In the previous chapter a study of the various properties required of building stones was made with reference to their constituent minerals. In the following articles a brief description of the principal rock forming minerals will be given to facilitate the study of the different kinds of building stones commonly used, together with their properties and uses.

Rocks, from which our stones and their products are derived, are composed of a variety of minerals. The importance of a brief knowledge of these minerals to an engineer for understanding the behaviour of stones and their products in his structures and to distinguish one kind of stone from the other, is quite essential.

The following are the principal rock forming minerals—

(1) *Silica* or free SiO_2 and its varieties. Quartz, sand, flint, rock crystal, chalcedony, agate, etc.

(2) *Silicates* or combined SiO_2.

(a) *Alumino-alkaline silicates*—containing, SiO_2. Al_2O_3 and K.Na or Ca.

(i) Felspars–with sufficient silica.
Orthoilase, $K_2O.Al_2O_3.6SiO_2$ or potash felspar.
Plagioclase or soda–lime felspar.

(ii) Albite. $Na_2O.Al_2O_3.6SiO_2$; Anorthite $CaO.Al_2O_3.6SiO_2$.
Felspathoids–with insufficient silica.
Lucite. $K_2O.Al_2O_3.4SiO_2$; Nephelene $(NaK)(Al\,Si)_2O_4$.

(iii) mica–Complex silicates.
Muscovite, $KAl_3Si_3O_{10}(OH)_2$; Brotite.
$K(Mg\,Fe)_3\,Al\,Si_3O_{10}(OH)_2$

(b) *Ferro–magnesiam Silicates*.

(i) Amphiboles – Hornblende–complex composition.

(ii) Pyroxene– Augite. $Ca(Mg\,Fe\,Al)(Al\,Si)_2O_6$.

(iii) Olivine $(Mg\,Fe)_2SiO_4$.

3) ***Oxides and other minerals.***

(a) Oxides. Hemetite, Fe_2O_3; Magnetite Fe_3O_4.

Limonite, FeO(OH) nH_2O
Manganite, FeO (OH); Pyrolucite, MnO_2
Chromite, $FeCr_2O_4$; Titanite, FeTiO .

(b) Sulphides. Galena, PbS; Zinc blend, ZnS; Iron Pyrites FeS_2.

A very brief description of a few more common of the above principal rock-forming minerals is given below.

Art. 35. Silica or free SiO_2. Quartz—Silica and the silicates form the largest class of minerals that are extremely important in the group of rock forming minerals. Quartz is pure silica, SiO_2. Sand and flint, contain quartz to a very large extent. In the rock form it occurs in sandstones and quartzite. As an important constituent mineral it is present in gnanites and gneisses.

Quartz is unaffected by weather. Silicious rocks are hard and durable. As a cementing material in granular stones, it imparts hardness and gneisses.

Quartz crystallises into the hexagonal system and has a hardness of 7, specific gravity of 2.66. It has varying transparency and colours due to the presence of small quantities of metallic oxides. Flint. chalcedony and agate are the common coloured varieties. While rock crystal is the colourless clear variety. Other properties of quartz are described later under its uses in the manufacture of bricks, ceramies, glass, etc.

Art. 36. Silicates—Silica occurs as silicate in chemical combination with other minerals. In this form it is readily affected by the weathering agents. There are two principal groups of silicates :—

(a) Alumino–alkaline silicates.

(b) Ferro–magnesian silicates.

(a) *Alumino–alkaline silicates*—In this group felspars are the most important ones. They are present in crystalline rocks such as granites, bassalt and trap, gneiss, etc. Felspars are the silicates of alumina, with alkaline substances like potassium, sodium and calcium.

The hardness of falspars is 6, and specific gravity from 2.5 to 2.7. The disintegration of orthoclase felspar to yeild kaolinite is explained in art. 19. Thus if stone contains a larger proportion of felspars, mixed with other softer minerals, it is readily liable to disintegrate and decay.

Felspars are widely used in the various manufacturing processes. Orthoclase or potash felspar–in the manufacture of porcelain ware and for glazing; in the making of glass, etc.

Felspathoids are not as common as felspars. They are characterised by a lower percentage of silica. Thus their hardness is less,–usually 5.5 to 6. They are commonly found in igneous rocks in general.

Micas—These occur in two varieties and are essentially silicates of alumina with potassium and hydroxyl. The muscovite is white mica and biotite is the dark variety. The colour of biotite mica is due to the presence of small quantities of iron and magnesium.

Mica has a perfect cleavage and could be split into very thin laminae or flakes. It has a hardness of 2.5 and a specific gravity of about 3. Micas disintegrate very rapidly and are therefore, a source of weakness if present in a stone. Mica is generally found as an essential mineral in granites, gneisses and mica schists.

(b) *Ferro-magnesian silicates.*

Amphibole :-hornblende. This is a very complex silicate with a dark green to black colour. Hardness is 5.5 and specific gravity 3.2. It decomposes readily to serpentine and asbestos•

Pyroxene--Augite. These are very similar to hornblende, but are slightly harder and heaviour. Augite readily alters to chlorite which has a greenish colour and a hardness of about 2•

Olivine—This occurs very commonly in bassalt stone. It has a glassy luster and a yellowish green colour. Olivine has a hardness of 6.5 and specific gravity 3.5. It is more liable to decompose and alters to serpentine.

Art. 37. Oxides and other Minerals in Stones—Though oxides and sulphides are found as common minerals in many stones, they have a great economic importance. The chief of these are iron, manganese, chromium, titanium, lead and zinc. The colours and pigments so common in stones are mainly attributed to the presence of these minerals. Of the various oxides and sulphides, those of iron need special mention. When the weathering action takes place on them, it is often accompanied by oxidation and hydration, and subsequent composition of the neighbouring minerals in a stone as explained in art 19. Streaks of mineral impurities of this nature also cause a stone to weather unevenly.

Art. 38. Secondary Minerals—There is another group of minerals of secondary origin as distinguished from those formed primarily in the rocks, as described in the privious articles. A few of these common rock forming secondary minerals are given below :-

(a) *Secondary Minerals due to Aqueous Origin.*

(*i*) *Calcite*—$CaCO_3$. This is an important rock forming mineral found in various capacities. It is the main constituent of limestones and marble. As a secondary deposit, it occurs as a cementing material to bind together grains of its own composition or silicious and argillacious types as in the case of sandstones and calcarious mudstones. As a cave deposit and spring deposit in veins, it builds up stalactites and stalagmites and calcarious tufa beds.

Calcite has a hardness of 3 and a specific gravity of 2.7. It has a colour varying from white to gray and a lustre varying from vitreous, dull to earthy. Dog tooth spar and iceland spare are its pure crystalline varieties.

The chemical combination of calcite viz., CaO and CO_2 s liable to ready decomposition. A drop of dilute hydrochloric acid causes effervescence, liberating CO_2 from the mineral. But on exposure to atmosphere, the anhydrons CaO absorbs moisture and becomes calcium hydroxide $Ca(OH)_2$, which further takes up CO_2 from the air to get converted into $CaCO_3$.

When rain water, aciduated with a charge of CO_2 gas, passes over calcarious regions, calcium carbonate, $CaCO_3$, dissolves in it as a bicarbonate. But Subsequently when CO_2 escapes, crystals of $CaCO_3$ are deposited.

Calcium carbonate is such an important mineral, that a further discussion of the same is given a different chapter under limes and calcarious cements.

(ii) *Dolomite*—$Ca.Mg(CO_3)_2$ or magnesian carbonate. The presence of magnesium imparts calcium carbonate an increased hardness and specific gravity. The mineral is commonly found in dolomitic limestones and dolomitic marbles. It is more stable and weather resisting than pure calcium carbonate.

Magnesite, $MgCO_3$, is a fine grained and compact mineral, commonly used for making refractory materials.

(iii) Gypum, $CaSO_4.2H_2O$, Zeolite, Na.Al.–hydrous silicate and glauconite, K.Fe–hydrous silicate are the other secondary minerals formed of aqueous origin.

(b) *Secondary minerals due to metamorphic action.*

(i) *Garnet*—Complex lime–alumina or magnesia–alumina silicate with a hardness of 7 and a specific gravity of about 4. They sometimes contain manganese and iron. It is found embedded in shists and in crystalline limestone. It is used as an abrasive for sawing and grinding stones. Garnets very gradually alter to chlorites and serpentine.

(ii) *Asbestos*—This is a fibrous mineral and is a complex ferro–magnesian silicate, occuring in serpentine rocks, as chrysotile. It has a physical property of being separated into fibres. The superior quality of asbestos could be spun into coarse threads and woven into cloth. It has excellent fire resisting properties which has made it a very valuable as a thermal insulating material.

(iii) Tourmaline, kaolinite, talc, beryle and epidote are other types of secondary minerals.

Art. 39. The outer crust of the earth :–Composition– Out of the total depth of 4000 miles to the centre of the earth man can hardly reach the outer thickness of about 8 to 10 miles. But till now the deepest section he has reached is about 2½ to 3 miles. Attempts are made to express the distribution of materials of varying densities from the centre of the earth to the outside,–the materials of density of about 10 is assumed to have been located for half the radius from the centre; and the outer crust of granitic rocks for about 10 miles thickness is of density less than 8. The shell next to granitic rocks and of a slightly greater thickness is termed as the lower crust of earth and consists of basalt rocks of a density slightly higher than 3. This is in line with the theory put forward that our earth was once a very hot body and due to its rotating motion, heavier substances were attracted to the centre while the lighter ones travelled towards the surface. The latter were essentially the oxides.

An average composition of the outer crust of about 10 miles, consisting of igneous, metamorphic and sedimentary rocks, may be taken approximately as given below :–

Table No. 1. Approx. Average Composition of rocks in the Outer Crust.

S. No.	Name of Substance		Approx. Percentage
1.	Silica	SiO_2	60
2.	Alumina	Al_2O_3	15
3.	Iron oxides ..	FeO and Fe_2O_3	7
4.	Lime	CaO	5
5.	Sodium oxide ..	Na_2O	4
6.	Magnesia	MgO	3
7.	Potassium oxide ..	K_2O	3
8.	Titanium oxide ..	TiO_2	1
9.	Water	H_2O	1
10.	The rest of the oxides such as those of Manganese, Carbon, Chromium, Sulphur and others. ..		1
		Total =	100

It will be seen from the above that oxygen is the most plentiful element in the rocks, and silicon comes next to it, as shown below :—

Table No. 2. Approx. av. percentage composition of elements in rocks.

1. Oxygen	O	46.5 percent
2. Silicon	Si	27.5 „
3. Aluminium	Al	8.0 „
4. Iron	Fe	5.0 „
5. Calcium	Ca	3.5 „
6. Sodium	Na	3.0 „
7. Potassium	K	2.5 „
8. Magnesium	Mg	2.0 „
9. Titanium	Ti	0.5 „
10. Rest of elements ..	—	0.5 „
	Total =	100.0 percent

Common Building Stones.

In the following articles, a brief description of the stones commonly used in building construction, is given. The description is based on the lines of requirements of good building stones detailed in the first chapter, together with a necessary reference to their constituent minerals and mode of occurance, to understand their behaviour as engineering materials.

Art. 40. Granite—This is a crystalline variety of igneous rock with quartz, felspar and mica as constituent minerals. Sometimes hornblende and pyronenes are also slightly present. It is a plutonic or deep seated rock of the acid type containing 60 to 80 percent of silica. Whenever granites are exposed to the surface, it is due to the weathering away of the over-lying crust that once covered them and under which the slow cooling process of the molten magma took place to impart them a crystalline structure. The texture of granites vary from coarse-grained to fine-grained, but the crystals of the different minerals are sufficiently large as could be recognised by a naked eye.

Granites have different shades of colour varying from grey, green to pink and red. Black varieties are also not uncommon. Granites possess a uniformity of texture and ability to receive and retain fine polish which make them more suitable for ornamental features, moulded and monumental work, heavy plinths, polished columns, pedestals for statues, slab for lintels, etc. The quarry refuse could be used for paving blocks and crushed for road and railway ballast. The increased field of application is due to the improved and modern methods adopted in quarrying and in transporting them to the place of use.

Granites belong to a class of very strong and heavy stones. It is specially suited for structures where strength and durability are essential requirements, as in the case of massive buildings, bridge piers, harbour and dock works, etc. They are very valuable and form an important class of building stones. Their use in common structures is limited owing to their high cost of dressing except in places where they are the only stones available from the local quarry.

Granite stones weather well. Their durability depends upon the relative proportions of quartz, felspar and mica present in them. It has been already pointed out that quartz is unaffected by weathering agencies and that felspars decompose and fall to powder readily, specially the potash or the orthoclase variety. Micas also exercise great influence on the texture and colour of the rocks containing them. They are characterised by perfect basal cleavage which allows water to percolate through them, and owing to the presence of metallic oxides, the weathering is also uneven. Therefore, the presence of micas is a sign of weakness in the stone.

Hence granites containing large proportions of quartz, orthoclase felspar and very little of mica, hornblende and iron are more durable. In addition, if they are fine-grained and uniform in texture and colour, they are the most valuable ones.

The minerological composition of typical granites is given below :-

Table No.3 Approx. Minerological Composition of Granites.

Component Minerals	Approx. Average percentages	Chemical Composition
Quartz ..	15	Free silica-SiO_2.
Felspars ..	65	Combined silica as alkaline silicate of alumina-potash, soda and lime.
Mica ..	5	Complex silicates of calcium, iron and magnesium.
Hornblende and Pyroxenes. ..	7	Ferro - magnesian silicates.
Other minerals..	8	

The crushing strength of good granites is round about 1200 tons per sq. ft. Their average weight is 170 lbs. per cu. ft. Specific gravity is about 2.7. The absorption of granites is hardly 0.5 percent.

Locality of stone–Nizam's state in deccan. Kanara district of Bombay province. Bundelkhand. Cutch, Bihar and Orissa.

Art. 41. Trap and Basalt—Under the general name of traps and basalts are included the amorphous varieties of building stones belonging to the basic igneous rocks, containing 40 to 60 percent of silica. Their minerological composition represents a greater proportion of felspars, hornblende, augite and iron, with a comparatively smaller quantity of quartz mineral. Some varieties are fine grained and micro-crystalline in texture, but the individual minerals or crystals are too fine to be easily distinguished. These stones are in general of greenish grey to dark grey in colour, sometimes representing shades of bluish black also. Traps and basalts were formed on the surface of the originally formed crust of the earth, due to the rapid cooling of the basic lava which once issued from the interior through the fissures. •

Traps and basalts are very hard, tough and compact, and are therefore expensive to work. Owing to their hardness and amorphous texture they are very seldom quarried in blocks. However, they possess great strength and durability and are heavier than granites. These qualities make them specially useful as road metal, flag stones and paving sets to resist abrasion, were and tear. Trap is extensively used in foundations of structures and as an aggregate in concrete work. In places where they are common as in the case of Deccan, they are largely used for rubble masonry walls in buildings. But they are not evidently suited for carved work and moulings.

The crushing strength of traps and basalts varies from 1000 to 1400 tons per sq. ft. Their average weight is 180 lbs.

per cu. ft. and specific gravity about 2.9. The absorption of traps and basalts is much below 0.5 percent.

Locality of stone — Deccan trap - well over an area of 20,000 sq. miles. Central Provinces and United Provinces.

Art. 42. Sandstones--These are stratified or sedimentary rocks composed of rounded or angular grains of quartz, cemented together by silicious, calcareous, ferruginous or argillaceous matter. The cementing materials are aften brought down by the percolating waters charged with these minerals in the hydrated form or otherwise, as in the case of hydrated silica removed from the decomposition products of felspars etc. After the water evaporates, the materials are deposited in the voids of the sand grains. Sandstones are named after the type of the cementing material binding their grains. Thus there are, silicious sandstones, calcareous sandstones, ferruginous sandstone and argillaceous sandstones. Sandstones sometimes contain mica also.

Again, we have fine grained and coarse grained sandstones, depending upon the size of the grains with which they are built up. The sandstones may be compact or open textured and porous. The grains may be angular, sharp and of varying sizes, and if their interlocking is perfect, we have a compact limestone. The compactness is increased if the interstitial spaces are also completely filled with a strong cementing material. Otherwise an open textured and porous sandstone is formed. The durability of sandstones depends upon the various favourable factors mentioned above.

Silicious sandstones are very strong and durable. If the cementing matter is clayey or insufficient, we have soft and friable sandstones. Sandstones resist heat well, except for the, presence of pyrites, mica and clayey matter. Porous sandstones are liable to be affected by frost. Freshly quarried sandstones contain a certain amount of quarry water or sap or mineral water. Hence they require to be weathered by exposure. Complete drying of the quarry sap is essential and should be effected from the interior of the stone.

Sandstones exhibit different shades of colours. The colouring matter is chiefly iron. Some sandstones are white, light grey and yellow, light brown. But red, pink, buff, bluish grey and brown coloured stones are also not uncommon.

Generally sandstones are easier to work and dress unless they are of the harder and of the more silicious variety. They could be also quarried easily and could be obtained in large blocks. They are extensively used as local building materials. The compact and the fine grained block variety is fit for ashlar work, mouldings, carvings and slabs for paving. The rough and coarse grained variety is used for rubble work. On the other hand, the use of sandstone as road metal is not much recommended as they do not stand well the wear and tear of traffic and make the road very dusty in dry weather. Also for massive masonry and monumental work, the use of sandstone is very seldom made.

Sandstones are also employed for abrasive purposes, in the form of mill-stones and grindstones. The sandstone for this purpose should be slightly coarse and open textured, so that it does not wear to a smooth surface. Only silicious sandstones are suitable as abrasives.

The crushing strength of sandstones varies form 400 to 800 tons per sq. ft. Their average weight is 145 lbs. per cu. ft. and specific gravity about 2.8. Sandstones exhibit an absorption of as much as 5 to 6 percent.

Locality of stone — found generally everywhere in India· viz:— Mirzapur, Gwalior, Nagpur, Jubbulpore, Gokak, Mysore, Kurnool, etc.

Art. 43. Limestones--Limestones include the group of stratified rocks chiefly containing carbonate of lime, $CaCO_3$ as the chief rock forming mineral. Dolomitic limestones $CaCO_3.MgCO_3$, contain the carbonates of lime and magnesia. Dolomites are formed by the partial replacement of calcium by magnesium, by the infiltrating waters, and in the extreme case when this replacement is complete, magnesites or $MgCO_3$ are formed.

Limestones are formed like the rest of the stratified or secondary rocks. The grains of calcium carbonate once deposited in layers are subsequently rendered campact by the superload of the over-lying strata and finally cemented by any one of the cementing materials as explained under sandstones. It may be noted that the grains of calcium carbonates in the limestones may themselves contain impurities such as oxide of iron, silica, clay or carbonaceous matter, depending upon the composition of the rocks from the weathering of which they are derived. Thus all limestones contain small proportions of alumina, silica, magnesia, iron oxide and to a smaller extent oxides of sulphur, phosporus, etc. and bituminous matter.

There are many kinds of limestones, each variety differing largely from the other in colour, texture, hardness and durability. Thus we have compact and fine grained limestones, grannular open textured limestones and crystalline limestones or marbles. From their composition limestones are classified as:-

(i) Argillaceous or clayey limestones or kankar.
(ii) Silicious limestones.
(iii) Magnesian limestones or dolomites.
(iv) Crystalline limestones or marbles (described separately).

Limestones are generally yellow or brown or dark grey in colour, sometimes with a greenish shade. They represent a dull and earthy appearance.

Argillaceous or Clayey Limestones — They are formed by the deposition of marine muds in which the various molluscs once lived. The composition of these limestones varies from a little of clayey and silicious matter to those containing only a little of lime. They are compact, hard and smooth. Argillaceous limestones do not weather well on exposure to atmosphere. They are most suited for the manufacture of hydraulic limes and cement. Kankar is another name given to them. Kankar occurs either in the nodular form or in blocks obtained from quarries. kankar containing less earthy matter is rather hard and tough and is suited as a road metal.

Silicious Limestones — These are similar to the argillaceous variety except that clay from them is replaced by silicious matter. Probably silica and calcium carbonate are deposited simultaneously. These stones are more compact and hard and weather well. They are hence better suited for building purposes, but they represent a dull and chalky appearance.

Magnesian Limestones or Dolomites — The presence of magnesium renders limestones more resistant to fire and weather. These stones are more compact and heavy. A true dolomite contains 54 per cent of calcium carbonate and 46 per cent of magnesium carbonate. But sometimes they contain iron carbonate also.

Compact limestones -- These are somewhat impure varieties of limestones containing some silica and clay. They are more compact and could be obtained in blocks. They are also known as Porbandar stones. A similar variety of limestones is available in Cuddapah and Shahabad. They are greyish, light-brown or black in colour and are very conveniently quarried in slabs of varying thicknesses. They are quite suitable for paving and are capable of receiving a fine polish.

Weathering qualities of Limestones depend mainly on the conditions in which they are used. Under ordinary conditions of atmosphere they weather well. But they are unsuited specially for external work in the acid laiden and smoke charged atmosphere of industrial towns, since they are soluble in waters charged with acids. Dolomites, on which the action of acids is slow, are more durable. Similarly limestones in which silica is present to a greater extent, say about 25 percent, exhibit better weather resisting qualities.

The uses of limestone are already referred to early in this chapter. It is used as a buliding stone in masonry walls and as a paving set in floors. The quarry spoils are used as road metal. Some varieties are capable of taking polish and hence are used commonly in baths and lavatories for flooring and dadoing. Limestones have a great industrial importance. They are used in the manufacture of fat lime, hydraulic lime and cement. Carbonaceous limestones yield bituminous cementing materials. Different chapters have been devoted for a study of such uses of' limestons. The part played by limestones in the manufacturing processes of various engineering materials is also explained wherever such uses of these stones are made.

The crushing strength of limestones varies from 300 to 600 tons per sq. ft. Their average weight is 165 lbs. per cu. ft. and specific gravity 2.6. The absorption of limestones has a wide range from 1 percent to 4 percent.

Locality of stone — spread almost all over India. The compact variety is found in Porbunder, Shahabad Deccan, Katni, Cuddapah, Kurnool.

Art. 44. Gneiss Stone--These are metamorphic rocks and have the same composition as granites since they are the altered rocks from granites, but their structure differs due to the metamorphic action. Gneisses have a stratified structure and planes of foliation along which they could be split up easily. These planes make their quarrying operation an easy task. They yield good paving blocks and road metal. Owing to their banded structure, they do not represent a clean appearance and hence are not used in important structures, where stone facing is desired. Gneisses contain less of mica in general.

Schists—These are also metamorphic rocks but represent a schistose structure or layers along which the stone could be easily split unlike gneiss. This is due to the abundance of mica membranes as in mica schists, talc layers as in talc schists, chlorite layers as in chlorite schists and hornblende or crysotile fibres of asbestos mineral as in hornblende schists.

Gneisses and schists contain secondary minerals also, which influence their properties as building stones. Where they are the only types of stones available, their use is extended to the construction of walls of ordinary structures. When crushed the gneiss stones give a good aggregate for artificial stone and concrete. They are suited for dry stone rivetments, pitching and aprons.

Locality of stone -- Mysore, Madras, Cutch, Bihar.

Art. 45. Laterite –This is a typical sandy, clay–like, porous or vicicular textured stone formed on the surface of rocks due to their superficial alteration in tropical countries. It contains mainly hydroxides of iron, alumina and manganese and the original minerals of the rock, viz., alkalies, lime, magnesia and silica are removed in solution. Silica is removed very slowly and is present to the last stage of alteration. Depending on the proportions of the three constituent minerals, the stone is known as ferruginous laterite, aluminous laterite and manganiferous laterite. The colours of these varieties are reddish brown, yellow or creamy, dark brown or black respectively.

The formation of a laterite capping requires a free movement of percolating water and a good drainage from below. It is observed that bacteria cause the disintegration and decomposition of the original rock surface for the subsoil water to act upon subsequently. Iron oxide travels upwards and hydrated silica passes downwards in solution, giving the required composition for the laterite thus formed.

Ferruginous laterite yields good building blocks which could be quarried almost in a rectangular form. Irregular and broken quarry waste is quite suited for road metal. It gives an elastic road surface. Aluminous laterite is termed as bauxite and is used to obtain aluminium and high alumina cement.

Laterite is quarried with the aid of pick axes. When freshly quarrid, the stone is wet and soft and could be easily cut into rectangular blocks of varying sizes resembling big sized bricks. But on exposure to the air, the evaporation of water from the quarry sap, renders them very hard and fairly durable.

Locality of stone -- West coast of India. Bihar and Orissa.

Art. 46. Quartzite—Silicious sandstones under the effect of metamorphic action yield quartzite. The stone is more dense in texture, better in strength and more durable than sandstones. The sand grains are firmly bound in silica. Some of the varieties are considered as the hardest and the strongest type of building stones. But they are very difficult and costly to work with, and break up into irregular shapes and uneven surfaces. However it is an excellant material for road surfaces.

Quartzites are available in various shades from brown and red to yellowish and white. The more foliated and thinner variety yields flag stones, while the harder and the more denser variety could be split up into paving blocks. They are quite suited for breast walls, rivetments, aprons and retaining walls, like trap, basalt and gneiss stones, where dressing is of secondary importance.

Locality of stone — South India, Central Provinces.

Art. 47. Marbles—These are metamorphosed limestones. Any limestone, when heated to redness in such a way that the carbon-di-oxide present in it is not allowed to escape, will on gradual cooling, crystallise and form marble. The change is only in texture with the chemical composition remaining unaltered. All the original minerals such as silicious, argillaceous, mica, hornblende and pyronenes are present in these converted limestones. Sometimes traces of iron and secondary minerals arc also found in marbles.

Marbles yield hard and compact building stones. Their crystalline texture enables them to receive a fine polish, but when exposed to weather they are not capable of retaining it for a long time. They are available in different shades of colour such as, white, yellow, grey, green, blue, red and black. Some white marbles are fine grained and homogeneous, combined with softness and durability. They are admirably suited for sculpters work. Owing to their high cost, the use of marbles is limited to inlaid and decorative work, table slabs, window sills, floor finishings, balusters, dados and steps etc. The impure and the ordinary variety of marble, and the quarry spoils are used for making lime.

Locality of stone—Rajpntana, Central Provinces. Baroda. Jubbulpore. Jodhpur, Aimer.

Art. 48. Slates—These are metamorphic rocks derived from the argillacious ones such as clay, mudstones and shales. The metamorphism is carried out to such an extent and so perfectly that the original planes of stratifications are completely obliterated and new well defined planes of splitting called *cleavage planes* are developed in the rock. The original mineral grains are flattened out and sometimes new micaceous minerals are formed. The cleavage planes are at various angles to the original bedding planes and are formed at right angles to the force of metamorphism.

To have the best slates, the original rock mass must be fine grained and homogenous with almost all of silica and alumina. In addition, they must de subjected to long continued pressure in one direction. The minerals of slates could not be recognized except with the aid of a microscope. The preasence of lime, mica, chlorite, iron and carbonaceous matter is not desirable, as the slate containing them do not weather well. The slates used for building purposes are hard and give a ringing sound when struck. They are perfectly cleavable and are least absorptive. They offer a good abrasive resistance.

Slates are of various colours: grey or greyish black, greenish grey, purple or reddish brown. They are best used as roofing material. Sometimes damp proof courses, steps and floor tiles are also formed of dense and harder variety of slates.

Locality of stone—Bihar, Rajputana, United Provinces,.

Quarrying of Building Stones.

Art. 49. Quarry and Quarrying—The term quarrying is generally applied to the art of extracting from the natural rock beds, the stones of various types as used for general building work, and broken stones and metal for roads and concrete work, etc. The exposed part of such a rock bed where all the work in connection with the above is carried out, is termed as a *quarry*. It may be noted that the various operations involved in quarrying are open to the sky. This differs from mining in which the various workings are carried out under the ground and not in an exposed condition. In the case of mining, the material to be extracted from the ground is at such a great depth that it is impracticable to have an open quarry.

Quarrying in preference to mining is often recommended since at a comparatively low cost much of the materials could be obtained easily and the stones always admit of inspection *in situ.*

Art. 50. Site for Quarrying--The selection of site for a quarry often requires a preliminary geological idea about the rock formations in the locality where a quarry has to be opened up. A quarrying engineer should carry out some exploitary work over the site, such as digging a few trial pits to obtain an idea of the underlying rock and the over burden to be removed to reach it.

Location of a Quarry—The exact location of a quarry depends on the following factors :—

(i) Availability of the desired building stone at or near the surface of the ground.

(ii) Nearness of the quarry to the existing communication lines, such as roads and railways.

(iii) The possibility of arranging the drainage for quarry pit at a very low cost.

(iv) The haulage facilities of the quarried materials to outside of the quarry for further conveyance.

(v) Availability of suitable sites for the location of power station, crushers and stone dressing and cutting machinery, etc.

(vi) In the case of quarrying with blasting, the locality of the quarry should be at a sufficient distance from the site of building works and other permanent structures.

Before the compact portion of the rock is reached, it is necessary to remove the capping of loose earth and the decaying softer upper layers of the rock, all of which is commonly known as overburden. Only that part of the rock which is not affected by weathering action should be utilised for the production of building stones.

Art. 51. Preliminary Considerations—Whatever method may be adopted in the actual operation of extraction of stones from a quarry bed, there are certain other things to be attended to for opening out a quarry.

Lay-out — After the site has been carefully selected, the quarry engineer should arrange for a complete layout plan of the various stages involved in quarrying, so that these stages are all kept in a sequence with the minimum expenditure of labour and rehandling of the materials. The haulage of the various materials should be effected without causing any interference. A faulty planning and carelessness on the part of the quarry engineer or the person in charge of a quarry, often leads to great losses by seriously affecting the quality and the quantity out-turn of materials.

Stability of a quarry—The quarrying of the rock should be done in such a manner that the structural stability of the rock sides is not affected. If proper care is not taken, dangerous landslides or slips will occur.

Use of Labour and Appliance — When enough labour is available in plenty, and also in the case of small quarries, the work is usually carried out manually. But the use of mechanical equipment when there is enough capital and the work has to be carried out on a large scale, cannot be argued. Each problem has to be solved by a very careful consideration of the situation and a satisfactory comparision of the two methods.

Examination of Structural Weakness in a Rock — The rock masses in the crust of the earth are invariably accompanied by fissures and cracks, planes of foliage and cleavage, bedding planes of stratification and joints etc. These are weak points in their structure where the stone offers least resistance for its splitting and separating into big blocks from the parent rock. Advantage is taken of such cracks, fissures and joints during quarrying operations. If these are far apart and the rock is very hard, as in the case of igneous rocks and gneisses, blasting has to be resorted to.

Art. 52 Methods of Quarrying — Depending on the structure and nature of the rock and on the purpose for which the stone is intended to be used, there are principally two methods of quarrying in use :–

(i) Quarrying by hard tools, such as crowbars, jumpers, pick–axes, feathers and wedges.

(ii) Quarrying by blasting with the aid of explosives.

In either case, quarrying may be carried out either by manuel labour, or with the aid of machinery, or by both, as mentioned in the above article. Sometimes the spliting of big boulders into smaller ones is also effected by burning a pile of fire–wood on their surfaces. This sets up uneven expansion in the rock and thus causes cracks.

Art. 53. Qnarrying in Soft Rock—The quarrying of this type of rock is carried out by taking advantage of their dip and strike joints, bedding planes and cleavage.

Removal of Over–burden—Before the useful rock is reached, the surface deposit consisting of a capping of loose soil and soft or weathering rock has to be removel. In the case of extensive rock beds and thick deposits of over–burden, this could be done quickly with the aid of an excavator of a suitable type. The rock side or surface thus exposed could then be quarried out as explained below. This process is known as *stripping* or *ridding*.

The rock is made to split and come out in blocks by first cutting long and deep channel at suitable places. Feathers and wedges are driven along the strike and dip joints. See figs. 4 and 5. If the stone is more compact and the joints are at greater distances, a series of holes of 6″ to 8″ deep and about 2″ in diameter are made in a row with the aid of a chisel and hammer. Crowbars and jumpers are then inserted in these holes and the rock is made to split and come out along the row of holes and the bedding plane in the form of big blocks.

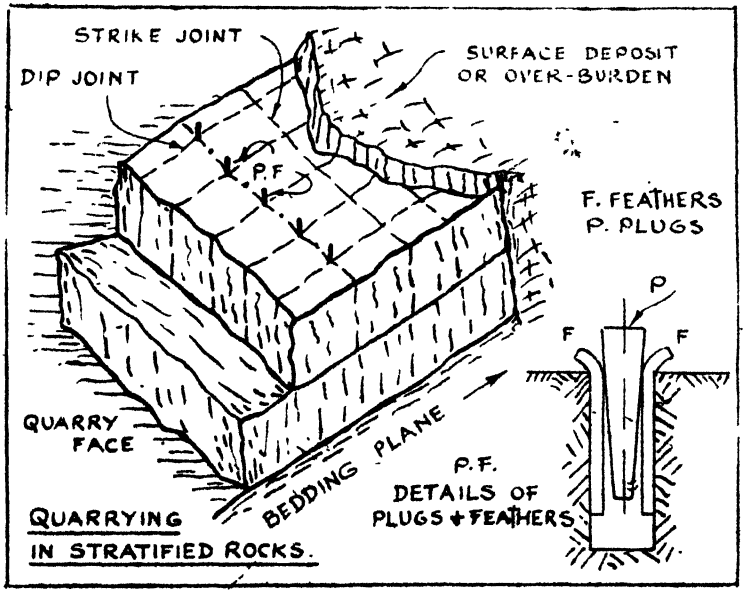


Fig. 4 and 5. Quarrying in stratified rocks.

Rough Dressing or Quarry Dressing — The big blocks are broken up into smaller ones before they are removed from the quarry, to facilitate their handling and transport. Moreover stones should be roughly dressed in the quarry, approximately to the size they are to be finally used in the structures.

Under the method of quarrying in soft rock are included the quarrying of sandstones, limestones, shales, laterite, slates, etc., belonging to the type of stratified and cleavable rocks.

Art. 54. Use of Machines in quarrying—When quarrying has to be done on a large scale machines are employed :—

(a) For channelling;

(b) For cutting out big blocks and then into smaller ones; and for taking out flag stones and slabs ;

(c) For breaking the cut pieces and quarry spoils into road metal, concrete aggregate or railway ballast ;

(d) For lifting and transporting the material in the quarry;

(e) For drilling holes in the rocks;

(f) For mechanically operated showels and bucket loaders for loading the broken metal into trucks and waggons;

(g) For carrying out excavation on a mass scale.

A brief description of the use of this machinery is given in the following article.

Art. 55. Quarrying with Machines—*Channelling machines* consist essentially of reciprocating saws or drills so operated as to cut grooves of any desired depth. Grooves of length ranging upto 40 feet could be cut with the aid of these machines. The machine is capable of moving on the rock surface. For softer stones saws could be used to cut large blocks from the rock mass.

Lifting Large Blocks for handling and cutting in general, is done with the aid of cranes and derric poles, which are conveniently mounted on a trolly or a waggon. Cranes are also used for loading the blocks into waggons for transportation. Mobile cranes are easy to handle and very convenient to move from place to place.

Cutting and Dressing of the blocks into smaller sizes is done with the aid of either circular saws or reciprocating saws. The stone block is mounted on a trolly which brings the stones before the sawing machines. The use of abrasives is very important in cutting a stone. Machinery is also used for planing and polishing the finished surfaces of stone blocks and paving sets.

Breaking, Crushing and Screening Machines — Big pieces of stones and quarry spoils are broken to smaller sizes with the aid of crushers such as, jaw-crushers, gyratory crushers or impact crushing machines. To have the best and effective crushing, some form of automatic feed is also installed. Sometimes, two stage crushing with preliminary crushers and final crushers is resorted to have better results.

Subsequent to crushing, screens are installed for the crushed material to passs through. Screening is necessary for sorting the material according to grades or sizes. Various types of screens such as fixed screens, movable screens or rotary screens are installed for the purpose.

Transporting of the materials in the quarry is done by a system of roads, trolly lines or rails, and roap ways. In a mechanised quarrying system, wheel barrows and carts are not to be commonly found. Motor trucks, tipping waggons, and cars, etc., are very commonly used.

Drilling machines for boring holes in rocks are used on an extensive scale, both for hard and for soft materials. Rotary type and percution type of power drills are used for small and for medium size of holes. But for deep holes impact drilling machines will be found very successful.

Art. 56. Qurrying by Blasting—The quarrying of hard and compact stones is carried out with the use of explosives. The rock is blasted in a systematic manner. It must be remembered that the aim of blasting is to loosen and separate out as much rock as possible out of the rock mass and not to shatter the rock into pieces. Blasting is also adopted to reduce the larger blocks into smaller and more convenient and handy sizes as required. This is usually termed as secondary blasting.

The various stages involved in the method of quarrying by blasting are the following :—

(a) Boring hole in the rock.
(b) Charging with explosive.
(c) Tamping.
(d) Firing.

All the other operations are almost the same as already described in the previous articles.

(a) *Boring hole in the rock* — Great skill and experience are required for the location of the exact spots in the rock mass where the intended explosion should take place to produce the desired effects. Such spots having been located, holes are bored by hand tools consisting of hammer and a short iron rod with a chisel edge. The size of holes usually varies from 7/8 - in. to 1½ -in. diameter and 4 to 8 feet deep. When stones are required in large quantities hand drilling may be replaced by machine drilling as mentioned above. Use of water is made to facilitate drilling operations. The rock powder and mud created during drilling are removed by a scraper or a spoon, or by a blast of compressed air.

(b) *Charging with Explosives* — The next operation is to charge the hole with an explosive. There are several varieties of explosives used for the purpose. The best suited should be always selected in each case.

Blasting Powder or gun powder, consisting of 70 to 75 parts by weight of saltpetre, KNO_3, and 15 parts of charcoal, with 10 to 15 parts of sulphur, generates the desired explosive force. This is considered as a weak explosive and loosens fairly large blocks in soft stones.

Dynamite or Nitro-glycerine—For explosions under wet conditions and for heavy work, dynamite should be used. This has a high explosive value and is available in the form of cartridges. The cartridge form of an explosive is specially suited under wet conditions.

Gun Cotton or nitrocellulose — This is still more powerful than dynamite. Great care is to be used for preserving and using it.

Cordite is another form of explosive commonly employed. It is also suitable to use under water. *Liquid oxygen* is sometimes used to a great extent in modern practice.

Before filling the explosives, it is quite essential that the hole should be thoroughly dry.

(c) *Tamping* -- Tamping is necessary to prevent the reaction of the explosive along the blasting hole itself. When the explosive is being put into the hole and before the tamping is done, a fuse of sufficient length is inserted. Tamping consists in filling up the hole with a specially prepared stiff sandy clay, which is tamped each time a little quantity is put to a small depth in the hole. A brass rod called the tamping bar is used for the purpose of tamping. Tamping has to be done very carefully and at the same time very skillfully to render the explosive very effective. Sometimes a priming needle of about 1/16 in. diameter is inserted in the tamping material which is subsequently removed after the tamping is over. The fuse is then introduced to admit of the explosive being fired. Sometimes a small quantity of gun-powder is poured in the hole to connect the explosive to the bottom of the fuse at the top.

(d) *Firing* -- The fuse mentioned above is kept of a sufficient length as to allow the person firing it, enough time to retreat to a safe distance before the explosion of the charge takes place. Two or more holes may be coupled with a common fuse for firing simultaneously each time and one or more groups of holes could be fired, as in the case of multiple blasting. The number of holes fired each time should be recorded as a guidance to ascertain if any charge has failed to explode. A dull sound of a muffled character indicates the liberation of a large mass of stone from the parent rock. Electrically operated firing devices are also adopted to create the spark needed for the explosion. This is safe and a number of explosions could be controlled from one place, in a series. Detonators are used for the purpose.

Secondary Blasting — When large blocks of stones are liberated from the initial blasting operation, they are again broken to smaller pieces by a secondary blasting operation in a manner as explained above. See figs. 6 and 7 for the details of blasting operations.

Art. 57. Line of Least Resistance—The effect produced by blasting depends upon the resistance offered by the rock, to the gases generated by the explosion. These gases escape into the air by the shortest distance and the portion of the rock which offers them least resistance. The *line of least resistance* is often taken as the shortest distance from the centre of explosion to the nearest face of the rock. If there is any fissure or any weak spot in the rock, its distance from the explosive, if shorter than the above distance, should be taken as the line of least resistance. It may be noted that if the tamping is not done effectively, the line of least resistance for the explosive will be along the blast hole itself. It is observed

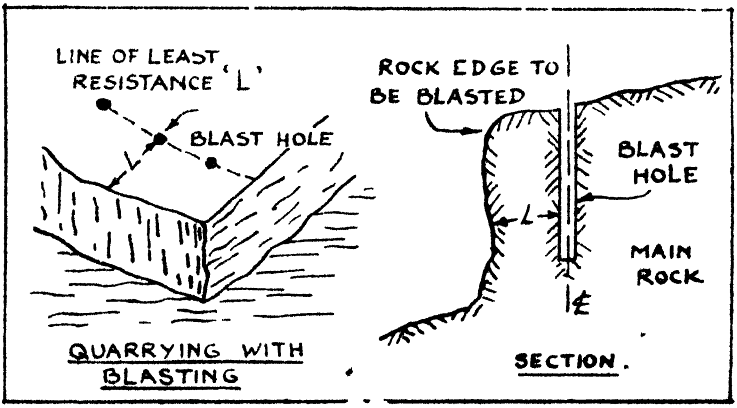


Fig. 6 and 7 Quarrying by Blasting.

that the depth of the hole should be about $1\frac{1}{2}$ times the line of least resistance.

As an approximate estimate for the charge of blasting powder, the line of least resistance is of some assistance. The following relation is nearly true,—

$$\text{Blasting Powder} = \frac{(\text{Line of least resistance})^2}{32}\ \text{lbs.}$$

For example, if the line of least resistance is 3 feet, the quantity of blasting powder required equals $\frac{1}{32} \times 3^2 = \frac{9}{32}$ = 4.5 ounces. It will be noted that only 2 ounces will be required if this line of least resistance is 2 feet.

After the stones are roughly dressed in a quarry, they are left for some time to lie in open air for seasoning.

Art. 58. Tools Used—The various types of tools used for blasting and stone work in general are illustrated in figs. 8 to 14.

After the quarrying operation, when the stone comes out in the form of medium sized blocks, it is further broken with the aid of a quarry hammer into smaller units as follows :—

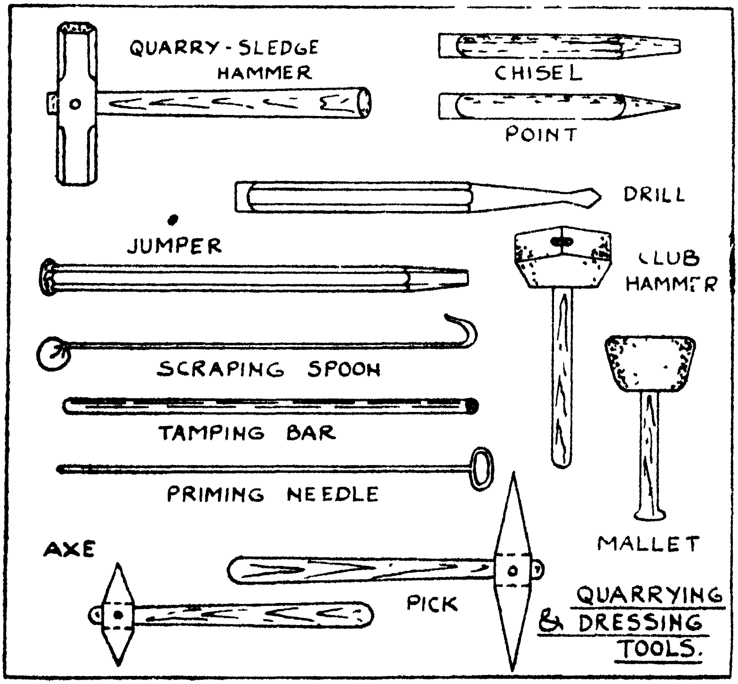
(i) *Khandki* — A face stone or a stretcher in stone faced walls.

(ii) *Header* — A longer stone used across a wall for bonding.

(iii) *Rubble* — Irregular shaped but approximately cubical pieces of stone used for interior filling and backing of a wall. Small sized rubble stones are generally termed as *chips*. They are slightly flat.

(iv) *Quoins*– or corner stones having two faces.

(v) *Block Stones* — Rectangular blocks of stones used for block masonry work, and mouldings, etc.



Figs. 8 to 14. Tools used.

(vi) *Stone Metal* — Broken stone of varrying sizes used for road surface, aggregate for concrete, crushed stone in place of sand. These are generally obtained from quarry waste.

(vii) *Flag Stones* and *Paving Sets* — These are thin stones used for flooring and road surfacing in general.

After rough or quarry dressing, the stones are conveyed to site of works where they have to be used. There, they are again dressed in the required fashion, such as, chisel dressing, tooled surface dressing, rubbed and polished surface finishing etc.

CHAPTER IV

Refractories And Clay Products.

Refractories.

Fire clay and fire clay bricks. Detrimentals and non-detrimentals. Varieties of fire bricks–acid basic and neutral refractory bricks.

Sand Lime Bricks.

Materials used. Process of manufacture, mixing pressing and hardening. Paving bricks.

Terra Cotta and its varieties.

Ordinary, glazed, porous, polished and fine varieties. Selection and preparation of clay. Moulding and drying. Burning and annealing. Uses and properties.

Building Tiles.

Roofing tiles; flooring and wall tiles. Process of manufacture. Circular tiles. Mangalore and Alahabad tiles.

Drain Tiles and Pipes.

Sewer pipes. Stoneware. Porous and glazed.

Glazes and Glazing.

Methods of glazing. Salt glazing. Single stage burning. Superior glazing. Process of burning–two stage. Technic of glazing.

Whiteware and Hollow Articles.

Process of manufacture. Preparation of slip. Casting fluid. Moulding the articles. Biscuit–stage burning. Glazing and second burning.

Refractories

Art. 92. Fire clay and Fire clay bricks—*Detrimentals and non - detrimentals* — We have seen that the purpose of burning clay bricks has been to form a small amount of fusible glass in the material. Usually a temperature of 1800° F to 2000° F is enough for the purpose of bricks, when a requisite amount of fusible glassy substance is formed in them just to impart the necessary qualities of strength and impervious nature. The products burnt at this temperature remain partly porous.

Constituents Fire Clay is employed for manufacturing refractories and refractory linings for furnaces. A refractory material is difficult to fuse, soften or melt at temperatures at which ordinary bricks soften and lose their shape. Good fire bricks should not show any sign of fusion even at 3000° F. The compounds of Al_2O and SiO_2 have a very high softening point. But the presence of lime, magnesia, iron oxide and alkalies act like fluxes and lower the softening point and consequently do not permit high temperatures to be attained in kilns for making fire bricks as such bricks will soften and lose their shape. This requires the fire clays to contain the smallest quantities of fluxes.

Silica, SiO_2, becomes soft at about 2750° F and finally fuses and becomes a glassy substance at about 3100° F. It melts around 3200^0 F. Due to this high softening and melting point, it is therefore used as a principal material in the making of refractories and fire bricks.

Alumina, Al_2O_3, has still higher softening and fusion temperature. It melts at about 3750° F. It is therefore, used with silica for making fire bricks and refractories.

Thus silica and alumina are termed as non–detrimentals; and lime, magnesia, oxide of iron and alkalies are termed as detrimentals

Uses — fire bricks are used for linings of furnaces to develop great heat for the smelting of ores and metals in the manufacturing process, for the construction of boilers, combustion chambers and chimney flues. Fire clay is required for making mortar to construct fire brick masonry.

Art. 93. Composition of Fire Clays — *The heat resisting qualities* of refractory materials depend upon the percentages of silica, alumina and oxide of iron in the fire clay. The following is the analysis of fire clays generally suitable for refractory work.

Table No. 7. Composition of Fire Clays.

Clay constituents	Non-detrimentals Percentages.		Detrimentals percentage.	
	Alumina	Silica, both combined and uncombined	Lime, Magnesia and iron oxide	Alakalies
Percentage	25 to 35	50 to 75	2 to 8	1 and less

Thus fire clays are generally composed wholly of kaoline and silica which are termed as non–detrimentals and almost of negligible quantities of lime, magnesia, oxide of iron and alkalies, which are termed as detrimentals.

Art. 94. Process of Manufacture — The various stages in the manufacture of fire bricks are the same as those for ordinary bricks. These stages include, digging, dry grinding, mixing and wetting, weathering and blending, tempering, moulding, drying, burning in kilns and annealing. It is desirable that the shrinkage should be very small and therefore little quantities of flint clay, sand or previously burned and pre-shrunk fire-clay is mixed in the ordinary fire-clay. The bricks are burnt in a down draught or a continuous kiln at temperatures ranging from 2500° F to 3500° F. At these high temperatures the process of burning and cooling down should be effected very slowly.

Varieties of Fire Bricks — The following are the principal varieties of fire bricks.

Art. 95. Acid Refractories—*Acid bricks* — Fire Bricks, Silica bricks and Ganister bricks.

Ordinary Fire Bricks — These are made of natural fire clay with a mixture of crushed flint clay, sand or previously burnt fire-clay, in the manner given above, and provide a very good type of acid refractory lining to furnaces.

Silica Bricks — They contain as much as 95 percent of silica and are manufactured from sandstones or quartzite, with an addition of 2 to 3 percent of lime to act as a binding material and flux. These are moulded under heavy pressure and burnt at 3200° F. Silica bricks are quite suitable for acid lining of furnaces and for some metallurgical operations.

Ganister Bricks — These are made from a selicious variety of ganister rock containing abou. 10 percent of clay, with an addition of 2 percent of lime, in a manner similar for silica bricks. As a result of high temperature burning, various modifications of silica are formed in the silica bricks. They are very compact, hard and rigid even at high furnace temperatures.

Art. 96. Basic Refractories — *Basic Bricks* — Magnesia bricks and Bauxite bricks.

Magnesia Bricks — are made from lime and magnesia rocks and are widely used for basic refractories in furnaces. Dolomite is also used for making these bricks. If these materials are burned at high temperatures, they become stable and are not affected by moisture. Little quantities of iron oxide and chrome-magnesia are added as flux to lower the fusion temperature and also to act as a bond. The burning temperature required for a first grade magnesia brick ranges between 3200° to 3600° F.

Bauxite Bricks — Bauxite containing about 85 percent of Al_2O, is mixed with 25 percent of clay and the bricks made therefrom are burned at a comparatively low temperatures of about 2800° F. to form these bricks.

Art. 97. Neutral Refractories — *Chrome Magnesia* bricks and *high Alumina* Bricks — From the above methods of preparing materials for acid and basic refractories, it is clear that silica and lime with magnesia form the chief constituents respectively. Neutral refractories are prepared from chrome and alumina. These are stable and do not react with silica or magnesia, and have very high softening point. They are also more inert to slags than the above two varieties.

Chromite bricks — are made from a mixture of chrome iron ore - 50 percent, ferrous oxide - 80 percent and bauxite with little silica - 20 percent. The materials are crushed and pressed to form bricks. At high temperature silica and the other minerals contained in the native chrome ore form a small quantity of glass to bind chromium and alumina particles. Chromite bricks are burnt at temperatures round about 3000° F.

Carborundum — This is a proprietory name and is prepared in Electric furnaces. In composition it is silicon carbide and has a very high softening temperature, usually well above 3500° F. It has the qualities of a neutral refractory material and is inert to slags.

Sand Lime Bricks.

Art. 98. Sand Lime Bricks — These are comparatively modern products and have recently come into common use as materials of construction. Sand-lime bricks are made essentially from silicious sand and slaked lime. In the bricks ordinarily prepared for structural purposes, about 90 to 93 percent or more of silica sand is used, and the remaining 10 to 7 percent or even less is lime.

Materials used — *Sand* — As far as possible *sand* must be made up of finer particles, uniform in size and well-graded. It should be free from surface coatings of clay, clay nodules, soluble salts and organic impurities The interlocking action of well-graded sand in producing dense, compact and less porous bricks is quite apparent. The *Lime* used may be pure high calcium or fat lime or a dolomite lime, but it is essential that it should be completely slaked and finely powdered. It may be noted that commercial lime contains to some extent nodules of unburnt calcium carbonate and unslaked CaO, or quicklime. They reduce the soundness of bricks and as it is not possible to completely eliminate them a very low percentage of these is often permitted.

Other minerals like finely ground silica, pozzolanic materials, etc. are also added to improve strength. Pigments of iron oxides, ochres, chromic oxides and carbon black are mixed with sand and lime to obtain the desired colour effects.

Art. 99. Process of manufacture — This consists in (i) Mixing, (ii) Pressing, and (iii) Hardening.

(i) *Mixing* — This stage in the process of manufacture is very important as it is essential that a thorough and an intimate mixture of sand, lime and water should be formed. To facilitate this a dry mix of the various constituents is first made and then the required quantity of water is added and mixed again. The quantity of water should just be enough to allow the mix to be moulded under pressure and the green brick to be handled without damage.

(ii) *Pressing* — The mixture is then taken to pressing machines where a pressure of about 15000 lbs. per sq. in is applied. This is a very high pressure and is developed in special types of machines.

(iii) *Hardening* — After pressing, the green bricks are sent directly to hardening cylinders or *autoclaves*. About 1000 to 1500 bricks could be hardened at a time. The autoclaves are long steel cylinders of about 50 feet in length and 6 feet in diameter. The cars carrying the pressed bricks are directly pushed in these cylinders and the doors are tightly closed. Steam is then admitted under a pressure of about 150 lbs. per sq. in. for about 6 to 7 hours, and after this period the bricks are allowed to cool down and are removed for use. During the autoclave treatment, hydrated calcium silicates are formed as mentioned above.

To produce *Paving bricks* sand lime bricks are impregnated with bitumen in vacuum after the hardening is completed. This imparts them excellent weathering qualities.

Sand lime bricks have accurate shape and size with sharp angles. They represent a clean appearance and their strength compares favourably with that of clay bricks; but their wet strength is somewhat less than their dry strength. Though they are widely used in place where clay is scarce, their use in places where clay bricks are manufactured, is not uncommon.

Art. 100. Paving Bricks — These bricks are manufactured to have maximum resistance to impact and abrasion. They should be more dense, compact and strong and less absorptive as compared to common bricks. This requires the formation of a larger proportion of fusible glass in the paving bricks.

The clay selected for making paving bricks is proporioned to contain *a higher percentage of iron*. This gives two facilities. The clay extrudes very well with the minimum water content for plasticity and at the same time gives also a dense mixture almost free of air in the inside. This facilitates the moulding of bricks by the stiff-mud process. Since iron acts as a flux, the fusion temperature is comparatively brought down resulting in the economy of fuel used. The bricks are burned at a slightly higher temperature and the presence of iron enables partial vitrifaction to take place and develop a natural resistant glaze.

Terra Cotta and Its Varieties.

Art. 101. Terra Cotta—*Ordinary, Glazed, Porous, and Polished or Fine Varieties*.

(i) *Selection and Preparation of Clay*—The term " terra cotta " means burnt clay. The composition of clays required for making terra cotta products are the same as used for fire bricks, but the selection is specially made for the best type containing,

(a) A higher percentage of iron, and

(b) A smaller percentage of lime, which is kept around one percent.

Usually single clay does not give the necessary composition for terra cotta. A mixture is made of the several clays of high alumina contents, to which are added silica sand, ground glass, and finely pulvenized old terra cotta or pottery ware. This reduces shrinkage on drying and imparts rigidity and strength.

In the process of terra cotta manufacture, the various ingredients are crushed and finely pulverized in a dry state and added in the required proportions to obtain a mixture of the desired composition. After adding water, the wet clay is kept in a damp condition for weathering and tempering for several days. Finally it is kneaded well in a pug mill and kept ready for pressing into a hand mould.

(ii) *Moulding and drying* — Special moulds of plaster of paris or templates of zinc are prepared, and the prepared plastic clay is pressed well into them by hand; The moulds are porous and are made about 6 to 10 percent bigger in size than the finished product. This allows for the easy drying and the shrinkage of articles put into the mould. The loaded moulds are kept for some days at the end of which the articles are taken out and dried further. The moulds may preferably be sprinkled with fine sand from inside before the clay is pressed in.

(iii) *Burning and Annealing* — The dried articles are carefully burnt in kilns in the same way as for the best type of bricks. The burning extends for about four days during which period the kiln temperature is kept at about 2200° F. The burnt articles are allowed to remain in the kiln for a further period of five days for slow cooling and annealing. The natural colour of well burnt terra cotta is light yellow or light buff. But the dried articles could be given a desired colour or *glaze* before burning, to give a *glazed surface finish*.

Art. 102. (i) Porous Terra Cotta — To develop sound proof or fire proof qualities, the material is made by adding saw dust or ground cork to the raw ingredients to prepare a mixture with which the articles are moulded. While burning, the organic matter burns out leaving behind a porous textured product. porous terra cotta is very light but weak structurally. It could be sawed and nailed very easily.

(ii) **Polished or fine Terra Cotta** — This is a high grade variety of terra cotta obtained by *burning twice* in kilns. In the first stage the moulded articles are burnt to a low temperature of about 1200° F. This is known as the *"biscuit'* stage burning. They are then cooled down and removed from the kiln for a coating with a glazing compound. Subsequently they are burnt a second time in the kiln at a higher temperature of 2200° F.

Uses — Terra cotta belongs to the superior class of earthen ware, very often used for ornamental work and also as a substitute for stone to produce decorative effects. Terra cotta blocks are used for building purposes with hollow interior, as per design, with a thickness of shell of 1″ to 1½ ″. They are also used for encasing steel columns and beams and in floors to have fire proof and ornamental work.

Good terra cotta is dense and uniform in texture. It is durable and is unaffected by acid charges in the atmosphere. It is light, strong and hard and can be made to any desired colour and design.

Building Tiles

There are principally three types of building tiles depending on the purpose of their use.

(1) Roofing tiles;

(2) Flooring tiles & wall tiles.

Art. 103. (i) **Roofing Tiles** — *Clay tiles* — Tiles in general have thinner sections as compared to bricks and therefore require better care and attention at all stages of manufacture commonly employed for bricks. Purer and stronger varieties of clay are selected and worked well by proper weathering, blending, tempering and kneading. The required amount of plasticity should be developed in the clay to admit of easy workability in their sections.

(i) *Circular Tile sections* such as those of country roofing tiles are conveniently made on a potter's wheel. They are first made in a hollow round tapering shape, about 11″ long, 4½″ by 8″ round diameter at the two ends, with a thickness of about 3/8″. They are subsequently cut into two halves longitudinally. They are burnt in kilns at ordinary temperatures. *Pan tiles* are also manufactured in a similar manner, but they are less curved and have a flat bottom. They are first moulded flat and then remoulded on a different mould to the required curve.

(ii) *Mangalore and Allahabad Tiles* — These belong to a better class of roofing tiles and are made in the same way as pressed bricks. The clay is rather of a stiff consistency and is pressed in moulds carrying the necessary indentations for purpose of drainage and interlocking when laid in position. In order to develop red colour in these tiles, a higher percentage of iron oxide is used. The burning of these tiles is the same as that described for clay building bricks except that they are burned harder to have more strength. The high pressure applied to them during moulding, and their burning in a down draught kiln to correct temperature, impart to these tiles, a hard and dense texture required to throw off rain water. The roofing tiles must have a very low absorption.

Art. 104. Flooring and Wall Tiles — *Clay Tiles.*

(i) *To Prepare a Correctly Proportioned Intimate Mixture*— For the manufacture of flooring and wall tiles, rich varieties of clay are required. Kaolin or china clay which is white in colour is best suited for the purpose. Such clays are liable to shrinkage, and hence they are mixed with a required amount of silica in the form of pure sand or flint crushed to a very fine powder. Sometimes a mixture of several clays such as fire-clay, shale and Kaolin may be made in the required proportion. The mixture is then ground and water added to it to prepare a thin slurry for straining it through a very fine mesh wire screen or a silk or muslin screen. The slurry is termed as " *Slip* ". The screened slurry is run into tanks where it is allowed to settle down. The top water is drained off and the bottom deposit is dried first in the filter press and then over the ovens. The dried clay mixture is reground to a fine powder.

(ii) *To Mould or Press the Tiles and to Burn* — The crushed powder is moistened, preferably by steam, to the consistency of wet powder to facilitate moulding. The moulding is done in a dry press and the moulded green tiles are directly sent into a kiln for burning.

The burning is done in two stages. In the first stage the green tiles are burnt to a low temperature of about 1200° F to be taken out again for a dip in the glaze solution for the required colour. After this the tiles are again sent into the kiln for second stage burning to a temperature of about 2200° F to fuse the glaze.

The above process is very much simplified in the case of common and cheap tiles. The stiff-mud process with wire cut ends is usually enough. Similarly firing is also done at one stage only.

For Decorative Tiles, when a number of tiles jointly represent one design, the picture or design is drawn on the tiles by spreading them after the first stage burning is over and the tiles are subsequently burnt a second time.

The preliminary requirements of flooring tiles are density, compactness of structure, hardness and strength. They should have very low absorption and high resistance to abrasion. Wall tiles can be of a comparatively smaller strength. The sizes of the tiles are 6″ × 6″ to 4″ × 4″. Sometimes hexagonal tiles are also made and their thickness varies from 3/8″ to 1/2″. Ceiling tiles are also prepared in the manner mentioned above, but they are thinner in section than flooring tiles.

Art. 105. Drain Tiles and Pipes—These are prepared to maintain a porous texture after burning, which is necessary to allow subsoil water to percolate into them when laid in the ground or water logged soils. They are manufactured either circular or ∩ shaped, and in lengths of 2 feet each.

The clays for drain pipes or tiles belong to the fire-clay variety. Sometimes a mixture of these clays, shale, and powdered burnt earthenware is used. They are very finely ground and washed in tanks. They are then thoroughly mixed, tempered and pugged to develop the required consistency and plasticity for being moulded by the stiff mud process. The clay must be perfectly homogeneous and of a uniform semi-stiff consistency to admit of hollow moulding. They are burned at a lower temperature, so as to develop the necessary strength without vitrifaction or glaze. These pipes are also known as agricultural drain pipes.

Art. 106. Sewer Pipes— Stoneware— They are made from highly silicious clays containing about 75 percent of silica and 25 percent of alumina. There are very small percentages of other ingredients. Such clays are difficult to fuse. They are mixed with certain proportions of powdered stoneware, ground and calcined flint, and sand, to prevent excessive shrinkages. A certain percentage of oxide of iron is also added for easy fusing and vitrifaction. The material so produced is hard, dense in texture and gives a ringing sound when stuck. It is very durable also.

Glazed Stoneware — This material is prepared by applying a glaze to the half baked porous stoneware, and by burning them again to a higher temperature for vitrification, of the half baked stoneware and also for the purpose of fusing the glaze to give a continuous surface coating.

Art. 107. Glazes and Glazing — A glaze is a mixture of glass forming materials of special composition, that is ground to powder e. g. lead silicates, boro-silicates, tin, titaninium and zirconium oxides, etc. These give colourless glazes.

For coloured glazes, other metallic oxides, such as iron oxide for brown and yellow colours, copper oxide for green, cobalt oxide for blue, manganese oxide for wine colour, are used.

Superior and rich clays with suitable alumina and silica contents are made into a slip or thin slurry and are used as glaze substances.

Powdered glass of the desired colour is also used as a glaze substance; e. g. opaque glass is used for green colour.

Art. 108. Purpose of Glazing — A glaze is applied to the surface of clay articles :—

(a) For improving the appearance.

(b) For producing decorative effect of the desired colours and design.

(c) For making them non-absorbant.

(d) For imparting them durability in general.

(e) For protecting them from the destroying effects of atmospheric agents and chemical actions.

(f) For preserving them, if used as sewers, from the corrosive action of sewage and sewer gases.

(g) For providing a smooth surface with rounded corners and arisis as required of sanitary ware used in lavatories.

Methods of Glazing.

Art. 109. Salt Glazing — Single Stage Burning — In this method of glazing, the sodium chloride or common salt is employed to form a glassy coating on the earthenware to form silicate of soda and other minerals present in the clay. It is extensively employed for making glazed stoneware articles. The process consists in throwing common salt into the furnace when the articles are fairly heated. The sodium salt is volatilised and decomposed by heat in the presence of oxygen and silica, while the chlorine gas goes away. The sodium then combines with silica to form sodium silicate which fuses together with silicates of alumina, lime and iron. The impervious and hard film thus formed, is called *glazing*. This method is very effective and at the same time economical also, the vapour of sodium salt enters the pours of the heated stoneware and gives a deep coat of an impermeable film of glass. The throwing of common salt into the furnace in right quantity and at the right temperature is an important and skillful operation.

Art. 110. Superior Glazing and Two Stage Burning — *Process of Glazing* — In this method of glazing, which is also known as white glazing or colour glazing, the glaze substances are ground to *a very fine powder* with requisite quantities of colouring matter. They are then mixed with water where they are held in a colloidal form of suspension. This colloidal and slimy like thin solution is usually termed as glaze slip.

(i) *First Stage Burning and Application of Glaze Substance* — The articles to be glazed are burned at a low temperature and as it comes out of the kiln, it is in the *"biscuit"* stage and is still porous as no glass formation or vitrifaction is allowed to take place in the body. The articles are then dipped momentarily in the glaze slip so that the particles of glaze substance enter and fill up their pores.

For porcelain and thin pottery ware, a rich clay glaze slurry is used. It is made to penetrate right through body of the article and on melting gives a homogeneous translucent ware of a superior quality. Sanitary ware, such as pans of water-closet, wash basins, sinks and bath tubs are given a galze in this manner. For the larger variety of sanitary ware, the glaze slip is sprayed on with an air jet, sometimes, when the article comes out of the extruding machine.

Sometimes the glaze slurry is applied by a brush, specially when the article has to be glazed with different colours or when only it has to be partly glazed with a colour. The portion to be not glazed is given a coating of liquid paraffin so that it remains in the unglazed condition after burning also.

In the case of delicate and complicated decorations with one or more colours, the glaze slurry is applied by hand or by transfer prints. This requires a special form of varnish to be applied to the porous articles burnt at biscuit stage, to facilitate the colour work to be executed by hand and also to transfer the prints from transfer papers on the article. It is generally adopted for expensive pottery ware.

(ii) *Second stage burning* — The glaze coated articles are then fired a second time in the kiln. It is necessary that they should not be touched by hand. Suitable temperature is maintained so that the melting point temperature of the glaze and the vitrifying temperature of the article are the same.

Articles of a delicate nature have to be protected while burning from the physical contacts of fire, soot and dust which would discolour them. The dried pottery ware is packed in fire–clay boxes called "*saggers*" which are stacked in the kiln for burning. Sometimes an enclosure of firebricks is formed in the kiln in which the articles to be protected are kept for burning. This enclosure is called a *muffle*.

Art. 111. Technic of Glazing — Considering the principles on which the glazing is effected, it will be seen that the following points should be observed for a successful operation :–

(i) the articles should be initially burnt to a hard and porous ware.

(ii) The glaze slip should be of the right composition and the glaze materials should be held in a state of perfect suspension.

(iii) The glaze materials should be uniformly of one size. The residue should not exceed 1 percent on a 140 mesh sieve and 2 percent on a 200 mesh sieve.

(iv) The melting point of the glaze and the vitrifying temperature of the clay should be the same. If the glaze melts early, the interior of the articles remain porous, and covered with a coating of glaze. This results in a weak product and when the glaze cracks, the porous interior is exposed.

(v) The co-efficient of thermal expansion of the glaze and that of the body should be the same. This is really a very difficult task and requires great skill. If the two co-efficients are different, cracks are formed on the glaze as the articles cool down. The glaze is then said to "*craze*". When such tiles are used in exposed conditions, water will percolate through the cracks and reduce their durability.

(vi) Highly decorative and ornamental work is done on the glaze appied as previously detailed, and pottery ware is subsequently rendered permanent by a brief firing.

Art. 112. Manufacture of Whiteware and Hollow Articles — The following are the stages in the manufacture of this class of pottery or clayware :—

(a) To prepare a slip;

(b) To convert the slip into a casting fluid;

(c) To cast the fluid into the plaster mould and to dry the articles.

(d) To burn to biscuit stage.

(e) To apply the glaze substance, and

(f) To burn the articles a second time.

A brief description of these various stages will now be given. Some of them have been already detailed in the early articles, but the general trend in the various stages in the manufacture of these articles is to take great care and precaution to see that thin articles of good quality are produced.

To Prepare a Slip — Rich varieties of weathered clays are taken and passed through washing tanks to remove extraneous matter, pieces of stone and pebble, pieces of wood, etc. It is then carried to settling tanks where water is removed. The liquid is then passed over a magnetite separator to eliminate all traces of iron which will cause stain in the articles during firing.

The settled fluid or slip is seived through muslin or silk screens to exclude oversized particles of clay and its constituents. This facilitates to develop a uniformity of texture. The fluid is then filtered through a filter press to drain away water, and the pressed stiff and soft clay is then kept under a shade in a damp condition for some days for aging.

To Prepare a Casting Fluid — At the end of the aging period it is mixed with water and the different types of very finely ground materials like felspars, crushed flint and burnt clay ware, are added in the specified proportions. The mixture is then thoroughly broaken in cylindrical ball mills and a slurry of creamy consistency is prepared. This is termed as " casting slip " or " casting fluid ". The essential requirements of a casting fluid is to hold a maximum amont of clay in suspension. It should admit of easy pouring in the casting moulds. This is secured by reducing its viscosity and increasing its pH value. Various hydrolysable salts are also added for this purpose.

Moulding and Drying — The casting fluid is then poured in measured quantities into Plaster of Paris moulds of the required pattern. The mould is a porous body and is in two parts to admit the removal of the article. After a few minutes, when a certain amount of water is removed from the fluid by percolation into the body of the mould, the excess of the fluid is poured out. Subsequently within an hour or so, the clay article formed inside the mould dries, sets and shrinks. The shrinking of the article admits of its removal by separating the two parts of the mould. The cast pieces are dried on hot air ovens.

The various stages of initial burning, glazing and final burning in saggers at the desired temperature as required for the dried pieces, are the same as those detailed in arts. 109 to 111.

Different Types of Clay Wares.

In addition to the types of clay products mentioned above a great variety of different types of clay wares are manufactured, each to serve a specific purpose. The following are the common types :—

Perforated Air Bricks in different designs and patterns.

Tiers or Bounding Bricks for tying two sides of hollow or cavity walls.

Chimney flue pipes and smoke flues.

Damp proof course bricks of a non-absorbant nature.

Arch bricks, invert bricks for sewers, with a special abrasive surface.

Gulley traps, intercepters, etc.

Ridge tiles, hip and valley tiles, etc.

CHAPTER V

Limes and Limestones

Cementing materials.

Introductory. Scope of study. Classification — argillaceous, calcareous and carbonaceous materials as cements. Calcareous cements.

Limes and Limestones.

Composition. Impurities in limestones and their effects—Magnesia, alumina, silicon, iron, sulphur, carbon, etc. High calcium limes, hydraulic limes, natural cements, pozzolana cements. Iron oxide, sulphates, carbonaceous matter, and alkalies. Composition of common varieties of limestones.

Tests on Limestones.

Physical tests and chemical tests. Heat test and hydraulic test. Acid tests. Classification of limes.

Chemical Analysis — interpretation. Ratios of oxides of calcium, magnesium, silicon, aluminium and iron and their index values.

Testing of lime and lime mortar— Strength for adhesion, soundness, tension and compression.

Manufacture of Lime.

Occurrence of limestones. Process of manufacture. Lime burning. Lime clamps. Lime kilns — intermittent and continuous types. Loading, lighting, burning, cooling and unloading. Figures for lime manufacturing processes.

Effect of Heat on Limestones. Calcination of hydraulic limes. Calcareous constituents. Argillaceous constituents.

Hydration and Slaking. Water required for hydration. Methods of slaking—hand slaking and mechanical slaking.

Artificial hydraulic lime.

Setting of limes–fat limes and hydraulic limes.

Cementing Materials.

Art. 113. Introductory — One of the principal stages of constructional engineering, either in the building of walls and parts of structures or in the making of concrete or road work in general, is the binding together of the various units of inert matter such as stones and bricks, with some type of cementing material. The chief purpose of this is to impart strength, rigidity, solidity, durability and such other structural requirements to the works so constructed.

In the previous chapter we have studied the various methods of obtaining stones from nature and manufacturing bricks from clays and also testing them for their requisite properties. In the following articles will be given the manner in which our cementing materials are obtained to bind together the above units, to form our structures.

Art. 114. Scope of Study — Generally the cementing materials are not found in a ready form in nature as could be used directly. In almost all cases, they have to be manufactured from the raw materials. Their description therefore includes —

(a) A study of the raw materials used for the purpose and their correct proportioning.

(b) The various stages involved in their conversion and manufacture.

(c) The properties and testing of the finished products.

All cementing materials have to be in a very fine state of division to admit of their being reduced to the condition of a paste for developing necessary adhesion and workability.

Art. 115. Classification — The various cementing materials could be classified into three main catagories :—

(i) Argillaceous materials.

(ii) Calcareous materials.

(iii) Carbonaceous materials.

Argillaceous materials — Kaolin is the base of all clays. The way in which clay acts as a binding material is already explained in Art. 60. It is probable that clays were the first cementing materials to be used in the construction field. They hardly require any preliminary processing before being mixed with water to form a paste for binding together bricks and stones. Clays do not harden under water. Water is only added to the clays to develop the necessary homogeneous nature, plasticity and workability in the paste so formed. It is only when this water evaporates, the desired *strength is attained by the bonded work.*

Clay with the right quantity of water could be worked to form a thin film which will bind the surrounding grains. It should be noted that with the increase in the percentage of water, clay acts like a lubricant and finally as a plastic body and a fluid. These are essentially the physical properties of clay. Some of the common examples where clay acts like a binding material, are :–

(a) The compactness of water bound macadam roads;

(b) The strength of the dried clay products;

(c) The compactness and strength exhibited by clay coated foundry sand;

(d) The formation of argillaceous sandstones where clay is the main cementing material; etc.

In all the above instances, the clay substance must be in a very fine state of division or virtually in a colloidal form. The high strength and hardness attained by clay products at fusion temperatures is another illustration to show this binding property of clay.

Art. 116. Calcareous Cements — In this and the next chapter will be described the making of the calcareous cementing materials. They require an initial heat treatment before water could be added to them to form a paste exhibiting cementitious properties. Calcium carbonate, $CaCO_3$, is the base of all limestones from which calcarious cements are made. In the action of these cements water not only acts physically to render them workable in the form of a paste, but it also enters into chemical combination with them in the process of subsequent hardening.

Carbonaceous Cementing Materials — These fall into an entirely different catagory of cementitious products and are described in a later chapter.

Limes and Limestones

Art. 117. Composition — Limes and limestones are the terms generally applied to all calcareous substances found in nature containing chiefly calcite or calcium carbonate, $CaCO_3$. This substance is the starting point in the manufacture of lime and is the basis of all calcareous cements in general, which are so widely used in the engineering field.

The raw materials contain varying proportions of other substances commonly known as impurities. They are seldom found pure in nature as calcium carbonate, $CaCO_3$. The chief impurities in limestones, present in varying proportions are, magnesium, aluminium, silicon, iron, sulphide, sulphates, carbonaceous matter, alkalies and other compounds. These impurities exercise marked influences on the manufacturing processes and the properties exhibited by the cementing materials produced therefrom.

Art. 118. Impurities in Limestones and Their Effects — The various impurities with their effects in limestones are given below :–

(i) *Magnesium Carbonate* -- $MgCO_3$, since calcium forms a double compound with magnesia, it is generally found that limestones contain magnesium carbonate in varying proportions. A stone containing very small quantities of magnesium carbonate and almost all of calcium carbonate is called a high calcium limestone; while dolomitic limestones contain very large quantities of magnesium carbonate and comparatively a smaller quantity of calcium carbonate. A true dolomite is half way between the above two extr me compositions. It contains 54 percent of $CaCO_3$ and 46 percent of $MgCO_3$. On the percentage composition of the component minerals, this stone contains 21.7 percent of Ca, 13.3 percent of Mg, 13 percent of carbon and 52 percent of oxygen.

Magnesian Limestones — These are harder, heaviour and more compact in texture. Magnesium carbonate becomes oxide at a much lower temperature so that by the time calcium carbonate oxidises, much of MgO is overburnt. This has an effect on slowing down the slaking process. However, the presence of magnesium carbonate imparts hydraulic properties to limestones. But limes containing large proportions of $MgCO_3$ are liable to crack and splinter and to subsequent disintegration. While lime containing not more than 5 percent of

MgO gives best results. Generally it may be noted that magnesian limestones represent irregular properties of calcination, slaking and hardening. These processes thereby become difficult to control.

Art. 119. Impurities in Limestones — (ii) *Clay* — This is the most important impurity present in the limestones. It produces the same effect as the carbonate of magnesium without the harmful ones. The hydraulic properties represented by limes is based on their contents of clay and magnesium carbonate either alone or jointly. Accordingly, for purpose of lime manufacture and use the following classification is made on the basis of contents of pure calcium carbonate.

(a) *Pure* or *Fat Limes,* or *High Calcium Limes* — These are very rich in caclium carbonate and contain less than 3 to 5 per cent of clay and other impurities and the rest is calcium carbonate.

A Fat lime is almost an oxide of Calcium CaO. When mixed with water to form a paste of the required consistancy, it requires exposure to atmosphere to enable it to absorb carbon-di-oxide, CO_2, and to form a hardened mass of $CaCO_3$. If kept undet water, a fat lime paste does not lose its plasticity and consequently does not set or become hard.

(b) *Hydraulic Limes* — The percentage of clay to produce hydraulicity in limestones usually varies from 10 t 30. Within these percentages limes represent varying degrees of hydraulicity. For example limes containing 5 to 10 percent of clay represent hydraulic properties in a very feeble manner and are called *feebly hydraulic limes*. 10 to 20 percent imparts moderate hydraulic properties required ordinarily in a structure. They are called *moderately hydraulic limes*. While limes containing 20 to 30 percent of clay are eminently hydraulic and are specially suitable for aqueous foundations, etc. They are called *eminently hydraulic limes*.

Hydraulic lime — as obtained from natural hydraulic limestones or artificially made ones, is a dry cementitious powder, containing round about 60 percent of calcium oxide alone or with magnesium oxide, 20 percent of silica and the rest, oxides of alumina, iron and carbon. After water is added to it to form a paste, it starts setting and hardening, thereby losing its plasticity even under water. Hence the term " *hydraulic* " is applied to these limes. Thus a hydraulic cementing material is one that will set or harden under water.

(c) *Natural Cements* — Natural cements are hydraulic cementitious materials, almost similar to hydraulic lime stones, but containing a higher proportion of clayey matter—usually upto 40 percent. The natural stones are complicated compounds of calcium, aluminium and silicon and after calcination or burning give cementitious products which exhibit a high value of hydraulicity.

Natural cements and some hydraulic limestones are very hard and consequently very difficult to burn and slake. They therefore, require pulverization and grinding as necessary steps before calcination, slaking and using. These processes are explained later in detail.

Art. 120. Impurities in Limestones — (iii) *Silica* — We have seen that silica occurs as free SiO_2 in the form of *sand* and in the combined form as a silicate. Free sand occurs in limestones as in a mechanical mixture, and has no effect in improving their qualities. It has rather a detrimental effect on them. With an increasing percentage of free sand, limes exhibit very poor cementing properties and never gain any hydraulicity. Such limes containing 15 to 20 percent of free SiO_2 are therefore, classed as "*Poor Limes*". Poor limes are generally lacking in their behaviour towards satisfactory clacination, slaking, forming into a workable paste with water and subsequent hardening. Free silica is present in fat limes usually to the extent of only 2 to 5 percent.

Silica in the form of *silicates* of calcium, magnesium and aluminium is beneficial in imparting hydraulicity to limes already mentioned above. Silicates are usually inert towards lime at low temperatures at which lime is generally calcined. At higher temperatures they combine with lime and form fused mases as explained further in the manufacture of cement.

Pozzolana Cements -- These are silicious materials artificially made from the acid slag of the blast furnace or from silicious clay and shales which are heated just below fusion point. It is necessary that these materials should be suddenly cooled down to render them active, as slow cooling would set up other reactions causing the material to become inactive or inert. The cooled product is ground with hydrated lime powder and the mixture gives a pozzolinic cement.

Pozzolinic cements when mixed with water for use as a plastic, in the form of a workable paste, represent good hydraulic properties.

The name pozzolana is derived from *Pozzouli,* a town in Italy on the Bay of Naples, near Mount Vesuvious. The sands around this town when mixed with hydrated lime was found to possess hydraulic properties. They are of volcanic origin. The silicious spray which once issued from the volcano suddenly cooled and fell down in the form of drops and droplets which gave these sands.

Pozzolinic materials have varying compositions. Lime and magnesia contents are very low, usually 2 to 10 percent; while silica is present even to the extent of from 40 to 60 percent. The rest is made up of oxides of alumina and iron.

Art. 121. Other Impurities in Lime Stone — (iv) *Iron Compounds* — Iron occurs in limestones in small proportions, as oxides, carbonates and sulphide. In high calcium or very pure limes, the compounds of iron should be almost absent. But for hydraulic limes, a certain proportion of iron oxide is necessary, and is also generally found to be present from 2 to 5 percent in them.

The compounds of iron, if present in limes are converted into iron oxide, Fe_2O_3, at lower temperatures of calcination, while at higher temperatures, iron combines with lime and silicates and forms a complex silicate. Pyrites, FeS are regarded as objectionable.

(v) *Carbonaceous Matter* is seldom present in limestones used for calcareous cements. But when present it indicates a very poor quality of lime.

(vi) *Sulphates* — These have no definite bad effect on limes, but they slow down the slaking action and increase the rapidity of setting. The use of calcium sulphate as a cementing material is explained later.

(vii) *Alkalies and other Compounds* — Alkalies such as compounds of sodium and potassium are objectionable when very pure limes are required. But they have no bad effect if present in hydraulic limes, upto 5 percent. In a similar manner, compounds of sulphur, phosphorous and chlorine are not desirable in good quality limestones.

The last mentioned impurities from iron downwards, are generally inert but cause a stain in the product.

Table No. 8. Composition of Common Limestones.

Principal Ingredients.	Percentage composition Quality of Limestone. High calcium lime	 Hydraulic lime.	 Natural cement.
Calcium oxide CaO.	97	40 to 60	about 85
Magnesia MgO.	1	30 to 40	10 to 15.
Alumina Al_2O_3	traces or nil.	2 to 5	5 to 12
Silica SiO_2	2	20 to 30	about 30
Ferric oxide Fe_2O_3	traces or nil.	2 to 5	about 5
Other impurities.	traces or nil.	upto 5	upto 2.

Art. 122. Composition of some Limes — The classification of the limes as detailed above, is used in the following description of some of their common varieties, to point out the fundamental differences existing in their composition.

We have arleady seen that the principal elements in addition to oxygen, which are commonly found in the limes are Ca, Mg, Si, Al, and Fe. Their compounds are responsible for imparting the cementitious properties to the limes and cements in general. They do not occur free in nature except iron which occurs in negligible quantities. They combine readily with oxygen to form CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3 and their existance could therefore be easily determined in their oxide form. The analysis of a cementitious substance is expressed on the basis of their oxide contents and the corresponding classification is made.

Tests on Lime Stones.

Art. 123. Tests on Limestones — Limestones as available in nature, are tested for their constituents :—

(i) To ascertain what quality of lime could be derived from them, and

(ii) To specify the proportions of the various ingredients in the manufacture of artificial cementitious products, such as artificial hydraulic limes and cements, etc.

An engineer is not required to carry out an elaborate chemical analysis of the ingredients of limestones for their exact determination. But he has to perform certain practical tests which will give him an idea of their existance and suitability as cementing materials. A detailed analysis of these materials is quite necessary when a synthetic product like artificial cement has to be manufactured. Those are the tests carried out by a chemist in a laboratory and it is often enough for the engineer to interpret the results of his tests for incorporating them in the manufacturing processes. Some of the practical tests on limestones are given below :—

Samples and Average Values — Whenever samples are taken for carrying out the tests, it should be kept in view that they should be the true representative samples of the limes or limestones with respect to which the tests are conducted. Each test should have at least 4 to 6 samples and an average value of the results of each sample should be taken for use. If the results of any sample deviate very widely from the average result of the other samples, its value could be omited.

Art. 124. Physical Tests : Texture, Appearance, Colour and Odour — Excluding the crystalline varieties of limestones, which include marbles, those used in the lime and cement trades are amorphous in texture. Deposits of chalk and fat limes could be recognised from their white or whitish brown or grey colour. While clayey and silicious limestones have light brown to dark brown colour and a dull earthy appearance. Magnesian limestones are rather heavy and hard.

A good hydraulic limestone is rarely white but shows a bluish grey buff, yellow or brown colour indicating the presence of clayey and silicious matter. It has a compact texture with an irregular dull fracture. Glittering particles in a freshly fractured surface indicates the presence of free sand grains. Hydraulic limestones have a clayey taste and an earthy smell on their freshly fractured surface. To bring out the smell and taste the surface of the sample may have to be damped.

Art. 125. Chemical Tests — (a) *Heat Test — Calcination.* The Bond between calcium oxide and carbon-di-oxide in calcium carbonate is very weak. When calcium carbonate, $CaCo_3$ or substances containing calcium carbonate are heated, there is an absorption of heat energy and the calcium carbonate is rendered active. The process of heating is commonly known as burning or calcining. It is usually carried out in open and at temperatures round about 1500°C. The reaction that takes place at this temperature could be represented as follows :—

$$\underset{\text{Calcium carbonate.}}{CaCO_3} \quad \underset{\text{Heat}}{\rightleftarrows} \quad \underset{\text{Calcium oxide or lime.}}{CaO} + \underset{\text{Carbon-di-oxide}}{CO_2}$$

The calcination is slow and requires a higher temperature as the clayey and silicious impurities increase. This indicates that the limestone possesses hydraulic properties.

Thus it could be seen that if a stone containing calcium carbonate is heated to dull red heat in open fire for sufficient period, the CO_2 is driven off and the sample loses its weight. The loss in weight gives an indication to the presence of $CaCO_3$ in the sample. For every loss in weight of 44 parts there must be 56 parts of lime by weight.

Usually 1 lb. sample is taken. It may have to be broken to smaller pieces before heating. Suppose such a sample weighs 0.868 lbs. after heating, indicating a loss of 0.682 lbs. Then this limestone will yield, if properly calcined, the following percentage of quick lime :—

$$\text{Yield of quick lime} = \frac{0.632 \times 56}{44} = 81 \text{ percent.}$$

Art. 126 (b) Hydraulic Test — Salking — Quick lime, CaO is an anhydrous product of calcination. When brought into contact with water it hydrates as follows :—

$$\underset{\substack{\text{Quick}\\ \text{lime}}}{CaO} + \underset{\text{Water}}{H_2O} = \underset{\substack{\text{Hydrated}\\ \text{lime}}}{Ca(OH)_2}$$

The process is known as *slaking*.

During the process of hydration, heat is given out and the energy thus liberated from quick lime is often enough to split it and make it crumble to powder. A vigorous slaking indicates a high calcium content in the sample while with hydraulic limes, the slaking action is very slow and some times eminently hydraulic limes have to be powdered for effective slaking.

If sufficient water is sdded to hydrated lime to form a ball of stiff consistency, the setting or hardening properties of lime could be tested. The hydrated lime is properly kneaded into a ball between the hands and it will be observed that it will become warm and will start becoming hard. If this ball is kept in water it will retain its shape and will not show any sings of dissolving or cracking or losing its shape. It sets and becomes hard, even when put in water. Fat lime or high calcium lime does not set in water.

It is, therefore, possible to determine whether a particular sample of limestones yield fat lime or hydraulic lime, by making observations on its behaviour for calcination, slaking and setting, in the manner detailed as above.

Art. 127. Acid Tests — (i) *A simple Acid Test.* To determine the presence of calcium carbonate in a given sample is to observe the action of dilute hydrochloric acid on it. This causes effervescence with the evolution of CO_2 and the formation of the calcium salt. The effervescence is less vigorous if the proportion of calcium carbonate is less in limestones and the resulting residue is also more. Pure limes could thus be distinguished by a very small residue and vigorous reaction.

(ii) *Acid Test* for a rough determination of composition of Limestones.

Crushing to Powder — The sample of limestone is crushed to fine powder and passed through a sieve of no. 50 or (297 - microns). About 300 grains of the sieved material is taken in a glass tube and the following tests are carried out, :—

To determine $CaCO_3$ — Pour dilute hydrochloric acid on this powder gradually until the effervescence ceases, stirring the contents with a glass rod occasionally. After the effervescence has stopped, pass the liquid through a filter of blotting paper and wash the residue on the filter by pouring on it some more clean water. The clay is eliminated as it comes out in suspension each time. It will be seen that only sand remains as residue which is now dried and weighed. Thus the quantities of sand and clay could be ascertained.

Art. 128. Classification of Limes — *High calcium limes, hydraulic limes, and poor limes.*

In the initial stage only when the quantity of $CaCO_3$ is determined, it is possible to know whether the sample is a high calcium limestone or a hydraulic limestone. In the second stage poor or lean limes could be distinguished from the hydraulic limes from the contents of clay and free sand. Hydraulic limes also could be graded from the percentage of clay contents.

Example — If the initial weight of a sieved sample of limestone is 317 grams and the weight of the dried residue on the blotting paper is 136 grams, we have,

$$\text{Calcium carbonate} = 317 - 114$$
$$= 203 \text{ grams} = 64\,\%$$

The residue after decantation and drying, weighed 66 grams, thus indicating the presence of clay to the extent of,

$$\text{clay} = 114 - 56 = 58 \text{ grams,}$$
$$= 15 \text{ per cent.}$$

The remaining quantity of 21 per cent is sand and other impurities.

Therefore, the limestone will yield a good quality of *moderately hydraulic lime*.

Interpretation of Chemical Analysis.

Art. 129. Chemical Analysis of Limes and Limestones — More correct values of the five principal components of limes and limestones, viz., Calcium oxide CaO, Magnesium oxide MgO, alumina Al_2O_3, silica SiO_2, and oxide of iron Fe_2O_3 are determined by a detailed chemical analysis and are used to indicate the hydraulic and cementation values of the samples. They are virtually the relations between clay and calcium content of cementitious materials.

The *hydraulic index* gives the ratios of the following components,—

$$\text{Hydraulic ratio or index.} = \frac{Al_2O_3 + SiO_2}{CaO.}$$

$$= \frac{\text{Alumina} + \text{Silica}}{\text{Lime}} \quad \text{..eqn. (1)}$$

Sometimes oxides of iron and magnesium are also introduced in the above ratio. Thus we have,—

$$\text{Hydraulic ratio} = \frac{SiO_2 + Al_2O_3 + Fe_2O_3}{CaO + MgO} \quad \text{..eqn. (2)}$$

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

Example — The chemical analysis of a certain sample of limestone gave the following percentage figures,—

CaO = 67; MgO = 3;
SiO_2 = 19; Al_2O_3 = 7; Fe_2O_3 = 4;

$$\text{Hydraulic Ratio eqn. (1)} = \frac{19 + 7}{67} = \frac{26}{67} = 0.39.$$

$$\text{Hydraulic ratio eqn. (2)} = \frac{19 + 7 + 4}{67 + 3} = \frac{30}{70} = 0.43.$$

If the values of percentages are 70, 1, 20, 7.5 and 1.5 respectively for another sample, then the values of the above ratios almost remain unaltered, specially the value of the first eqn. Hence a better and a more reliable way of expressing the results of chemical analysis would be with the aid of molecular ratios. The percentages of the components are divided by their molecular weights and the value of the ratio is obtained. The molecular weights of these oxides are,—

CaO = 56; MgO = 40 ;
SiO_2 = 60; Al_2O_3 = 102; Fe_2O_3 = 160.

Thus we have, taking into account, the molecular weights, the modified value of the ratio is given by,—

Modified Hydraulic index or cementation index.

$$= \frac{\frac{SiO_2}{60} + \frac{Al_2O_3}{102} + \frac{Fe_2O_3}{160}}{\frac{CaO}{56} + \frac{MgO}{40}}$$

$$= \frac{0.93\ SiO_2 + 0.55\ Al_2O_3 + 0.35\ Fe_2O_3}{CaO + 1.4\ MgO}$$

$$= \frac{0.93 \times 19 + 0.55 \times 7 + 0.35 \times 4}{67 + 1.4 \times 3}$$

$$= \frac{17.67 + 3.85 + 0.40}{67 + 4.2} = 0.46$$

Table No. 9. Hydraulic Value.

Quality of lime	Hydraulic ratio or Index, eqn. (1)	Cementation value or Index, eqn. (4)
Feebly hydraulic lime	0.1 to 0.2	0.3 to 0.6
Moderately hydraulic lime,	0.2 to 0.3	0.6 to 0.8
Eminently hydraulic lime	0.3 to 0.4	0.8 to 1,0

Sometimes the combining weights and the molecular weights are both taken into account.

Cementation index.

$$= \frac{2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.7\ Fe_2O_3}{CaO + 1.4\ MgO} \quad \text{Eqn (4)}$$

$$= \frac{2.8 \times 19 + 1.1 \times 7 + 6\ 7 \times 3}{67 + 1.4 \times 3}$$

$$= \frac{63.0}{71.2} = 0.88$$

The hydraulicity of a limestone can now be expressed on the basis of these ratios. Thus we can write,—

Sometimes the reciprocal values of the ratios given in eqns. 1 to 4 are taken. Thus the ratios in the above example are 2.55, 2.33, 2.18 and 1.14.

Testing of Lime and Lime Mortar.

Art. 130. Testing Strength of Lime Mortar — (i) *To Prepare Lime and Lime Mortar,* 1: 3 *ratio*— Well burnt and slaked pieces of lime sample to the extent of about 5 lbs. are ground to fine powder to pass through a sieve of No. 30 mesh. No powder should be rubbed on the screen. Under burnt and over burnt samples should be omitted from the total lot of the sample burnt. It is mixed with standard sand in the ratio of 1 : 3 i. e. one of lime powder to three of sand. Standard sand is one, all the grains of which shall pass through No.10 sieve and none shall pass through No.24 sieve.

To this mixture of lime and sand is next added a requisite quantity of water to prepare an intimate mixture or mortar of stiff workable consistency and the following tests are carried out. The technic of mortar making is explained later.

(ii) *Adhesive Strength* — Two bricks, say of the size of 9 ″ × $4\frac{1}{2}$ ″ × $2\frac{1}{2}$ ″, are placed flat in a cross fashion one over the other, with a joint, $\frac{1}{2}$ in. thick of the above mortar. This gives a contact area of $4\frac{1}{4}$ ″ × $4\frac{1}{4}$″ = 18 sq. ins. for adhesion. The two bricks should be thoroughly soaked in water before jointing.

Curing Before Testing — The jointed bricks should be kept wet with the aid of a damp gunny bag for 24 hours and then kept covered with wet sand for a further period of 24 hours. Afterwards they are kept immersed in water for 7 days.

The two cemented bricks are now tested. The load required to separate them at the joint is noted and gives the adhesive strength of the mortar, which should not be less than 600 lbs. over an area of 18 sq. ins. or 32 lbs. per sq. in.

(iii) *Soundness test* — This test is carried out for a good quality of hydraulic lime. The sieved lime is mixed with the necessary quantity of water to prepare a paste. The paste is made into a small ball in the hands and a pat of 4 ins. diam. and ½-in. thickness is made out of it. The pat is then allowed to set under a wet cloth by keeping it between two glass plates, for 24 hours. After keeping it under water for a further period of 24 hours, it is then exposed to steam for 5 hours. At the end of this period, the pat should not show any signs of cracking or warping. Sometimes, lime is mixed with 3 to 5 times sand or equal volume of portland cement to carry out this test, but the results expected are the same.

Art. 131. (a) Test for Tensile Strength — The lime mortar of 1:3 ratio, prepared as detailed early in the above article, is used in the following test. A briquette of the shape of figure **8** is prepared and cured for about 7 to 10 days. The section at the central neck is 1½ in. square and the tensile strength as shown by a testing machine should be around 100 lbs. or 45 lbs. per sq. in. The tensile strength after 24 days immersion in water should be about 200 lbs. for the briquette or 90 lbs. per sq. in. This indicates good hydraulic lime.

The above test is not specified for fat lime and feebly hydraulic lime.

(*b*) *Test for Compressive Strength* — With the aid of the same lime mortar of 1:3 ratio, 2″ to 3″ cubes are made and are cured as previously specified for a period of 7 to 10 days. When put under a compression testing machine, a good hydraulic mortar should indicate a crushing strength of about 4 to 5 times its tensile strength, i. e. about 200 lbs. per sq. in. after 7 to 10 days and 400 to 500 lbs. per sq. in. after 24 to 28 days curing.

Manufacture of Lime.

Art. 132. Occurrence of Limestones — It has been already pointed out that lime contains essentially five elements calcium, magnesium, silicon, aluminium and iron and that all these are generally found as oxides. The quantities of the other elements are very small. We have also seen how the varying proportions of these components impart different characteristic properties and behaviour to limes and limestones used for different purposes. Therefore, the selection of the raw materials should be based on the purpose for which the lime is required; and the manufacturing process should be so arranged that a lime of the required composition is obtained to satisfy the tests and the needs.

The calcareous materials used for obtaining lime on a large scale for use in the building trade, occur principally in two forms in nature,—

(a) *Nodular form.* (b) *Block form.*

Kankar is the term generally applied to limestones containing some quantity of clayey and silicious matter as distinguished from fat or high calcium limes. Kankar may be either in the nodular form or in the block form.

(a) *The Nodular Variety* is found as a surface deposit scattered either along the hill side or on the banks of nalas and streams. They are collected either by hand picking or with the aid of minor excavations with a pick-axe. This forms a chief source to obtain lime for local supplies, usually on a small scale. The nodules are of sizes varying anything from below one inch cube to 4 ins. or so. Very small sizes are uneconomical to collect and to burn as well.

Before calcining, the nodules are cleaned of any mud sticking to them and then broken to uniform sizes between 1 and 2 inch cubes.

(b) *The Block Form* occurs as solid deposits of limestone rocks of various catagories from granular compact to crystalline. The stone is quarried out on a large scale, either exclusively to manufacture the cementing materials or to obtain building stones. In the latter case, the quarry refuse or the spoils could be utilised for the same purpose of obtaining lime.

Calcareous materials could be also classified as,—

(i) The *Inorganic Forms* of calcium carbonate chiefly include limestones of argillaceous, silicious and ferruginous varieties, dolomites and marbles. (ii) The *organic varieties* are chalk, shell limestones and coral.

Art. 133. Processes of Manufacture of Calcareous Cements — The principal stages involved in the different processes of manufacturing lime are calcination and hydration, (the manufacture of cement is dealt with later). But the materials require pre-calcination and post-calcination treatment, to suit the raw materials and the products desired.

Fat limes and feebly hydraulic limes are easy to manufacture while moderately hydraulic limes and eminently hydraulic ones require special treatment.

Again the process of manufacture can be an *intermittent* one or a *continuous* one, depending upon the nature of supply and demand. The fuel used also may be different in each case, such as firewood, coal, oil or gas and each requires a modification in the process of manufacture.

The adoption of one method of manufacture or the other is very much influenced by the local conditions also. Such as the type of fuel cheaply available and the market where the lime could be disposed off, etc.

Art. 134. Lime Burning — Limestones have to be burnt to bright red heat in order to obtain lime powder. This requires some type of an enclosure called a kiln, so that :—

(a) The required temperature can be developed and maintained.

(b) The various operations such as limestone burning, loading and unloading could be regulated.

(c) The burnt matter shall have a very small quantity of over-burnt or under-burnt particles.

(d) The process can be kept continuous, if required, to ensure a steady out-turn of lime. And

(e) To minimise the heat and other loses in general so as to effect the economy of the outlay.

These conditions are almost the same as those which necessitate the installation of brick kilns. Kilns may be either vertical or horizontal, but in a majority of cases the vertical design is commonly adopted. The horizontal type has its own speciality as explained later, and is employed mainly in the manufacture of cement.

Art. 135. Lime Clamps — As in the case of bricks, limestones are also burnt in cheap enclosure known as *clamps.* On the bank of a river or a hill side, excavation of a suitable size is made and temperary side walls of mud masonry are built. The faces of the wall and the interior, are protected with mud plaster and a cow-dung coating.

Art. 136. Lime Kilns — When a proportionately large quantity of lime is required, a fairly permanent enclosure built up of brick or stone masonry in lime mortar could be constructed. The floor of the kiln can be of flag stones set in mud or lime mortar.

Lime kilns can be made to work either *intermittently* or *continuously.* The former system is adopted if there is no continuous supply of raw materials and fuel, while the adoption of the latter method requires a steady and a continuous supply of limestones and fuel. Continuous kilns are very economical to work and convenient to operate. There is not much loss of heat and time since the kiln is not allowed to cool down. But, if firewood is used as fuel, the kiln has to operate on the intermittent system. With intermittent kilns there is always a risk of getting over-burnt material near the flues and under-burnt stones at the top.

Kilns can be constructed partly below ground level to minimise the heat losses through the walls and also to reduce the labour required for loading and unloading them.

Kilns can be either rectangular or circular in plan, but the circular ones are found to work satisfactorily for the con tinuous type. Intermittent kilns can be built rectangular or circular. In fact, the prevailing practice in any locality generally governs the shape and design of a kiln.

Art. 137. Intermittent Kilns -- The various stages in the operation of an intermittent kiln are :—

(a) *Loading of the Kiln* with alternate layers of fuel and lime stones. If firewood is used, a thicker layer of the same has to be used. Horizontal flues are kept in the wall of the kiln, at or near the bottom. They are arranged circumferencially for a circular kiln; and along the longer side in the case of a rectangular kiln. Vertical flues are also kept, in the body of the kiln, connecting the horizontal flues. Flues are formed by arranging the bigger sized pieces in an arch and ring fashion as shown in the figure later.

The top of the kiln could be loaded with the underburnt limestone pieces of the previous charges.

(*b*) *Lighting the Kiln* and *Burning the Limestone* —The kiln is lighted in the flues to start calcination. Moisture and carbon–di–oxide escape from the top. The completion of calcination is only understood by experienced lime burners. Allowing about 12 to 24 hours for lighting the kiln and bringing it to the maximum temperature, a further period of about 48 hours is required for complete calcination.

Methods of observation — Thorough and satisfactory burning is tested with the aid of an iron poker or rod of $\frac{3}{4}$--in. diameter which should enter readily through the kiln when inserted. When a gradual sinking of the stones in the kiln is obseved, it is a good indication for complete calcination, and a skillful workman is able to judge the progress of burning with the aid of this observation. The colour of the flames helps to determine the temperature in the kiln which could be controlled by damping or opening the flues.

Quantity of Fuel—100 cu. ft. of good kankar require on an average—

(a) 50 to 70 maunds of babul wood and jungle wood respectively.

(b) 15 to 20 cu, ft. of good Bengal coal.

(c) 20 to 25 cu. ft. of inferior type of coal.

(d) 40 to 50 cu. ft. of charcoal.

(e) 50 to 60 cu. ft. of double screened engine ash.

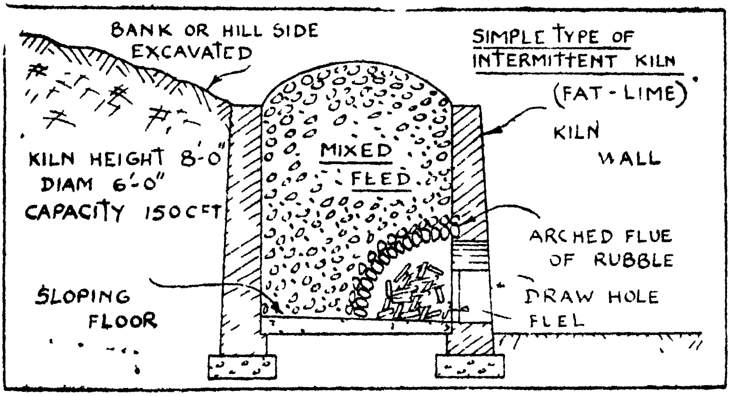


Fig 28. A Simple lime kiln or a lime clamp

Alternate feed method is adopted when firewood is used as fuel. While *mixed feed* method is most suitable with coal, charcoal or cinder. In the former case, fuel and stones are arranged in alternate layers and in the latter case, fuel and stones are mixed in the requisite proportions and are fed in the kiln from the top.

(c) *Cooling and Unloading*— The kiln is then allowed to cool down for some days before unloading of it could be started. The calcined stones are drawn from the flues and the over–burnt and under–burnt ones are picked up from the properly burnt ones.

Art. 138. A Simple Lime Kiln — Fig. 28 shows the details of an intermittent kiln built very cheaply by the side of a hill or a river bank. The main flue is formed with one ring of big sized stones with sufficient voids for maintaining a steady draught during calcination and also to effect the flow of cold air during cooling. It is, therefore, necessary that the main flues should face the direction of the prevailing winds.

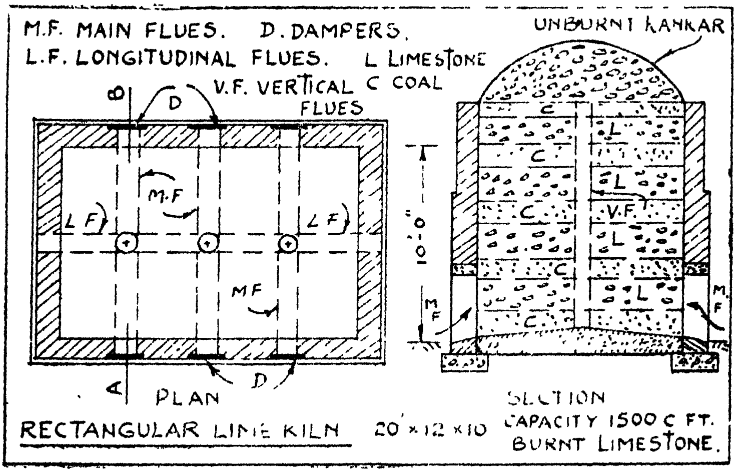


Fig. 29. Intermittent rectangular lime kiln.

Allowing 10 days for loading, calcination, cooling down and unloading, this kiln would yield about 100 cu. ft. of calcined limestone, which if, fat lime would yield about 250 cu. ft. of lime powder.

Art. 139. Rectangular Intermittent Kiln — In Fig. 29 are shown the details of a rectangular type of a lime kiln.

This would work better as an intermittent kiln for burning high calcium lime or fairly hydraulic lime. The longer side of the kiln is built facing the prevailing inds. Openings are kept in the walls on all the four sides to form the flues. The floor of the kiln is sloping gently towards the walls, having the main flues.

Loading — It will be seen that fuel and limestones are laid in the kiln in alternate layers; and at the top the underburnt kankar nodules, picked out from the previous charge, are heaped up so that they will get burnt duiing this charge.

Arrangement of Flues — The necessary passages or flues for the flow of hot gases.and air through the body of the kiln are of three types :—

Main flues, cross flues connecting the main flues, and *vertical flues* connecting the main and cross flues at their junctions.

Flues are formed by placing very carefully the big sized limestones to form horizontal arches for the main and cross flues and vertical rings to form vertical flues. Apart from the use of the requisite quantity of fuel, an efficient and successful lime burning in an economical manner, depends much on the skillful and judicious formation of these flues. During the period of calcination, there will then be established a regular and a uniform flow of hot gases throughout the kiln.

After the limestones are calcined, the kiln is allowed to cool down as usual for unloading.

Art. 140. Continuous Lime Kiln — In Fig. 30 are given the details of construction of a continuous kiln for burning stones which would require a fairly high temperature for calcination as in the case of hydraulic limestones. The central section 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 also provided with a lining of fire clay plaster or bricks. The kiln is built partly below ground level and a loading platform is provided at the mouth of the kiln to facilitate the dropping of the mixed feed.

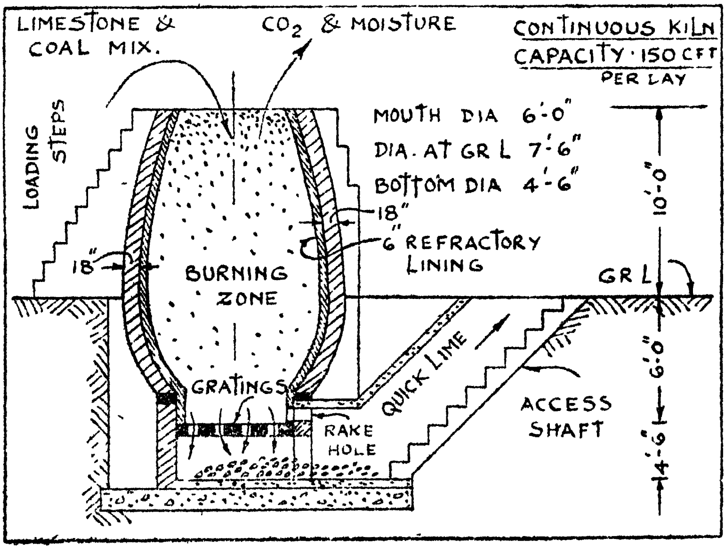


Fig. 30 Continuous lime kiln.

As the level of the material at the top of the kiln gradually sinks, the feed consisting of a mixture of limestones or kankar and coal or cinder, is put at the mouth. A grating is provided at the bottom with holes to draw the calcined particles. The top of the grating could be raked to admit of an easy fall of the calcined particles.

The burnt limestones are then collected and brought to the surface for further treatment of slaking or hydration.

Art. 141. A Modern Furnace Fired Kiln for Lime— Fig. 31 shows an improved type of a modern vertical kiln. The fire boxes with the gratings are shown as a separate attachment to the main body of the kiln. The required number of these fire boxes, usually two — is arranged around the kiln Below the level of the fire boxes is located the cooling zone and above it is kept the burning zone or the zone of perfect

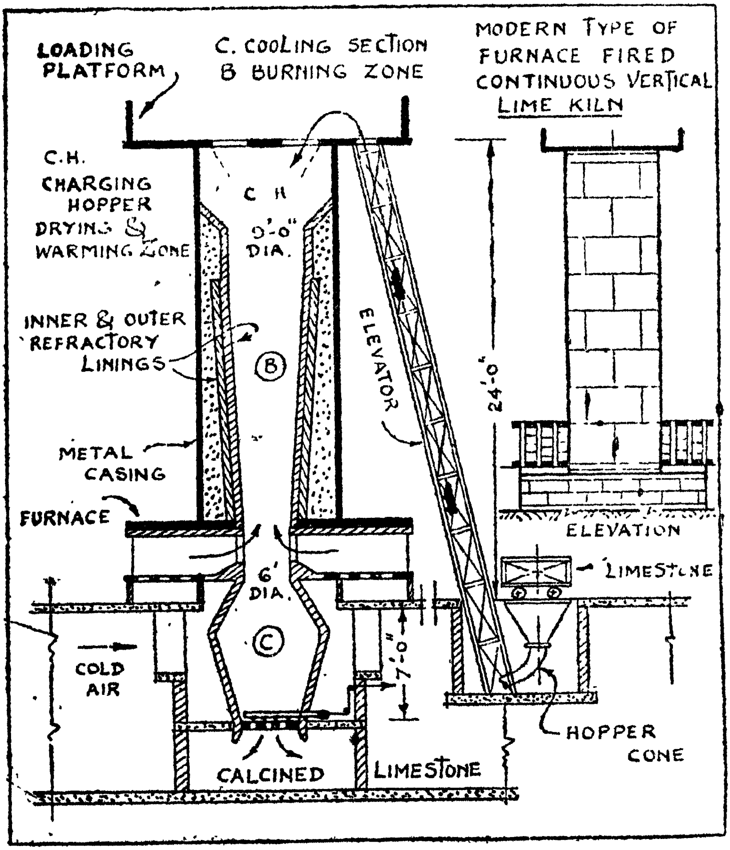


Fig. 31. Modern continuous lime kiln.

calcination. Above this zone is the feeding section with the necessary provision for the loading platform for the mixed feed. In a completely modernized system, there is a provision for an automatic feeding arrangement. The tipping waggons which are filled with the mixed feed at the ground level, are hauled up to the feeding platform with the aid of a wire rope along an inclined trolly line, as shown in the figure.

The fuel used could be either coal, powdered coal, oil, or gas.

The yield of this kiln for the dimensions given in the figure is round about 100 to 125 cu. ft. of good hydraulic lime per day.

Art. 142. Effect of Heat on LimeStones —

(i) *Evaporation of Moisture* — The water contents in the stone could be evaporated at temperatures of about 500° to 600° F.

(ii) *Dissociation* — (*a*) *Pure or Fat Limes or High Calcium Limes* — It has been explained that at low temperatures of about 1500° F limestones decompose, giving 56 parts by weight of calcium oxide or lime, CaO, and 44 parts by weight of carbon-di-oxide, CO_2, for every 100 parts by weight of calcium carbonate, $CaCO_3$. In this process of forming calcium oxide, heat is absorbed to the extent of about 770 B. T. Us. per pound of $CaCO_3$ or 1380 B. T. Us. per pound of CaO formed. A part of this heat is given out during the process of slaking or hydration.

There is also a shrinkage in volume during calcination to the extent of about 10 to 15 percent.

The temperature at which dissociation takes place is a function of concentration of $CaCO_3$ in limestone. It also depends upon the pressure at which the reaction is allowed to take place. In fact, the pressure of carbon-di-oxide is the criterian. Pure limestones melt at a very high temperature near about 4800° F, and we have seen that, if CO_2 is not allowed to escape, they will again crystallise to form marble on cooling.

(*b*) *Magnesian Limestones* — Magnesium carbonate dissociates at a lower temperature of about 1000° F to 1200° F, so that by the time limestone dissociates, at about 1500° F, much of magnesium oxide is over-burnt and becomes almost inert. It has been already pointed out that this has a bad effect on the slaking of calcium oxide and the subsequent hardening and weathering of mortars. Generally 5 percent MgO is desirable in lime.

(*c*) *Calcination of Hydraulic Limes* -- Limestones belong to the catagory of derived rocks and we have seen the various influences of the respective impurities contained in them, on their behaviour. One of the important effect has been that the temperature of calcination is raised. This may reach even 2300° F, if the impurities are to an appreciable extent. At these higher temperatures, in addition to dissociation, secondary reactions are set up between the various constituents of limestones. The exact nature of these reactions is still under investigation; but the experimental observations have proved that the product of calcination at that high temperature is one that shows hydraulic properties.

Art. 143. Effect of Higher Temperatures — To simply the understanding of the complicated reactions, which set up between the constituents of limestones, we can look upon them as consisting of —

(*a*) *Calcareous constituents,* containing compounds of lime and magnesia.

(*b*) *Argillaceous constituents,* containing compounds of silica, alumina and oxide of iron.

The essential requirement of calcination is the dissociation of CO_2 from the calcareous constituents to form CaO and MgO which are the cementitious oxides to form hydrated lime. In the presence of the argillaceous constituents, the temperature of calcination is raised to dissociate CO_2 from the nodular form, to which the limestones are reduced ordinarily for burning them. The temperature usually attained in the kilns, to effect this is round about 2350° F.

It is also necessary that a maximum amount of the cementitious oxides should be formed during the process of calcination so that the resulting lime will have a minimum of CO_2 content.

A Continued Maintenance of a high temperature of about 2850° F is followed by a series of complicated reactions, which could be listed as follows :—

(a) Decomposition of argillaceous components at about 1200° F to form SiO_2, Al_2O_3 and Fe_2O_3.

(b) Decomposition of calcarious components at temperatures higher than 1500° F to form CaO, and MgO.

(c) At temperatures still higher than those mentioned above and which are attained in the zone of calcination in a hydraulic lime kiln, the dissociated compounds are *rendered active* and *combine chemically* to form partly, silicates and aluminates of calcium. These reactions are incomplete in hydraulic limestones since there is not enough of clay in them to combine with all the calcium oxide. The limestones are so selected that the parcentage of clay in them is limited. Also, the temperature of calcination is kept within about 2000° F, which is insufficient to complete the formation of silicates and aluminates generally. These materials are highly cementitious in nature and complex in composition. It may be noted that oxide of iron does not so actively take part in these reactions, since it requires a still higher temperature to render itself active.

Thus we can write that a hydraulic lime is composed of a mixture of :—

(i) Free or quick lime plus magnesia, not less then 60 percent;

(ii) Not more than 10 per cent of CO_2.

(iii) Complex cementitious materials of calcium, silica and alumina, in the following percentages :—

— 12 to 15 percent in a feebly hydraulic lime.

— 15 to 20 percent in a moderately hydraulic lime.

— 20 to 25 percent in an eminently hydraulic lime.

See art. 122 for the classification of hydraulic lime

In the above composition, the presence of free or quick lime is essential to bring about hydration as explained later; the limit of CO_2 indicates the efficiency of calcination process; while the complex silicates and aluminates bring about subsequent hardening of hydraulic lime.

Natural Cements — These are obtained from natural hydraulic limestones after their calcination and hydration.

As they contain a higher percentage of clay, they require a temperature higher than that required for hydraulic lime to bring about the dissociation and chemical reaction, as explained above.

A further discussion of the above reactions in detail is given under the manufacture of a more exact and synthetic material known as Portland Cement or Cement, in general.

Art. 144. Hydration — After calcination, the next essential stage in the process of manufacturing lime powder is *Hydration.* After hydration we obtain lime powder which is used for various purposes such as white washing, lime putty, plaster and for general building work.

Hydration of lime is accompanied by :—

(a) Chemical combination of CaO with water to form $Ca(OH)_2$.

(b) Evolution of heat energy.

(c) Increase in volume.

These play a very important part in conducting the process of hydration, and also in imparting cementitious qualities and workability to the products of hydration. They are described below.

Art. 145. Chemical Combination with Water —The calcined limestones contain the oxides of calcium and magnesium in varying proportions. These oxides show a great affinity for water, — calcium oxide showing proportionately greater affinity than the magnesium oxide. When they are brought into contact with water chemical reaction takes place according to the equation.

$$CaO + H_2O - Ca(OH)_2$$

thus showing that for every 56 parts of calcium oxide, 18 parts of water combine to form 74 parts of calcium hydroxide.

Art. 146. Generation of Heat During Hydration — The reaction set up during hydration is accompanied by the evolution of about 500 B. T. Us. of heat which is generally enough to attain a temperature of 700° F. The liberation of energy during this reaction causes the lump of quick lime CaO, to split up and fall to powder.

In the case of *fat limes,* precautions should, therefore, be taken to see that the heat generated during slaking is properly preserved and no sudden cooling takes place. As a result of heat reacting lumps, the bigger ones break down to smaller ones to expose their interior for further slaking action. This is kept continuous until the whole of the lime is slaked.

But for *hydraulic lime,* the rate of slaking is very slow and the limestones are hard and compact. The heat energy of hydration is not enough to break them down to set up and to maintain a continuous process. They are, therefore, mechanically broaken to a suitable size and some times even pulverized before hydration, for satisfactory results. Under these conditions, it becomes necessary to cool the products during hydration.

Art. 147. Increase in Volume During Hydration — Hydration is also accompanied by an increase in volume. This is due to the molecules of CaO combining with those of water and getting bigger in size. In addition, when the calcined lumps fall to powder, the void spaces formed between the particles give an additional increase in volume to the mass, This increase in volume is proportionate to the calcium contents of the limestones. High calcium limes get an increase in volume to the extent of about 2½ to 3 times on hydration while the hydraulic limes hardly experience an increase of 50 percent, depending upon their hydraulicity.

Art. 148. Hydrated Lime and Slaked Lime — When hydration is complete and satisfactory, the calcium hydroxide so formed exists mainly in the colloidal form. In fact, it is the aim of hydration to produce a comparatively dry *hydrated lime* powder. This powder can be formed into a paste with a further addition of water. When this paste is mixed with sand, it forms a plastic mass of workable consistancy, known as *mortar*.

It may be noted that, the finer the hydrated lime powder is, the more thin the lime paste made from it will become to form a continuous film around the sand grains. The technic of mortar and concrete making is explained later.

When pure lime is used for white washing, etc. the calcium hydroxide must exist in a colloidal form of suspension in water to given better covering properties. For this purpose *slaked lime* is found to give best results. Slaked lime is formed by adding slightly more water than that required to convert quick lime into a hydroxide.

What has been said of lime CaO, is also true for magnesia MgO. But Magnesia hydrates very slowly and requires a longer period to complete the process. The bad effects of including unslaked particles of magnesia in a cementitious product have been already mentioned.

Similarly, the limes that are impure or those that are over-burned are slow-slaking. This is due to the particles of calcium oxide not getting a full chance to come in contact with water on account of the presence of foreign matter.

Art. 149. Water Required for Hydration and Slaking -- This quantity depends upon the nature of the product required and the contents of the free lime CaO, present. Generally about one-third of the oxide of lime by weight, will represent the quantity of water required for chemical combination. But a sufficient quantity should be added as an exrta t allow for evaporation losses and for producing a slaked lime, if desired.

A good quality of *high calcium lime* requires about 40 lbs. of water for every 100 lbs. to produce lime powder or hydrated lime and about 50 lbs. of water for the same quantity to produce a stiff paste of lime or lime putty. Magnesian limestones require smaller quantities than those mentioned above.

The quantity of water required for *hydraulic limes* is calculated on the basis of their free lime content. Only enough water should be added for the hydration of free calcium oxide and that required for evaporation losses etc. No more water should be added so as to combine with the cementitious silicates and aluminates of calcium present in hydraulic lime. Otherwise these will harden and the lime becomes useless before it is put in the works where required. Hydraulic limes should be kept in a dry place and should be slaked just before use. Otherwise they become stale.

If sufficient water is not added, some quantity of lime will remain unslaked. The particles of unslaked lime are a source of serious trouble, if present, in the slaked lime. These particles slake subsequently when more water is added at the time of their use and their consequent expansion causes cracks and blisters.

Art. 150. Methods of Slaking and Hydrating Lime—Keeping in view the various principles on which the hydration of quick lime depends, different methods are employed for different types of limes, so that no unslake particles of CaO will remain after slaking.

When the burned limestones are drawn out from the kiln, it is possible for an experienced lime burner to sort out to a great extent, in the initial stage, the under-burned and over-burned particles. The latter are discarded as they are inert and weaken the quality of lime, in addition to the difficulty they cause in slaking. The under-burned particles are sent back to the kiln for recalcination.

Depending upon the magnitude of the work and the quality of the lime required, slaking or hydrating could be carried out in two ways :—

(a) Hand slaking.

(b) Mechanical slaking or Hydrating.

These are described in the following articles.

Art. 151. Hand Slaking—

(i) *High Calcium Lime* or fat lime is slaked by *drowning* the particles in a tub containing enough quantity of water. The tub is covered to preserve the heat.

(ii) *Slaking by Immersion* is suitable in the case of feebly hydraulic limes. The lime is filled in a basket and the latter is then immersed in a tub filled with water. The basket is withdrawn when the sound of the reaction is apparent. The exact time of immersion is a matter of experience.

(iii) *Slaking by Sprinkling* is adopted in the case of hydraulic lime. The lime is spread on a specially prepared non-porous platform and water for hydration is sprinkled by means of a watering can with a rose. Simultaneously, lime is turned over with spades. The slaking action is accelerated, if the lime is initially pulverized in grinding mills.

(iv) *Air Slaking* — This method simply explains the process of slaking of lime by taking moisture from the air when kept in an exposed condition. This process of hydration is also accompanied by the formation of a certain proportion of calcium carbonate by taking carbon-di-oxide also from the air. Lime is thereby spoiled. It is also difficult to control this process.

Art. 152. Mechanical Slaking or Hydrating— The production of hydrated lime is carried out on a large scale with the aid of mechanical appliances. Various types of hydrating plants are used whereby hydrating could be carried out in a specific quantity each time or the process could be kept continuous. By whichever method the hydration is carried out, the following points should be observed :—

(a) Only the necessary quantity of water must be added to the lime, at a uniform rate.

(b) A thorough mixing of lime and water must be made.

(c) The temperature of hydration should be properly controlled by suitable cooling method.

A hydrating plant essentially consists of a crusher and a hydrator with suitable storage tank and silos. Devices for conveying the material from one unit to the other are also provided.

The hydrated lime is then passed through a sieve of 20 to 80 meshes to an inch, to yield a powder of the required fineness.

Art. 153. Artificial Hydraulic Lime — Where natural hydraulic limestones are not available, or those of the limestones that are available, do not possess hydraulic properties to the required degree, but are essentially fat limes, it is possible to manufacture hydraulic lime artificially.

(a) *Fat Lime and Clay* -- Fat lime or feebly hydraulic limes are calcined and slaked to obtain quick lime and hydrated lime powder of known composition.

To this lime powder is added clay in the required proportion, to make good the deficiency of silica, alumina and oxide of iron, which are essential to impart hydraulicity.

The exact proportion in which lime and clay are added depends upon the quality of hydraulic lime required as shown in table No. 8. After the lime and clay are thoroughly mixed, water is added to form a stiff paste which is again kneaded well. The stiff mixture is now converted into small hand balls of about 1″ to 1½″ diameter, which are subsequently dried.

Calcination --The balls as prepared above are claimed in a kiln at the required temperature and then hydrated to form hydraulic lime powder.

If soft materials like chalk, are available, they are mixed with clay in the raw state and small nodules are prepared with an addition of water, as detailed above. The nodules are subsequently burned.

(b) *Fat lime and Surkhi* — We have seen that surkhi is a finely ground powder of bricks and brick bats passing through a specified sieve to attain required fineness. For making surkhi slightly under-burnt brick bats made from alkaline earths, are useful. The hydrated lime powder is mixed with surkhi and sand in the ratio of 1 : 1 : 2 or 1 : 2 : 1 respectively as required and then thoroughly ground with water to obtain a good variety of hydraulic lime mortar.

Artificial hydraulic limes are very costly to manufacture and when cement could be obtained easily, their manufacture could be avoided.

Setting of Limes.

Art. 154. (a) Setting of High Calcium or Fat Lime— The calcium hydroxide $Ca(OH)_2$ which is obtained by slaking quick lime CaO, has now the property of absorbing CO_2 from the atmosphere to crystallise and harden, as follows–

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

The hardening of fat limes and that of fat lime mortars, therefore, depends upon the extent to which they are given a chance to come in contact with the atmospheric carbon-di-oxide. This reaction is generally very slow and is naturally confined to the surfaces.

The addition of sand to lime imparts porosity to the mass and partly helps the air to reach the interior to some extent. It also subdivides the lime paste into a thin film and exposes a greater part of it to atmospheric action. Thus the hardening action could be secured in an improved manner; but it could be seen that fat limes have no intrinsic property of hardening and have to depend upon an outside agency for the same.

Thick masonry walls, if built of fat lime mortar, will have their interior remaining almost in a soft condition. The water easily evaporates from the mortar leaving behind a soft powdery mass in the joints in the inside of such walls.

In an exposed condition fat limes do not weather well on the exterior. But for interior work and for plaster of internal wall surfaces mortar made of fat lime hardens sufficiently and weathers well. When used for white washing, it gives excellant results.

Art. 155. (b) Setting Action of Hydraulic Lime — we have seen that hydraulic lime contains:—

(i) Free oxides of calcium and magnesium; and

(ii) Complex cementitious materials, which are silicates and aluminates of calcium and oxide of iron.

In the initial stage, when this lime is hydrated .to form a dry powder the hydroxides of calcium and also that of magnesium, are formed. Subsequently when more water is added to this hydrated lime when used in combination with sand to form mortar, complex chemical reactions are set up in which hydrated salts of calcium silicates and calcium aluminates are formed. Calcium hydroxide also takes part in this. As a result of these reactions, the hydraulic lime sets and becomes hard, thus showing that it has an *intrinsic property of hardening* when water is added to it. A good hydraulic lime sets very well under water and when tested by means of a briquette, it attains after 28 days, a tensile strength of about 250 to 300 lbs. per sq. in. when mixed with sand 1 : 3 ratio. The briquette is kept in a damp condition for 3 days and in water for the remaining period for purpose of curing.

CHAPTER VI

Portland Cement.

Constituents of Cement.

Portland cement. Raw materials. Calcareous and argillaceous. Constituents of portland cementacidic and alkaline. Principles of proportioning.

Functions of Cement Ingredients.

Lime, magnesia, silica, aluminia and oxide of iron. Calcium sulphate. Setting action of cement. Hardening. Heat evolved.

Manufacture of Cement.

Methods. Wet process and dry process. Stages of manufacture.

Wet Process.

Preliminary treatment of raw materials proportioning, wet grinding and preparing slurry. Wash mill. Correction of slurry.

Fuels used. Coal - pulverisation. Rotary kiln - its component parts and functioning. Clinkering. Cooling of clinker and storage. Grinding of clinker. Retarder–its action and purpose. Cement storage, packing and dispatch.

Dry Process.

Crushing and drying; proportioning and final grinding. Air separators. Raw mix.

Tests of Portland Cement.

Importance. Tests. Fineness sieve and specific surface tests. Chemical composition, strength–tensile and compressive. Setting time. Normal consistency. Soundness. B. S. S. specifications.

Types of Cements.

Normal cement. Rapid–hardening or High early strength cement. Quick setting cement. Low heat cement. High aluminia cement. Blast farnace cement. Coloured cement. White cement.

Constituents of Cement.

Art. 156. Portland Cement — Portland Cement is a product obtained by the calcination at a very high temperature, an intimate mixture of correctly proportioned calcareous and argillaceous materials. The calcined product which is called *clinker,* is then finely pulverized by grinding into a powder and is mixed with calcium sulphate or gypsum, to abtain *cement*.

Art. 157. Raw Materials—The raw materials used for making portland cement are those commonly included as

(a) Calcareous materials; and

(b) Argillaceous materials.

The *calcareous materials* include compounds of calcium and magnesium; *argillaceous ones* include mainly silica, alumina and oxide of iron. Limestones and marls are the common types of calcareous materials while the argillaceous materials are usually clay and shale. Cement works are generally located in places where these materials are available in plenty and also occur adjacent to one another.

Cements are manufactured in several varieties, but the most common one used is normal setting or ordinary cement, usually called Portland cement. In the following articles are given methods of manufacture of this common variety of cement. Other special types of cements are described subsequently, at the end of the chapter.

Portland cement can be manufactured with a single raw material. But it is vary rare to find the components of such a natural rock to be in a correct proportion so as to complete the chemical reactions expected to take place in the manufacturing process. This therefore requires two or more raw materials to be used. They have to be correctly proportioned and thoroughly mixed.

Art. 158. Composition of Portland Cement — To understand the technique of proportioning the raw materials, it is necessary to know the follwing:—

- (i) Composition of portland cement.
- (ii) The constituents that go to form it.
- (iii) The functions played by the constituents.

The chemistry of portland cement is very complicated. It is generally enough for an engineer to understand the functions played by each constituent in imparting setting and hardening properties to cement.

(a) *Mineral constituents* — Portland cement has a chemical composition of a very complex nature. The

Table No. 10. *Mineral Constituents of Portland Cement.*

Serial No.	Constituents	Nomenclature	Approx. % comp.
1	Tricalcium silicate	$3\ CaO.\ SiO_2$	40
2	Dicalcium silicate	$2\ CaO.\ SiO_2$	32
3	Tricalcium aluminate	$3\ CaO.\ Al_2O_3$	10
4	Tetracalcium alumino - ferrite	$4\ CaO.\ Al_2O_3.\ Fe_2O_3$	10
5	Calcium sulphate	$CaSO_4$	3
6	Other compounds	—	5

important constituents of portland cement could be represented as follows :—

(b) *Acidic and Alkaline constituents* of Portland cement. On an average, the composition of portland cement can be given as follows :—

Table No. 11. *Acid and Alkaline Constituents.*

Serial No.	Cement constituents	Percentage composition	Percentage molecular wt.
1	Calcium oxide, CaO	62.0	1.10
2	Magnesium oxide, MgO	1.5	0.04
3	Silica, SiO_2	22.0	0.37
4	Alumina, Al_2O_3	7.0	0.07
5	Oxide of iron, Fe_2O_3	3.0	0.02
6	Sulphur trioxide, SO_3	1.1	—
7	Alkalies —	1.0	—
8	Loss on ignition	1.5	—

The acidic constituents are SiO_2, Al_2O_3, Fe_2O_3 and the alkalinic ones are CaO and MgO, omitting the rest. The percentage of acidic constituents is round about 32 and that of the alkalinic ones is 63.5. The ratio of these constituents is given by :—

$$\frac{CaO + Mgo}{SiO_2 + Al_2O_3 + Fe_2O_3} = \frac{\text{Alkaline constituents}}{\text{Acidic constituents}} = 2$$

The molecular weights for the respective oxides are given on page 150.

Sometimes the equation no. 4 given on page 151, is also used :—

$$\frac{2.8\ SiO_2 + 1.1\ Al_2O_3 + 0.7\ Fe_2O_3}{1.0\ CaO + 1.4\ MgO} = 1.$$

Thus from the above composition for a normal setting portland cement, the values are :—

$$\frac{2.8 \times 0.37 + 1.1 \times 0.07 + 0.7 \times 0.02}{1.0 \times 1.1 + 1.4 \times 0.04}$$

$$= \frac{1.03 + 0.08 + 0.02}{1.1 + 0.05} = \frac{1.13}{1.15} = 1 \text{ (approx.)}$$

(c) *Necessity of Proportioning.*

It will therefore be seen that in order to have constituents of definite composition as mentioned above, it is necessary that the calcareous and the argillaceous materials should be carefully selected and proportioned. It is possible theoritically to make a mixture of the raw materials and calcine or heat the same to a very high temperature to obtain *clinker*. But it is necessary that a thorough and an intimate mixing of the raw materials is essential to ensure a thorough chemical reaction between the ingredients while clinkering.

Art. 159. Functions of Cement Ingredients —

(i) *Lime–CaO*—Lime forms nearly two–thirds of cement and therefore its proportion has an important effect on its qualities. A sufficient quantity of *lime* must be present in the raw materials to form the required silicates and aluminates of calcium. A deficiency in lime reduces the strength of cement and causes it to set quickly; an excess will make cement unsound and cause it to expand and disintegrate. Usually lime is kept below the required value.

(ii) *Silica* SiO_2 -- The quantity of *silica* should be enough to form dicalcium silicate and tricalcium silicate. Silica imparts strength to cements and is present usually to the extent of about one fifth of the cement.

(iii) *Alumina* -- Al_2O_3. has the property of imparting quick setting quality to cement. It lowers the clinkering temperature. Since a specific high temperature is necessary to form clinker of required composition, an excess of alumina weakens the cement. Compounds of alumina react readily with water. Alumina forms about one fifteenth of the cement.

(iv) *Magnesia* -MgO — This is usually kept at a very low percent. The permissible percentage is 1.5 to 3. Within these values it has no bad effect; but when present in larger percentages, magnesia is harmful.

(v.) *Calcium Sulphate* — $CaSO_4$ -- This is in the form of gypsum, and has an effect in slowing down the setting action. The initial setting time is increased as explained later. Gypsum is added after the clinker is formed and during the process of grinding it, to form cement.

(vi) *Oxide of Iron* — Fe_2O_3 -- This requires a very high temperature to enter into chemical combination with calcium andaluminium to form tricalcium aluminoferrite, which mparts hardness and strength to cement. The colour of cement is chiefly due to iron compounds.

(vii) *Sulphur,* as calculated on the basis of sulphuric anhydride SO_3, is limited to 2 percent. An excess quantity of sulphur causes the cement to become unsound.

(viii) *The Alkalies* present in the raw materials are carried away ordinarily in the flue gases during clinkering so that cement contains only small quantities of the same, often less than 1 percent. An excess of alkaline matter causes efflorescence.

Setting of Cement

Art. 160. Setting Action or Cement Hydration — The cement constituent compounds are all in an anhydrous state. These compounds have different rates of hydration, and when water is added to portland cement, chemical action begins between them and water.

(i) Under favourable conditions, tricalcium aluminate, $3CaO. Al_2O_3$, and tetra-calcium alumino-ferrite, $4CaO. Al_2O_3. Fe_2O_3$ hydrate almost in one day.

(ii) Tricalcium silicate, $3CaO. SiO_2$, the most important constituent, is the next to hydrate and within a week a substantial part of it reacts with water. It is responsible for the strength of cement in early days.

(iii) Dicalcium silicate, $2CaO. SiO_2$, is the slowest compound to hydrate and the process continues for several days. This compound is responsible for the progressive strength of cement.

The process of hydration is essentially the formation of crystals and gels, from the solution of cement and water, and continues for a long period. Specially the hydration of the last two constituents extends even upto one year. The hydration can be illustrated as follows :—

$$3\ CaO.\ SiO_2 + xH_2O = 2CaO.SiO_2.xH_2O + Ca\ (OH)_2$$

$$2\ CaO.SiO_2 + xH_2O = 2CaO.SiO_2.xH_2O$$

$$3\,CaO.Al_2O_3 + 6H_2O - 3CaO.Al_2O_3.6H_2O$$

$$4\,CaO.Al_2O_3Fe_2O_3 + xH_2O \quad 3CaO.Al_2O_3.6H_2O + \text{Iron compounds.}$$

As these crystals adhere to one another and to the surface of sand and aggregate with which cement is mixed, in a short time, depending upon the type of cement, the entire mixture gets set and hardened.

Art. 161. Heat Evolved during Setting — The setting action of cement, as seen above, is essentially a process of hydration and is *accompanied by the Evolution of Heat*. The tricalcium aluminate gives out much of the heat. Similarly tricalcium silicate also generates considerable heat during hydration.

Since hydration of cement continues for a considerable period, extending well over a year, the problem of dissipating heat generated during hydration becomes important in the case of massive and thick concrete structures like dams, etc. A rise in temperature to the extent of 60 to 80° F is observed in many cases. The rise in temperature is the largest during the first few days. But in large masses of concrete the maximum temperature is generally reached as late as after 2 to 3 months. Several devices of cooling down the interior heve to be adopted.

Effect of Temperature on Hydration and Setting. The temperature at which the curing of cement takes place has an effect on the rate of setting. Upto a temperature of 85 to 90° F, the rate of setting varies directly with the temperature. But at higher temperatures, cement hardens so rapidly that it becomes very difficult to handle the concrete and to make it campact before it sets.

Manufacture of Cement.

Art. 162. Methods and Stages in Cement Manufacture — There are two processes employed for the manufacture of cement :—

(a) The Wet Process.

(b) The Dry Process.

The adoption of one process or the other depends on the nature of the raw materials available. Though these two processes differ in details of their operation, the fundamental stages in the manufacture of cement are the same, viz.:—

(i) Proportioning of the raw materials and preparing an intimate mixture of the same. In the dry process the intimate mixture is a very finely ground powder, while in the wet process, it is in the form of a wet slurry.

(ii) To burn the mixture at a very high temperature in kilns and to prepare clinker nodules of the same.

(iii) To grind the clinker to the required degree of fineness with gypsum for obtaining cement.

These processes will now be discribed in detail.

Art. 163. Proportioning of Raw Materials — *Principles* — We have seen that limestones and marls, which form the calcareous raw materials for manufacturing cement, contain calcium carbonate, $CaCO_3$, as the chief constituent; and also varying proportions of silica, alumina, oxide of iron and alkalies. They also contain magnesium carbonate, but it is necessary that its percentage does not exceed 5. An analysis of the raw material is made and the contents of lime, silica, alumina and oxide of iron are determined.

Similarly, the percentage composition of the argillaceous materials such as shale or clay is determined for their contents of silica, alumina, oxide of iron, lime, etc. Sometimes slag and mill scale are used as additional raw materials.

From the calculated composition of the calcareous and the argillaceous materials as mentioned above and with the help of the desired ratio of alkaline and acidic constituents as given in art. 158 the proportion in which the two raw materials should be added to obtain the required mixture, is specified.

The purpose of this article and the previous ones is to stress the importance of proportioning as an essential step in the making of cement. The details about specifying the exact proportions of mixing two or more raw materials involves mearly the use of formulae of relations between the ingredients.

Before the raw materials are proportioned, they have to be given a preliminary treatment such as *crushing* and *grinding*.

Wet Process.

Art. 164. The Wet Process of Manufacturing cement — *The wet Process* of manufacture of portland cement, consists of the following stages :—

Stage No. 1. To prepare Cement Slurry.

(i) To obtain the raw materials from the quarries.

(ii) To crush the raw materials.

(iii) To mix the raw materials and wet grinding of them in mills to obtain slurry.

(iv) To elevate the slurry to correcting silos.

(v) To store the corrected slurry.

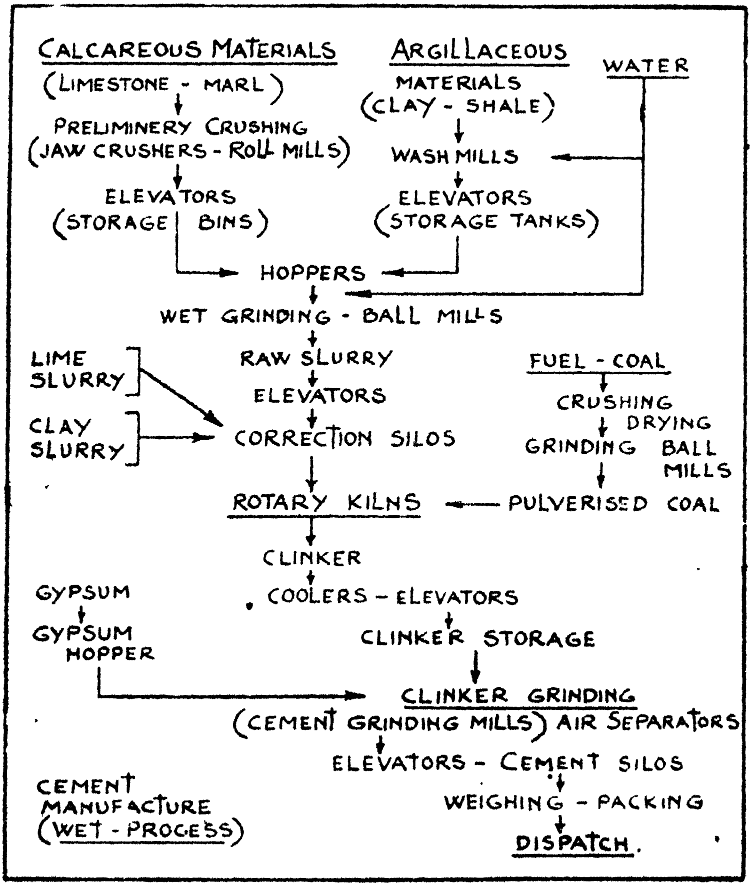


Fig. 32. Flow diagram for the Wet Process.

Stage No. 2. To obtain Cement Clinker.

(i) To pump the corrected slurry into rotary kiln.

(ii) To feed the rotary kiln with fuel (pulverised coal).

(iii) To prepare cement clinker in rotary kiln.

(iv) To cool the clinker and store the same.

Stage No. 3. *To Prepare Cement.*

(i) To grind the cement clinker to a very fine powder with a retarder (gypsum).

(ii) To elevate and to store the cement in silos.

(iii) To fill the bags for dispatch to the works for use.

These various stages are described in the following articles, with reference to the flow diagram shown in fig. 32.

Art. 165. Preliminary Treatment of Raw materials — The raw materials such as limestones, marl or chalk and shale or clay are obtained from the neighbouring quarries. They are brought to the site of cement manufacture, independently in trucks or waggons. Regular quarries are opened out for the purpose to maintain a steady and a continuous supply of the required quantities of the calcareous and the argillaceous materials, to meet the capacity of the cement manufacturing plant.

Crushing — This is generally required for almost all limestones and chalk, and sometimes to shale and clay rocks. Crushing is done by means of Jaw, Gyratory or Roller crushers. The purpose of crushing is to prepare the material for grinding in mills. If the material is hard, two stage crushing has to be adopted. When the material comes out of crushers, it is finally of the size of $\frac{3}{4}$-in. to 1-in. The crushers are fitted with screens so that the maximum size of the crushed pieces is automatically controlled as it passes through them. One type of a *Jaw Crusher* is shown in fig. 33.

Elevators — The crushed materials are then elevated to the required height by means of continuously operated chain buckets and stored independently in large bins. A typical storage bin has a diameter of 10 to 15 feet and a height of 60 to 80 feet.

Art. 166. Proportioning, Wet grinding and Preparing the Slury — The elevated crushed materials are allowed to drop down at a controlled rate from the storage bins through the hoppers fixed at their bottom. They fall into a common inclined trough channel and slide down for feeding into the grinding mill which is termed as a *Wash Mill.* A requisite quantity of water is also let into the trough channel to mix with the raw materials while entering the Wash Mill.

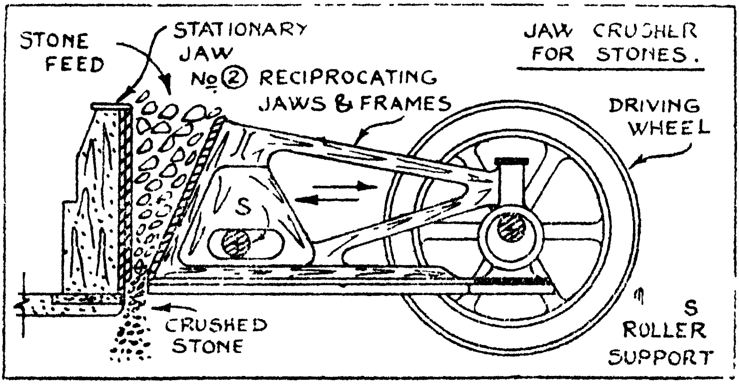


Fig. 33. One type of a Jaw Crusher.

Wet Grinding — This is done in *a Wash Mill* which is essentially a thick and a heavy steel cylinder of about 8 to 10 feet diameter and 30 to 40 feet length. It is kept slightly inclined in its horizontal position and is capable of rotating on its longitudinal axis. Inside the mill are kept steel balls of the required sizes, The mill is closed at both ends with provisions for feeding at one end and drawing out the ground material at the other. It rotates at a very moderate speed of about 15 to 20 revolutions per minute as a result of which the steel balls together with the contents, are lifted and are allowed to fall in rapid succession. This produces a ponding or hammering action on the materials by the balls. As the balls slide down, a grinding effect is also produced. By the combined effect of pounding and grinding, and in the presence of water, the material is crushed to the required fineness. A screen is placed at the lower end to enable only the material crushed satisfactorily, to pass through.

Preparation of Slurry — The raw materials are reduced to a very fine state of division in the wash mill so that about 80 to 85 percent of the particles are capable of passing through a 200 mesh sieve. The quantity of water used in the wet process is round about 50 to 60 percent and the raw mix exists in a complete homogeneous condition of suspension in water. Such an intimate mixture is termed as *Slurry* and is sufficiently liquid to flow through pipes and to admit of being handled by pumps. The slurry is then collected into a storage tank where it is prevented from settlement by a system of continuously operated rakers and hanging chains.

Art. 167. Correction of Slurry — The slurry from the storage tanks is pumped into the correcting silos which are usually three in number, to serve the following purpose in rotation :-- One silo is being filled in with the slurry from the storage tank; while the slurry from the second one is examined for its composition by taking samples and correcting the same as required. The third silo contains the slurry corrected for its composition and which is being drawn for feeding into the rotary kiln. Sometimes the correction of the slurry is effected in two stages. This requires an additional silo after the first one for rough odjustment of composition initially. In this case we require a series of four silos.

The correction of slurry composition is effected by adding in specified quantities, the slurry of either argillaceous matter or calcareous matter separately prepared and held in independent tanks.

In all the above silos, the slurry is kept in a state of agitation by mechanically operated stirring devices and also by compressed air blown up from the bottom. The silos have a diameter varying from 15 to 25 feet and a height of about 40 to 50 feet.

Art. 168. Fuel for Cement Kilns — In the second stage of cement manufacture clinker is prepared out of the corrected slurry, by burning it in rotary kilns. The fuel used for the purpose may be either coal, oil or gas. If coal is used, it requires initial treatment by way of pulverization, while oil and gas could be used directly. The essential requirements of any type of fuel are that (i) it should develop the necessary clinkering temperature; and (ii) it should maintain the same temperature constantly by regular burning.

Pulverization of Coal — The above two requirements of coal depend upon its physical characteristic. It should be thoroughly ground to the required fineness, and the most common device used for this purpose, is the Ball Mill method. Coal has to be initially crushed and dried before being ground. It is injected into the kiln from the end opposite to that at which the corrected slurry is pumped. The temperature to be developed is about 2900 to 3100° F in the clinkering zone of the kiln.

Art. 169. Rotary Kiln — *Cement Kilns* are of the rotary type. They are essentially horizontal cylindrical shells of steel plates $\frac{3}{4}''$ to $1\frac{1}{2}''$ thick, measuring round about 8 to 12 feet in diameter and 200 to 400 feet in length. The kiln is placed in an inclined position at a slope of about 1 in 20, and is mounted on roller bearings. A circular toothed wheel is attached around the steel shell of the kiln at a convenient place in its length to facilitate its rotation, at about one revolution per minute. One or more kilns could be arranged in parallel as required, so as to operate independently.

A Lining of Fire Bricks — such as magnesia or alumina bricks is provided to preserve the interior heat and also to prevent the outside steel shell from getting heated. The refractory lining helps to balance the temperature of the burning zone in addition, by acting as a storage of heat.

Art. 170. Stages in Cement Clinker Formation —

(i) *Drying zone. Elimination of Water from Slurry* — The corrected slurry is pumped into the rotary kiln from the upper end. In the first few feet of the length of the kiln, a system of *thick* iron hanging chains is provided. The slurry which is pumped in the form of a spray against the surfaces of the hot links of these chains, dries and peels off in the form of flakes and drops down at the bottom of the kiln. This section of the kiln is the drying zone and has a temperature of about 400 to 500° F. The water from the slurry is eliminated in this zone.

(ii) *Calcination Zone* — This is the next zone where calcination takes place. The temperature is about 1200° to 1500° F. The flakes that drop down from the slurry coated chains of the upper zone, gradually slide down into this zone by the combined effect of slope and rotation of the kiln.

(iii) *Clinkering Zone* — As the particles pass down from the calcining zone, they enter sections which are progressively hotter ranging from 1500 to 3000° F. In this zone, the calcareous, and argillaceous materials are rendered chemically active, and when the required high temperature is reached, they enter into chemical combination to form the cement compounds of silicates, aluminates and ferrites. These compounds come out as vitrified glassy nodules of varying sizes from 3/8″ to $\frac{1}{4}$″ and downwards.

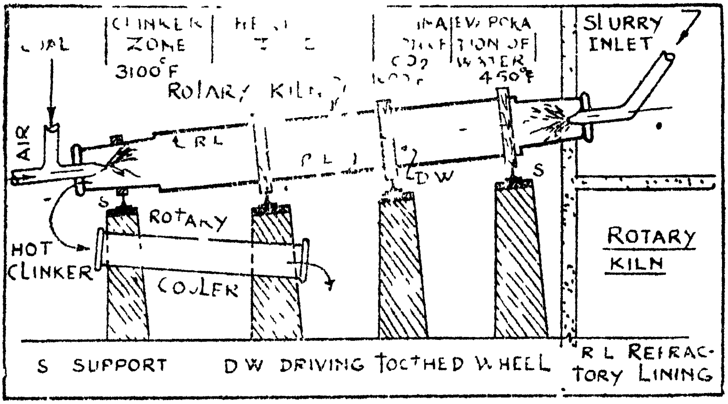


Fig. 34. Rotary kiln and cooler.

(iv) *Firing Zone* — The method of blowing-in of the pulverised coal, oil or gas from the lower end of the kiln to generate heat in the firing zone is already given in the previous article.

In fig. 34 are given the details of a rotary kiln.

Art. 171. Clinker Cooling and Storage — The hot clinker has to be cooled and stored before grinding it into cement. Cooling cylinders are mounted on the lower end of the rotary kiln into which the hot clinker falls and is cooled. These cylinders are open at both ends for the free circulation of air. Alternatively an independent rotary cooling cylinder could be provided for the same purpose of cooling down the clinker. Rotary coolers in either case independent or mounted on the kiln, are provided with *thin* iron chains in their interior and as the hot clinker comes in contact with their surface it gets cooled.

The cooled clinker drops down from the lower end of the coolling cylinders, and collects into a pit. It is then conveyed from the pit by means of a belt conveyor to clinker storage houses.

Art. 172. Effect of Grinding the Clinker — The third stage in the cement manufacture is fine grinding of the clinker as formed above together with a small proportion of a *Retarder.* Grinding is essentially a physical treatment and is necessary to form cement.

Fine grinding gives more facilities for the various anhydrous constituents of cement to come in contact and react with water, readily. It makes the cementitious properties of these constituents more prominent. Therefore, in order to develop high strength at early stages, the cement should be ground to a greater fineness than required for ordinary cement. Finer cements harden rapidly also.

In addition, fineness of grinding imparts workability anp density to the mortars and concrete. Expansion and contraction are very much reduced with finer cements.

Considering all the above good effects, it will be noted that to produce cement of the requisite qualities, it must be ground to the required degree of fineness. But there is a practical limit to grinding as very fine particles exhibit a tendency of floating in the air and produce an effect known as " blowing. "

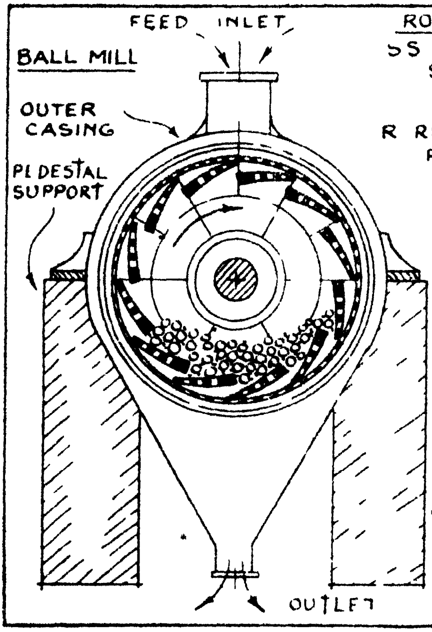


Fig 35 Ball Mill

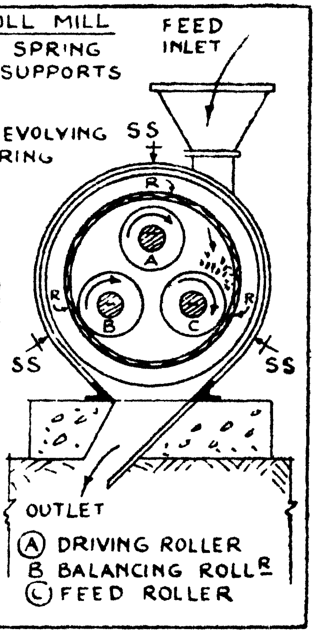


Fig 36 Roll and Ring mill

Art. 173. Grinding of Clinker for Cement — We have seen that cement is obtained by grinding clinker. This operation is done in two stages. *Preliminary Grinding* and *Final Grinding*. In the preliminary grinding the material is reduced so as to pass through a 20 mesh sieve. During final grinding cement is reduced to the fineness of 200 mesh or 74 micron.

Grinding Mills — The following types of mills are used for the purpose of grinding clinker:—

(a) For preliminary grinding :—Ball Mills or Roll and Ring Mills are used.

(b) For Final grinding :— Tube Mills are used.

But cement could also be ground in a single mill known as compartment mill, which is essentially a combination of Ball and Tube Mills.

Art. 174. Priliminary Grinding — *Ball Mills* — A typical Ball Mill is shown in section in fig 35. The action of a ball is similar to a wash mill with the exception that there is no water used in the former case. A ball mill is essentially a steel cylinder into which are kept iron or steel balls of 2 to 5 inches in diameter. The cylinder is kept in a horizontal position and is rotated at a low speed. The clinker which is ground passes through holes of the screens provided in the periphery of the rotating cylinder.

Roll and Ring Mills — See fig. 36. A roll and ring mill consists of a fixed cylindrical shell inside which are provided, a suspended ring and three rollers. Of these, one is a driving roller and the other two are free rollers. The clinker is crushed by the centrifugal pressure and by the friction between the rollers and the ring as well.

The powdered material as obtained after the priliminary grinding is capable of passing through a sieve of 20 mesh.

Art. 175. Final Grinding of Cement — *Tube Mills* — See fig. 37. A tube mill consists of a horizoutal rotary cylinder of steel 6 to 8 feet diameter and 25 to 30 feet long. The principal of working is the same as the ball mill, but the steel balls are only of about 1 inch diameter. During final grinding, the material has to be reduced to a very fine powder so as to pass through a 200 mesh sieve. This size of particle offers two practical difficulties. They reduce the grinding effect on the bigger size particles and they could not be effectively sieved on a large scale. Thus for separating very fine particles on a large scale "*air seperators*" are employed. The finer particles are carried away by means of a current of air, leaving behind the coarser particles for further grinding as a return feed.

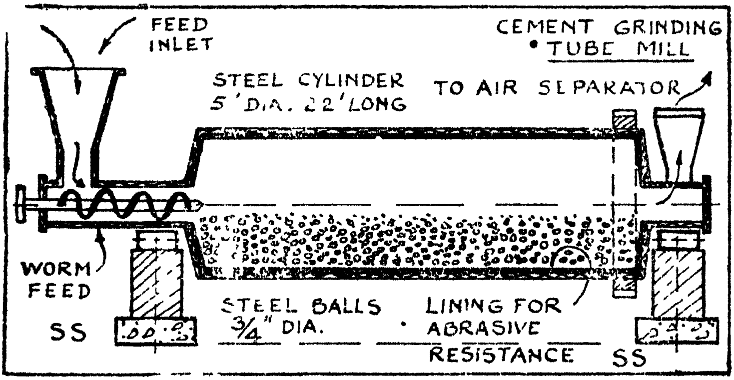


Fig 37. Tube Mill.

Compartment Mills — The two processes of preliminary and final grinding can be carried out in a common mill, known as a compartment Mill. The mill has three or four compartments and the steel balls are of different sizes in each compartment from 4″ to 1″, the compartment near the feed containing the bigger size grinding media. These mills are also fitted with " air separators " as mentioned above.

Art. 176. Mixing of Retarder with Clinker —

Importance of Adding a Retarder — We have seen that if cement contains only the four constituents as given in art. 160, the setting and the hardening action commences, almost immediately after the water is added. It should be noted that cement when once starts setting should not be disturbed.

But from the practical point of view, some period, should be allowed to pass from the time cement is mixed with water to form mortar or concrete, till it is finally placed in the construction work. Ordinarily this period is about 15 minutes to 30 minutes, and is counted as working period required for the use of cement.

The addition of a retarder, retards the initial setting action of cement. Gypsum or calcium sulphate, $CaSO_4$ is added to the extent of 3 to 4 percent, to the clinker while grinding, for delaying the commencement of the setting time.

Action of a Retarder — It was pointed out that the compounds of alumina, viz. tricalcium aluminate and tetracalcium alumino-ferrite react very quickly with water and are the first to hydrate. With the addition of gypsum, alumina reacts with calcium sulphate to form calcium sulpho-aluminate, which is insoluble and does not hydrate. This has a general retarding action on the starting of the initial setting after the water is added and also retards the hydration of tricalcium silicate. If more gypsum is added, the initial set is very much delayed and the proportion of SO_3 increases more than the permissible value of 2 percent in the finished cement.

Art. 177. Cement Storage — *Cement Silos* — Cement is now-a-days generally stored in large sized reinforced concrete vertical cylinders, called cement silos. Their diameter varies from 25 to 35 feet and height from 50 to 80 feet. Three to four silos are provided and cement is drawn from them at the bottom, as and when required.

Cement Packing — Cement is packed in gunny bags or in bags of cloth or paper, with the aid of automatic weighing and packing machines. A special rotary type of a screw feeding device with a trigger is provided for filling the bags. When a specific quantity of cement is admitted in each bag, the trigger is operated by the weight of the filled bag and the feed is automatically closed. The bags are then stitched or tied by a wire and sealed for dispatch, either by lorry trucks or by waggons. One cu. ft. of cement weighs 93 to 94 lbs. and one bag of cement weighs 112 lbs.

Cement Storage — The following precautions should be taken for the storage of cement on works :—

(a) Cement should be stored in a dry place and on a raised platform, which is covered and guarded from the sun, wind and rain.

(b) As far as possible, long periods of storage should be avoided.

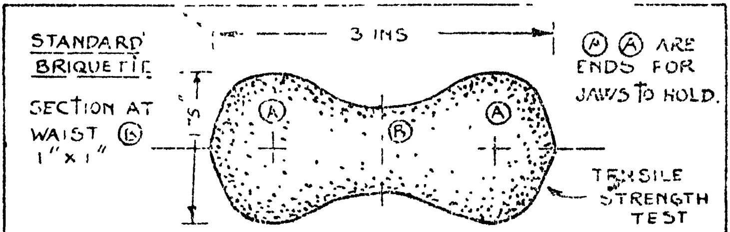
(c) Cement exposed to atmosphere may absorb water vapour and carbon-di-oxide and consequently hydrate and lose strength. Heat and humidity accelerate hydration. Under these conditions, cement is said to *deteriorate*.

(d) The storage of cement in rainy season is not recommended.

Dry Process.

Art. 178. The Dry Process of Manufacturing Cement —The difference between the Dry process and the wet process of manufacture of cement lies in the preparation of the correctly proportioned feed required for the rotary kiln. In the Dry process the feed is a very finely ground powder, Thus we have, if 32.4 percent of water is required to prepare C. P. of N. C., then P = 32.4 and the percentage of water for gauging standard mortar is calculated as follows :—

$$\tfrac{1}{4}\,(0.78 \times 32.4) + 2.5 = 8.82 \text{ percent.}$$



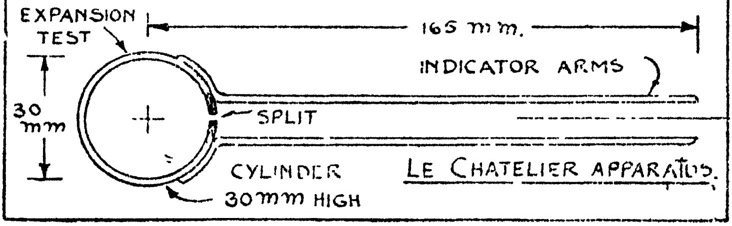


Fig. 43. Briquette for tension strength of cement

Fig 44. Le chatelier apparatus for expansion test

(c) *To Make Standard Briquettes and Cubes* — The materials are mixed well on a steel plate and filled carefully in the briquette moulds. For the tensile strength test, the briquettes have a special shape, as shown above, for giving facilities to catch their ends in the jaws of a tensile testing machine. But the moulds for the compression test are simple as to yield cubes of 2.78 in or 7.06 cm. size. The area of each face of cube is thus 7.75 sq. ins. or 50 sq. cms.

After the moulds are filled, they are kept in a damp condition for 24 hours and the briquettes are then taken out of the moulds for being kept submerged in clean fresh water, until they are taken out for testing at the end of the specified periods.

(d) *Testing the Briquette Strength of Cement* — A minimum of six briquettes and cubes each are made out of Standard Mortar as detailed above and tested. Their average value is taken for their strength.

Tensile Strength after a period of :—

3 days — to be not less than 300 lbs./ sq. in.
7 days — to be not less than 375 lbs./ sq. in.

Compressive Strength after a period of :—

3 days — to be not less than 1600 lbs./ sq. in.
7 days — to be not less than 2500 lbs./ sq. in.

Art. 185. Setting Time Tests — Cement is tested for :-

(a) Initial Setting Time; and
(b) Final Setting Time.

Both the tests are carried out with the aid of Vicat Needle Apparatus. The plunger of 1 c. m. or 10 m. m. diameter, used in preparing C. P. of N. C. is replaced by a needle of 1 m. m. square. The diagram of the apparatus shown in fig. 89, has this needle of 1 c. m. fitted to it.

Neat cement paste is prepared by taking only 0.85 P of water. Cement and water are properly gauged and the cylindrical mould is carefully filled with it. Standard spatula as shown in fig. 42 is used for the purpose.

(a) *Initial Setting Time* — The mould is then brought below the Vicat needle which is then allowed to sink into the same. The process of letting the needle sink into the paste of cement is repeated until the cement starts setting and the needle could only sink about 35 m. m. into it, and not for the full depth of 40 m. m.

A record of time is kept and the period that elapses between the time when the water is added and the time when the needle ceases to sink into the cement paste completely but only for a depth of about 35 m. m. is termed as the *Initial Setting Time*. The importance of providing a sufficient initial setting time is already explained under the effect of a retarder in cement.

(b) *Final Setting Time* — After the initial setting time is determined, the needle of the vicat apparatus is removed and is replaced by an annular attachment having a circle diameter of 0.5 cm. shown in fig. 40. The central square of the attachment is 1 m. m. When the cement is finally set, the needle makes only an impression on the surface of the cement paste. This time interval is also noted.

The Setting Time of cement as determined above shall be :-

(a) Initial Setting Time — not less than 30 minutes.

(b) Final Setting Time — not more than 10 hours.

Art. 186. Test for Soundness of Cement — *Purpose of Test* — If cement contains free lime and magnesia, these will hydrate very slowly in a subsequent stage and the mortar and concrete prepared with such cement is therfore liable to expand and crack after a few months. Not more than a mear trace of free lime and magnesia is permitted in cement.

Apparatus used — This test is carried out by subjecting cement to an increased rate of hydration and observing how it behaves. All the previous four tests are carried out at room temperature of 58° to 64° F, but this test is carried out with the aid of boiling water.

The cement paste which is required for this test is prepared by using 0.78 P percent of water for gauging. The "Le Chatelier" Apparatus used to conduct this test is shown in fig. 44. The box, which is made of copper holds 12 moulds at a time.

Method of Testing — The test mould is filled with the neat cement paste, gauged with 0.78 P of water. It is cured for 24 hours at about 60° F. The distance d_1, between the two pointers is noted. The mould is then submerged in water, which is brought to boiling point in about 30 minutes. The rise in temperature is kept uniform to ensure a steady accelerated hydration. The water is kept boiling for one hour and is then allowed to cool down to room temperature. The distance d_2 between the pointers is again measured The difference between the two measurements, $d_2 - d_1$ indicates the expansion of the sample of cement under test. This should not be more than 10 m. m. or 0.4 in.

Art. 187. "Rapid Hardening" or "High Early Strength" type of cement — We have seen that setting or hardening of cement depends upon the facility given to its constituents to come in contact with water and to react consiquently. Thus rapid hardening or high early strength cements could be produced by increasing the fineness of grinding i. e. by increasing their specific surface. The following tests are specified for this type of cement :—

(a) *Fineness test.*

(i) After sieving on a No. 170 - mesh sieve, this type of cement should not leave a residue of more than 5 percent.

(ii) Rapid hardening portland cement should have a specific surface of not less than 3250 sq. cms. per gram, as already given.

(b) *Strength of cement* — The test briquettes and blocks are made of standard mortar, and cured as specified, and tested.

(a) *Tensile strength* after a period of :—

1 day — to be not less than 300 lbs./ sq. in.

8 days — to be not less than 450 lbs./ sq. in.

(b) *Compressive Strength* after a period of :—

1 day — to be not less than 1600 lbs./ sq. in.

3 days — to be not less than 3500 lbs./ sq. in.

Other tests for rapid hardening cement are the same as those for Ordinary Portland Cement.

Tricalcium Silicate Contents — It may be also noted that an increase in the tricalcium silicate content in cement also imparts it rapid hardening qualities. This requires an increase in the lime contents and the consequent careful clinkering at a higher temperature. With an increase in lime content in raw materials, there is always a danger of the presence of free lime in cement.

Rapid hardening cement has the advantage of increasing the speed of construction. The form work could be removed quickly and the members could be loaded early. However, this type of cement is slightly costly.

Art. 188. Varieties of Cements — Cement is available in various types. The following are the principal varieties :—

(i.) Ordinary Portland cement or Normal Setting Cement.

(ii) Rapid Hardening or High Early Strengh Cement.

✓ (iii) Quick Setting Cement.
(iv) Low Heat Cement.
✓ (v) High Alumina Cement.
(vi) Blast Furnace Cement.
✓ (vii) Coloured Cements.
(viii) Calcium chloride and Cement.

The first two types have been hitherto described. A brief description of the rest will now be given.

Art. 189. Quick Setting Cement — When cement is required to be placed under running water, it is necessary that it will start setting within a few minutes after being mixed with water and that it will complete its setting acrion within half an hour and become hard. Such cements contain a higher percentage of alumina, which hydrates quickly to form calcium aluminate and calcium alumino-ferrite. They also contain a smaller percentage of retarder. It is very difficult to work with a quick setting cement as all the mixing and placing of concrete has to be done before the initial setting starts.

Art. 190. Low Heat Cement — In thin sections of concrete castings, the difficulty is to maintain the heat of hydration so that concrete will become hard early. Cement, if allowed to hydrate at about 60° F, will harden in almost less than half the period it would take if the hydration temperature is about 85° F.

But in large masses of concrete, we have seen that hydration of cement continues for a long period and generally the rate of generation of heat is more than could be dissipated ordinarily. To avoid the installation of complicated devices for conducting the heat from the interior to the exterior, cements with Low Heat of Hydration are used.

These cements contain a lower percent of tricalcium silicates, – the constituent which hydrates quickly and a higher percent of dicalcium silicate – that hydrates slowly. Thuss low heat cements are vertually those that have a very slow and a controlled rate of hydration. The proportion of tricalcium aluminate is also reduced. Thus, we have, the composition of low heat cement given by :—

Table No. 12. Composition of Low Heat Cement.

Type of Cement	$3CaO.SiO_2$	$2CaO.SiO_2$	$3CaO.Al_2O_3$
Ordinary Cement	40 p. c.	30 p. c.	10 p. c.
Low heat Cement	30 p.c.	40 p. c.	7 p. c.

Low heat cement develops a lesser compressive strength. viz. about 1600 lbs. / sq. in. against 2500 lbs. / sq. in. for ordinary cement, in 7 days. They are specially manufactured for mass concrete work.

Art. 191. High Alumina Cement—This cement has a high proportion of aluminates, usually well over 35 percent. It develops strength very rapidly and becomes as strong in 24 hours as ordinary cement does in 28 days. The setting action is mainly due to the formation of calcium aluminates which are the first to hydrate in any cement.

A rapid process of hydration is necessarily accompanied by an equally rapid liberation of heat, which is not desirable at ordinary temperatures. In fact, it is necessary that with any cement, (i) the gaining in strength with age, (ii) the corresponding rate of hydration, (iii) the liberation and the dissipation of heat during the curing period, should all balance in such a way that concrete does not shrink and develop cracks subsequently. Tricalcium aluminate is liable to high volume changes after setting, which is necessarily a disadvantage for using high alumina cement.

High alumina cement is manufactured by calcining a mixture of lime and bauxite. It is more resistant to attack by sulphate and acid, and also to the action of frost. It is commercially known as " *Cement Fondu*" and "*Lumnite.* "

Art. 192. Blast Furnace Cement — Blast furnace slag is used to the extent of 60 to 65 percent in making cement. It is ground with clinker; but before it is mixed with it for grinding, it has to be crushed preliminarily to a granulated form.

Slags are virtually rapidly cooled igneous rocks and when finely ground, blast furnace slag in particular represents cementitious properties. Usually one ton of blast furnace slag is produced for every ton of pig iron manufactured. The slag contains all the basic elements of cement, viz., silica, alumina and lime, — the exact proportions of each depend upon the basic or acidic type of the slag. The cement produced from the blast furnace slag exhibits the same properties as the normal setting cement. It is equally strong and durable and results in an economy owing to the use of the waste product of iron industry. If an excess of sulphides is present in slags, cement develops a tendency to disintegration on expose to the weather. This is usually a drawback for a free use of slag.

Art. 193. Coloured Cements — Colours are imparted to ordinary cements by mixing colouring matter in the form of mineral pigments to it. Usually 5 to 10 percent of the colouring matter is added to obtain the required shade. The mineral oxides used as pigments, are rather costly.

Iron oxide gives red, yellow or brown colour; chromium oxide gives green colour; cobalt gives blue colour. For black or brown colour, manganese dioxide is used.

White Cement is prepared by choosing the raw materials almost free from iron. It is the normal setting or ordinary cement, except for the absence of any colour but white colour. The commercial term for white cement is " Snowcrete ".

Art. 194. Calcium Chloride and Cement — Calcium chloride acts as an accelerator, and the rate of development of strength is increased by the addition of about 2 percent of calcium chloride to the ordinary cement. A higher percent of calcium chloride causes excessive shrinkage of concrete and at the same time, it is detrimental to the reinforcement of R. C. C. work. Cements to which chlorides are added, show better setting and hardening properties in cold weather.

Art. 195. Uses of Cementing Materials— Limes and Cements — Uses of limes and cement are essentially in the making of mortars and concrete, which are considered as materials directly used for construction. Water plays a very important part in all the operations where limes and cements are used. Having obtained the desired type of the cementing material and after testing it, the engineer now proceeds to manufacture mortars and concrete. Hitherto the cementing materials were considered as being made up of several components for the purpose of their manufacture and to study their properties; but when they are used in the making of mortars and concrete limes and cements are considered as one of the materials which go to make them. The design of mortar and concrete, mixes, the selection of raw materials of which limes and cements are considered as the manufactured raw materials, and the technic involved in the subsequent stages in their making, are described in the following chapter. It is assumed that only the tested materials possessing specific properties are used for the purpose.

CHAPTER VII

Mortar and Concrete.

Mortar and Its Composition.

Cementing materials : sand, surkhi, water, etc.

Sand. Typs of sand. Functions of sand in mortar. Properties of good sand. Tests for silt and organic contents. Size of sand and grading. Sieve analysis. Bulking of sand and its effects. Proportioning of sand.

Types of Mortar.

Lime mortar; Cement mortar; Combination mortar; light weight mortars ,– cinder, sawdust and fibrous plasters.

Lime Mortars.

Proportioning, mixing and grinding. Mortar mill. Cement mortar. –method of preparing. Uses of Mortar.

Gypsum Plaster.

Composition, manufacture and uses. Keene's cement. Plaster of paris. Sorel cement.

Concrete and its Constituents.

Aggregates–coarse and fine. Binding materials. Water. Properties of concrete. Strength, durability, etc. Effect of age on strength.

Necessity for Grading.

Importance. Fineness modulus. Combined aggregate. Moisture and aggregate.

Water Cement Ratio.

Effect on strength. Consistency and slump.

Mortar and Its Composition.

Art. 196. Mortar — The cementing materials described in the previous chapters are used in combination with an inert matter such as sand, to prepare *mortar*. Thus we have lime mortar, cement mortar, surkhi mortar or combination mortar. We can describe mortars as intimate mixtures having the consistency of a paste, and prepared by mixing various proportions of a binding material and inert matter and water. When the materials are freshly mixed, mortars have a plastic consistency which could be easily worked with trowels to fill in the joints in masonry or to render the surfaces of walls by plastering, etc. But by virtue of the setting properties of the binding material used they set and become hard subsequently.

Lime mortars and surkhi mortars require grinding with water as an essential step to prepare them as this ensures a thorough and an intimate mixture of the ingredients. It should be noted that cement mortar does not require any grinding at all.

Art. 197. Functions of Sand — (1) *Types of Sand*— Sand plays an important part as an engineering material. In concrete work it is generally termed as fine aggregate. As a natural product it is obtained as river sand, nala sand and pit sand. Sea sand should not be used for the following reasons :—

(i) It contains salt and is therefore hygroscopic. The structures remain damp and are affected by efflorescence.

(ii) It contains shells and organic matter which decompose in the body of mortars and concrete and reduce their life and strenth, Sand can be also obtained artificially by crushing stones. On very large works as in the case of constructing dams and bridges, if natural sand is not available in large quantities, artificial sand is very commonly used.

(2) *Functions of sand* — Sand is used in mortars and concrete for the following purposes :—

(i) It subdivides the paste of the binding material into a thin film, which is the principle involved in using all cementing materials.

(ii) It offers the requisite surface area for the film of binding material to adhere and spread.

(iii) It acts as a medium between the stones and bricks on the one hand and cementing material on the other, as in the case of masonry construction and concrete.

(iv) A well graded sand adds to the density of mortars and concrete.

(v) It prevents shrinkage effects of the cementing material and imparts homogeneous nature to the mass.

(vi) It allows Co_2 from the atmosphere to reach to some depth in the case of fat lime mortars and thereby improves their setting power.

(vii) By varying the proportion of sand, mortars and concrete could be prepared economically to any required strength.

(viii) Economically, the use of sand increases the bulk of mortar and reduces their cost. In this way, it could be considered as an adulterant.

(ix) It is claimed that some reactions take place between silica, SiO_2 of sand grains and the constituents of the cementing materials to form a hardend mass of silicates.

Art. 198 (i) Properties of Good Sand — *General properties*—Sand should consists of sharp, angular and hard grains, which should be approximately cubical in size. It should be strong and durable and should be as far as possible, pure silica, SiO_2.

It should be clean and free from coatings of any foreign matter such as clay and silt. It should not contain any organic matter. Sea sand is not suitable for engineering works and therefore, should not be used as already mentioned. Usually 3 to 4 percent of clay and silt is ordinarily permitted for practical reasons. It is preferable that sand should be washed before use, on all important works.

(i) *Test for Silt and Clay* — These, if present in sand, could be ascertained by determining the percentage loss in weight of a sample of it, after washing the same with the aid of clean water.

(ii) *Test for Organic Impurities* — The presence of organic impurities is estimated by stirring the sample of sand with a 3% solution of sodium hydroxide or caustic soda, in a glass bottle. The mouth of the bottle is closed and the contents kept for 24 hours to stand. The colour of the liquid turns brown, if any organic matter is present in sand. The quantity of the organic matter could be then judged from the darkness of the liquid.

(ii) Size of Sand - Grading of Sand — All grains of sand should pass through 1/4" - 3/16" mesh sieve; at the same time sand should not contain very fine particles and when sieved on No. 100— mesh sieve the residue should not be more than 5 percent. In between these two extreme sizes, sand should contain grains of uniformity varying sizes or it should be graded, in order to yield dense mortars. The gradation of these various sizes is determined by *Seive Analysis*. A known quantity of the sample of dry sand, ay about 100 to 150 grams, is taken and passed in a consecutive order through the B. S. S. sieves given in table No. 13. The residue on each sieve. is weighed and expressed as a percentage of the original weight of the sample. The percentages of the respective retained quantities are added and divided by 100 to obtain the *fineness modulus* figures of the sample. But to ascertain the distribution of the particle size, the above percentages are plotted, preferably on a logarithmic graph paper, against the corresponding sieve numbers, to obtain the size distribution curve. The principles of grading are explained later under concrete.

Table No. 13. B. S. S. Sieve Numbers.

British Standard Sieve sizes for Gradation of Aggregates .

1½"; 3/4"; 3/8"; 3/16".	No. 7; 14; 25; 52; 100.

The fineness modulus of sand should be between 2 and 3. A smaller value of the fineness modulus indicates the presence of larger proportions of finer particles, thus showing that the total surface area of the grains of that sample is more. This requires correspondingly a larger quantity of the cementing material. Alternatively it can be said that for richer and stronger mortars of a denser type, smaller size sand should be used, and vice versa with a practical limit for slability of handling. Brick masonry work requires finer sand for mortar than that required for stone masonry work.

(iii) Moisture and Bulking of Sand—The presence of moisture in sand influences its volume. Upto about 4 to

5 percent of moisture by weight of sand, there is a steady increase in volume to about 20 to 25 percent. A very simple experiment could be performed to illustrate the phenomenon of bulking of sand by taking dry sand of known volume in a measuring glass cylinder and adding small quantities of water successively. It will be observed that each time there is an increase in volume upto about 5 percent of moisture. For the subsequent additions of water there is a decrease in volume until the sample is flooded or saturated with water.

The Bulking of Sand for small moisture contents is due to the formation of thin film of water around the sand grains and the interlocking of air in-between the sand grains and the film of water. Since it has been a common practic to measure sand by volume in preparing mortar and concrete, due allowance should be made in its volumetric measurements for its apparent increase in bulk. It is clear from the above that the bulking is more with finer sands and its maximum value is at a slightly higher percentage of moisture than for coarser sand. Graphs are drawn for each type of sand used on works to show the relation between its increase in bulk and the percentage moisture contained.

Proportioning of Sand.

Art. 199. Types of Mortar — Different kinds of works require different strength for the mortars used for their construction. This requires the proportion of sand to cementing material to vary for making mortars to suit different purposes. The following are the common proportions used for mortars. The ratios given are for " binding material " to " sand ".

(i) *Cement mortars* — 1 : 2 or 3 for pointing ; 1 : 3 or 4 for plastering , 1 : 5 to 8 for masonry work.

(ii) *Lime Mortars* — Fat lime mortar, 1 : 1 or 2; ordinary building lime mortar, 1 : 2 or 3; Hydraulic lime mortar, 1 : 2. If Surkhi mortar has to be prepared, an equal volume of surkhi as that of sand is added to the same volume of lime.

(iii) *Gauged Mortars* — or Combination mortars. The setting properties and density of ordinary lime mortars could be largely improved by adding about 1 : 6 or 1 : 8 of cement to lime mortar. The process of adding cement to lime mortar is termed as gauging. Sometimes to impart water resisting properties, oil is added to mortars to the extent of about 3 to 5 percent by weight of binding material.

(iv) *Cinder Mortar* — Cinder screenings from railway engines and boiler ashes are used as artificial substitutes for sand. They are sufficiently hard and gritty. For use in light weight mortar and concrete, cinder should be crushed to uniform size and screened before use. It is necessary that cinder used should be free from ash, etc. The same ratios as for sand are also used for cinder. It is possible to drive nails through such mortars and concrete, due to their soft and porous nature.

(v) *Light - weight Mortars* — These are prepared by mixing wood powder, wood shavings or saw dust along with sand and lime or cement. Cinder mortar is also considered as light weight mortar. Sometimes fibres of jute, coir and hair cut into suitable small pieces, or asbestos fibres, are also used to obtain mortar for fibrous plasters.

For developing adhesion under special condition, small quantities of juice from bail fruit and joggery or glue could be added to mortars.

Waler used with Cementing Materials — The cementing materials like cement and lime used for preparing mortars are those as obtained and tested as detailed in the previous chapters.

Only fresh and clean water, free from organic impurities should be used for making mortar. Acidic, alkaline or saline water and similarly the water containing oily or greezy matter, should not be used. It may be remarked that water which is fit for drinking is also useful for making mortar and concrete.

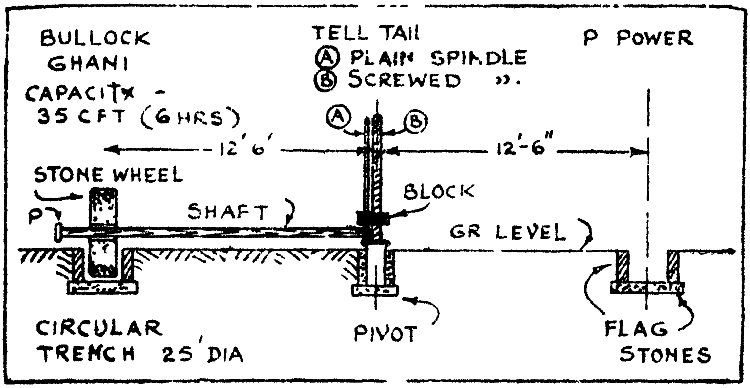


Fig 45. Bullock Ghani.

Lime Mortars

Art. 200. Grinding Lime Mortar—Lime mortars and surkhi mortars are prepared by grinding the ingredients in a specific manner. The purpose of grinding is manifold. In the first stage, it prepares an intimate paste of a liquid consistency of lime and water. The sand which is subsequently mixed in the second stage with this liquid paste is covered completely with it in the form of a thin film. During these stages grinding facilitates the making of an intimate mixture of sand and the cementing material in combination with water. In fact, grinding is purely a mechanical process. However, it also allows the unslaked particles of lime, if present, to slake completely.

Small quantities of mortars as are those required for repair works, etc. could be conveniently prepared by ponding the ingredients in small mortar pits, by employing human labour. While large quantities of mortar require to be ground in animal driven mortar mill. But for a steady and a continuous supply of mortar, as in the case of large constructions, power driven mortar mills are employed.

Art. 201. Bullock - driven Mortar Mill or Ghani — In Fig 45. the details of a ghani are shown. The mortar mill essentially consists of a circular trench of about 20 to 30 feet diameter and 15″ deep. The width of the trench is kept 10 to 14 inches so that the grinding stone or roller could move freely in the trench with a clearance of about 2″ to 3″ on either side to accommodate mortar.

A horizontal wooden piece or shaft is used for driving the wheel or the roller in the trench. The roller could be fixed in the wheel or may be kept free to rotate in it. At the centre of the circular trench and at one end of the shaft is fixed a device known as the " *Tell Tale* " for recording the number of grindings made by the wheel. The tell tale consists of a screwed spindle with a block fitted in it. The block also connects a second unscrewed or plain spindle which moves freely in it. For each revolution, the block is raised or lowered by one screw so that by counting the number of screws travelled, by the block during the grinding period, the total number of grindings made could be obtained.

Generally, a ghani could be loaded twice in a day of 12 hours, and 25 to 35 cu. ft. of mortar could de obtained each time, depending upon the size of the ghani.

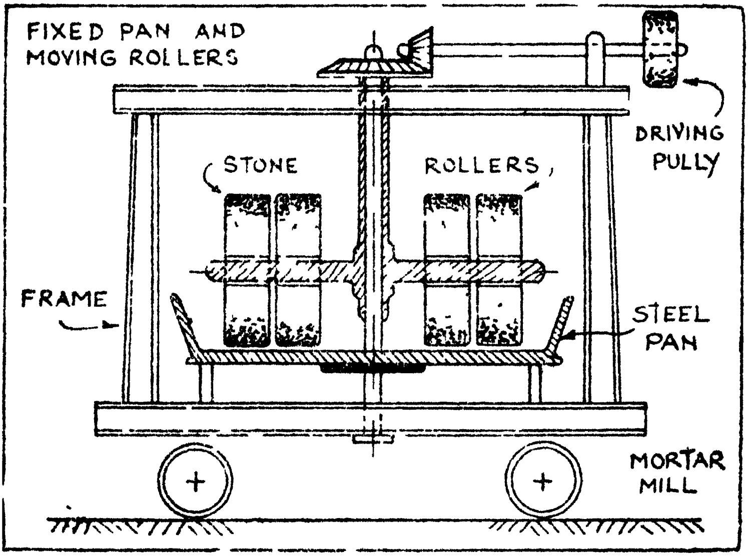


Fig 46 Power driven Mortar Mill

Art. 202. Mortar Mill — Power Driven — The details of a power driven mortar mill are given in fig. 46. There are two types of mortar mills :—

(i) In one type, the pan is stationery and the rollars are both rotating and revolving. This is more suited for small size mortar mills where the pan diamater is about 3 to 4 feet. Usually there are two rollers to ballance the moving parts,

(ii) In the second type, the pan is rotating and the rollers are held in a stationery position. But the rollers are rotating in this position on account of their contact with the pan. This is more suited for large size mortar mills with pans of 6 to 8 feet diameter.

Art. 203. Principles of Grinding — Lime and surkhi 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. About 180 revolutions are given for the purpose. If there are two roller,s only 90 revolutions are enough to obtain 180 grindings.

In the second stage, sand or its substitute is added in the required proportion and 180 grindings are again made. During the process of grinding, the mixture is properly turned by a scraper and a requisite quantity of water is again added to impart the proper consistency.

Storing Lime Mortar — After grinding, lime mortar is stored in a mortar pit under a shade. The pit is specially prepared with a non-porous floor and sides. It is heaped up in the form of a small dump with water poured in on the top to keep it wet. Ordinary lime mortar should be consumed within a week after grinding. Otherwise it becomes stale and loses its strength. But good hydraulic lime mortar should be used within 24 to 72 hours after grinding.

Double Ground Lime Mortar — Mortar required for plaster work is generally made out of fat lime or feebly hydraulic lime. After it is ground first as detailed above, it is stored wet for about a week. At the end of this period it is ground a second time to ensure a thorough slaking of all the lime particles and to develop good adhesive quality as required for plaster work. If the mortar used for plaster work contains unslaked particles of lime, there will be " blisters " appearing on the surface of the finished work.

Double ground lime mortar is admirably suited for plastering of the internal wall faces and ceilings. The interiors of rooms finished with lime mortar, are maintained at a balanced tempereture and could be given the desired finish.

Cement Mortar.

Art. 204. Method of Preparing — There are three distinct steps in the making of cement mortar. They are the following :—

First step — The materials, viz., sand and cement are measured in a dry state and spread to a uniform thickness on a non-porous platform, - cement being spread over sand. As usual, sand is measured in cubic feet with the aid of measuring boxes, but cement is measured by weight, - 93 lbs. being taken as equivalent to 1 cu. ft. The ingredients are turned over and a dry mix is thus made.

Second step — The quantity of water to be added for any particular batch is calculated and only half that quantity is sprinkled on the above dry mix. The mixture is again turned over twice or thrice to prepare a semi-wet mix.

Third step — The remaining quantity of water is now added to the semi-wet mix as prepared in the second stage and again the whole mixture is turned over twice or thrice to form cement mortor of the required consistency. Only so much materials should be mixed in each batch as could be conveniently used before the intial setting of cement commences.

Art. 205. Use of Mortar — Under cementing materials the uses of mortar have been already enumerated. The most important use of mortar is to bind together the various units like, stones bricks and paving sets, etc. to form the masonry. Mortar along with coarse aggregate forms concrete. Its use in plaster and pointing is also equally important. In fact, the use of mortar is unlimited in engineering works where jointing and finishing of the types mentioned above has to be done.

To keep the work wet — All work done in lime and cement mortar should be kept wet for about 15 to 21 days for the purpose of curing. During this period, as explained, important chemical reactions take place and the whole mass gains strength by becoming hard. Until the work sets and becomes hard it is termed as green work and should be protected from drying by occasional sprinkling with water.

Mortar should be of a semi-stiff consistency for masonry work; but for plaster and pointing it should be of stiff consistency so as to adhere to the wall face when dashed against it. It should also admit of working on the face by means of a trowel and a float. Very thin, lean or liquid mortars are termed as *grouts* and are specially prepared to fill in the cracks or narrow joints. The process is known as "grouting", Sometimes pressure is used during grouting for deeper and satisfactory penetration of the grout.

Gypsum Plaster.

Art. 206. Composition and Principle —

(i) *Effect of Heat on Gypsum* — Gypsum cement belongs to a different class from those described hitherto, which were silicate cements. Gypsum from which they are derived could be represented by $CaSO_4.2H_2O$, but the water of crystallisation is not firmly held by the mineral so that when it is powdered and heated, it loses a part of it. The water which is lost could be regained under favourable damp or moist conditions. At very high temperatures, gypsum loses all of its water of crystallisation and is turned into an " anhydrite ".

Thus there are two distinct stages in the dehydration or elimination of the two molecules of water from gypsum, namely :—

(a) Half hydrate or $CaSO_4.\frac{1}{2}H_2O$ or $2CaSO_4H_2O$. when $\frac{3}{4}$ - water is driven off at about 250° to 800° F.

(b) Anhydrate or $CaSO_4$.
when all the water is driven off at about 400° to 450° F.

Art. 207. (ii) Setting of Gypsum Plaster — *Effect of moisture*—The setting or the hardening property of gypsum plaster depends on its combination with water, to recristallise. Enough water is added for the anhydrate to become a paste to work with and this water supplies the water of crystallisation for its hardening. Thus we have,

$$2\,CaSO_4.H_2O + 3H_2O \underset{\text{Heat}}{\overset{\text{Hydration}}{\rightleftarrows}} 2\,CaSO_4.2H_2O$$

and $$CaSO_4 + 2H_2O \qquad CaSO_4.2HO_2.$$

Thus it would be seen that gypsum plasters owe their hardening property to their hydration with water. More water should not be added to gypsum plaster than what is just necessary to work with.

Gypsum plaster is also used in a liquid form which could be poured into moulds to the desired archtectural contours.

Art. 208. Manufacture of Gypsum plaster – Natural gypsum rock is first crushed and ground to a very fine powder. It is then heated in large retorts under constant stirring conditions to a temperature of about 250° to 300° F. At this stage half hydrate or $2CaSO_4.H_2O$ is formed. This is known as plaster of paris, or gypsum plaster.

For making Gypsum wall boards and tiles, the above material is further heated to about 450° F. to form a complete anhydrite or $CaSO_4$.

To control the setting of gypsum plasters, a *Retarder* has to be generally added. The plaster thereby remains in a plastic condition to work with for about 45 minutes to one hour. Liquid gum or glue in a very thin and dilute form is added as retarder to slow down the period of initial setting. Sometimes small quantities of fibrous materials like hair, wood shavings, jute and coir cuttings are also added to increase adhesion of gypsum plasters.

Gypsum plaster material is available in a ready form with the necessary sand added to it, usually in the ratio of 1; 3 or 1; 4.

Art. 209. Gypsum Products — These are commonly gypsum plaster boards and gypsum tiles. This form affords a good base for light weight and fibrous plasters, as already described, while the latter are used for making light partitions. These products are sufficiently soft and could be sawed to any size from the standard panels.

Art. 210. Varieties of Gypsum Plaster — (i) Keene's Cement is a more dense plaster than ordinary gypsum plaster formed with the addition of alum to anhydrate gypsum, or plaster of Paris.

Other materials added to plaster of Paris are, borax, and barium, sulphates of sodium and potassium, to yield cheaper varieties of cements with better controlled setting periods. They also help to increase the density of plaster of Paris.

Art. 211. (ii) Sorel Cement — Though the presence of magnesium oxide MgO is harmful inlimes and cements, it can be used independently to prepare a cementing material in combination with magnesium chloride, $MgCl_2$. This material is termed as *" Magnesium Oxychloride Cement " or " Soral Cement "*. $MgO.MgCl_2.7H_2O$.

Megnesium Carbonate, $Mg\,CO_3$, is calcined thoroughly and ground to a very fine powdar, which is pure MgO. To this is added the solution of magnesium chloride, $MgCl_2$ to bring about the expected reaction as follows :—

$$3\,MgO + MgCl_2 + 7H_2O = 3MgO.MgCl_2.7H_2O.$$

Mgnesium oxychloride cement is used with sand, saw dus or some type of fibrous material to prepare plaster boards andt tiles for interior decorations. They do not weather well for external use. They are rather expensive which limit their common use.

Characteristic of Concrete.

Art. 212. Concrete and Its Manufacture - *Advantages of Concrete Construction* — Concrete is perhaps the most important material used in the constructional field. It is considered generally as an artificial stone or as a substitute for natural stone. The main advantages with concrete are that, it is free from the defects and flaws with which natural stones are associated, it could be cast to any desired shape and could be manufactured to the required strength, economically. The cost of maintenance in the case of concrete structures is almost negligible. Concrete does not deteriorate appreciably with age.

Though concrete is very often described as a mixture of inert and active components, it may be considered as a chemically combined mass where the inert matter acts as a filler and the cement paste or the paste of binding material acts chemically as a binder.

Art. 213. Stages in Making of Concrete —

(i) *Design* of a concrete mix for strength and durability.

(ii) *Selection* of materials and proportioning for making the desired concrete with the requisite properties.

(iii) *Mixing* the ingredients of concrete, transporting and placing the same in the previously prepared position or formwork.

(iv) The *curing* of concrete to bring about the necessary chemical reactions in the paste of the binding material.

Every stage mentioned above has an influence on the properties of concrete.

Art. 214. Constituent materials of concrete — The following materials go to form concrete :— (i) *Inert matter, Aggregate*.

Coarse Aggregate — Gravel, broken stone, broken bricks, usually of the size of 3/16 to 1/4 inch and above upto 1½ to 2 inches are commonly used as aggregates. It has almost the same functions to perform as those of sand in mortar, detailed in article 197.

Fine Aggregate — Sand is commonly used as fine aggregate and should possess all the properties as mentioned under mortar.

The aggregate forms the main bulk of concrete, around the surfaces of which the binding material adheres in the form of a film. The crushing strength and watertightness of concrete and its resistance to wear and tear depend upon the aggregate. In addition, aggregate balances the shrinkage and volume changes of concrete.

Art. 215. (ii) Active Matter — *Binding material and water* — *Cement, Lime,* surkhi or some type of bituminous material. The last one is discussed separately as it forms a different class of cementing material. The binding material as the name implies, binds the individual units of aggregate into a solid mass, by virtue of its inherent properties of setting or hardening in combination with water.

Art. 216. Functions of Water — Water serves three purposes in concrete making :—

(a) To wet the surface of aggregate to develop adhesion, since the cement paste adheres quickly and satisfactorily to the wet surface of an aggregate than to a dry surface.

(b) To prepare a plastic mixture of the various ingredients and to impart workability to concrete which is necessary to facilitate its placing or pouring in the required position and for consolidation as well.

(c) Water is also required for the hydration of the cementing material to set and harden during the curing period.

Enough water should be available for this chemical reaction to take place to form interlocking crystals. Some more water should be added to allow for evaporation losses depending upon the climatic conditions. The exact quantity of water required for a given volume of concrete is worked out as explained later.

Art. 217. Properties of Concrete —The serviceability of concrete for various purposes is mainly due to its special properties as a material of construction. These properties like all other manufactured materials, have to be tested.

(i) *Strength* — Concrete should be strong under loads, as an essential requirement of any structural member. But with the type of concrete generally made and used, the actual loads on it are rather low in several instances than the designed strength could take.

Crushing Strength — This is an important property of concrete for which it is fundamentally designed. 6″ cubes are made of concrete and tested for the crushing test under a testing machine. The Americal practice is to make cylinders of 6″ diameter and 12″ height. The crushing strength is expressed in lbs. per sq. in. at 28 days after the cube is made. The cube tests give a much greater values of crushing strength usually about 25 to 30 percent more, than those given by cylinders.

Adhesive Strength and *Shear resistance* of concrete are also tested.

Tensile strength of concrete is not taken into account in the design of reinforced concrete structure. But in the case of reservoirs it requiras to be considered to avoid the formation of cracks in wall and floor.

Art. 218. Properties of Concrete (*Contd.*) — (ii) *Durability* — Structures built of concrete should be durable. In fact durability is closely associated with watertightness and density. A dense concrete is more durable than a porous one, since in the latter, rain water and frost will have a weathering effect which reduces the life of concrete.

(iii) *Resistance to Wear and Tear* — Concrete should have a sufficient resistance to wear and tear, by abrasion, specially when used for road work and in floors of wear-houses godowns, transit sheds and platforms, etc.

(iv) *Adaptability to Architectural features* and mouldings. This property of concrete is important from its usefulness of being moulded into various shapes and curves, and is very useful in the making of cast stone products.

Art. 219. Properties of Concrete (*Contd.*) — (v) *Workability* — Concrete when freshly made should admit of easing handling and easy placing in the formwork. It should be capable of being consolidated by vibrations or any convenient method. It should not be too dry nor too wet; it should not be harsh also at the same time, since these are the characteristics of producing porous and weak concrete.

(vi) *Economy and Cost* — The design of concrete mix, selection of materials, workmanship etc. should be so made that the above qualities are properly attained by concrete with a minimum expenditure. Generally it is economical to use concrete on many occasions when a comparison is made with other materials of construction.

Art. 220. Effect of Age on Strength — Concrete gains strength with time. Being a plastic material, while freshly made, it requires some type of formwork for supporting and holding it for some time until it gains strength. It is important that concrete should become hard, self supporting and strong within a resonable period to enable the formwork to be removed for reuse elsewhere. The economy of concrete construction lies in the reuse of formwork. Ordinary cement concrete gains about 70 percent of its final strength within 28 days and about 90 percent in the course of one year. To examine the gain in strength with age, test cubes are made and tested.

Art. 221. Rate of Gain in Strength — It is equally important that the gain in strength of concrete with age, should not be abrupt. The cubes are tested at intervals of 7 days, i. e. on the 7th, 14 th, 21 st, and 28th days after they are made and the progressive gain in strength during these days is studied. But the important tests are 7–day and 28–day tests and their relation is expressed as follows :—

$$S_{28} = S_7 + 30\, S_7$$

i. e. if a concrete cube when tested on the 7 th day shows a strength of 1450 lbs. per sq. in. then the expected strength of that batch of concrete after 28 days, is

$$S_{28} = 1450 + 30; \quad 1450 = 2600 \text{ lbs. per sq. in.}$$

The gaining in strength of concrete with time depends upon the type of ecment used; i. e. rapid hardening cement gains as much strength in 7 days as the normal setting cement gains in 28 days. The same strength is gained in one day only by high alumina cement concrete. But the final strength attained by these concretes are almost the same. See fig. 47. The required number of test cubes are made and are properly cured. At least four to six cubes should be used for the tests at each stage.

Art. 222. Factors Affecting Properties of Concrete — The strength, durability and other properties of concrete mentioned hitherto, depend on various factors, such as :—

(i) Grading and moisture contents of coarse and fine aggregate. Maximum size of aggregate. Presence of foreign matter in the aggregate.

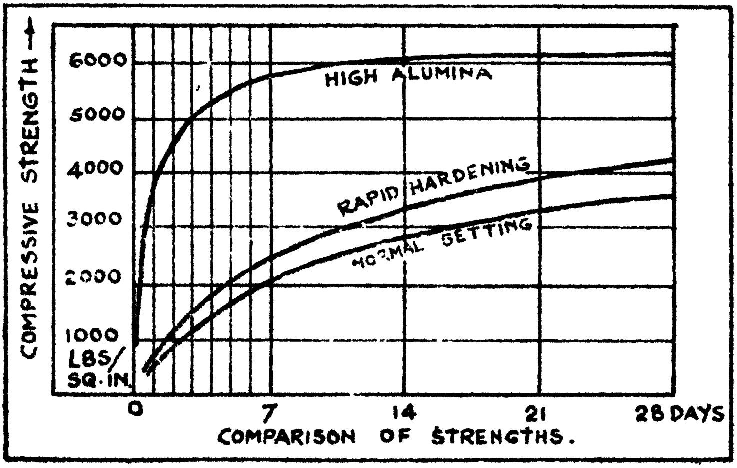


Fig. 47. Strength of different types of cement concrete

(ii) Water Cement ratio.

(iii) Proportioning of the various ingredients of concrete.

(iv) Methods of measuring the concrete materials, — by volume or by weight.

(v) Machine mixing or hand mixing.

(vi) Placing and consolidation of concrete and method adopted.

(vii) Methods of curing concrete.

In the following articles is given a brief description of the manner in which the above factors affect the properties of concrete.

Properties of Aggregate.

Art. 223. Grading of Aggregate — (i) *Importance of Grading* — Grading indicates the art of combining the various sizes of the particles composing the aggregate, to produce a dense and an economic mixture using minimum cement per unit volume for a given strength. The principle of grading is that the smaller particles fill up the voids, or empty spaces between the larger particles. To secure proper interlocking of the various sizes of aggregate, it is necessary that the particles should be angular and sharp with their shape approximating to cubicals.

Art. 224. Size of Aggregate and Surface area of Particles — It is clear that if a given volume contains smaller size particles, the total surface area of all these particles is more than what it would be, if the same volume contained bigger size particles. This justifies the use of a smaller size of aggregate for stronger and richer mixes as they require more cement paste.

The maximum size of aggregate is indicated by the number of the sieve through which about 90 percent of it passes. This permits about 10% by weight of the oversized particles. Thus, if the size of fine aggregate is 3/16", then not more than 10% of the particles by weight are permitted to remain on that sieve number. The common sizes used for concrete work are given in table no. 14.

Table No. 14. *Aggregate sizes for different work.*

S. No.	Type of work	Size of aggregate	Nominal ratio.
(a)	For thin castings and ornamental grill work.	½ ins.	1 : 1½ : 3
(b)	For R. C. C. work in slabs beams and columns and walls in general.	¾ ins.	1 : 2 : 4
(c)	For foundation concrete, rafts and thick sections.	1 in.	1 : 3 : 6
(d)	For massine works, dams, heavy foundations, road slabs, etc.	1½ ins.	1 : 3 : 6 or 1 : 4 : 8

Art. 225. Sieve Analysis — Test for grading of aggregate is carried out with the aid of sieve analysis. The set of standard sieves used for the purpose is given in art. 198. The series of sieves contains a set of 9 selected sieves from 1½-in. to No. 100. The aggregates are sieved and the percentages retained on each is recorded, by weight. The fineness modulus of the coarse aggregate, F_c and that of the fine aggregate F_f are determined. In the accompanying table, values of F_c and F_f are given as obtained in a particular case.

Table No. 15. *Fineness Modulus of Coarse and Fine Aggregates.*

Weight of Sample 1250 *gms.*

B. S. Sieve series.	Fine aggregate; amount retained.		Coarse Aggregate; amount retained.	
	Wt.	%	Wt.	%
100	1250	100	1250	100
52	1120	90	1250	100
25	650	52	1250	100
14	360	29	1250	100
7	199	15	1250	100
3/16"	50	4	1140	91
3/8"	..	..	720	58
3/4"	..	..	180	13
$1\frac{1}{2}''$	..	..	..	..
Total of percentages		290		668

The fineness modulus of fine aggregatt. Ff = 2.90.

The fineness modulus of coarse aggregate, Fc = 6.63.

The results are plotted in fig. 48. to study the uniformity of grading.

Art. 226. Combined Aggregate — The fineness modulus and volume of the total or combined aggregate should then be determined.

Fineness Modulus — When the fine aggregate and coarse aggregate are mixed, we obtain combined or total aggregate which will have its own fineness modulus. Alternatively, it is possible to work out the proportion in which the fine and coarse aggregates of known fineness modulus, F_f and F_c, should be mixed in order to obtain a combined aggregate of the required fineness modulus F. Thus, if x is the ratio of fine aggregate to be mixed with 1 of coarse aggregate, we have,

$$x = \frac{F_c - F}{F - F_f} \quad \cdots \quad \cdots \quad (1)$$

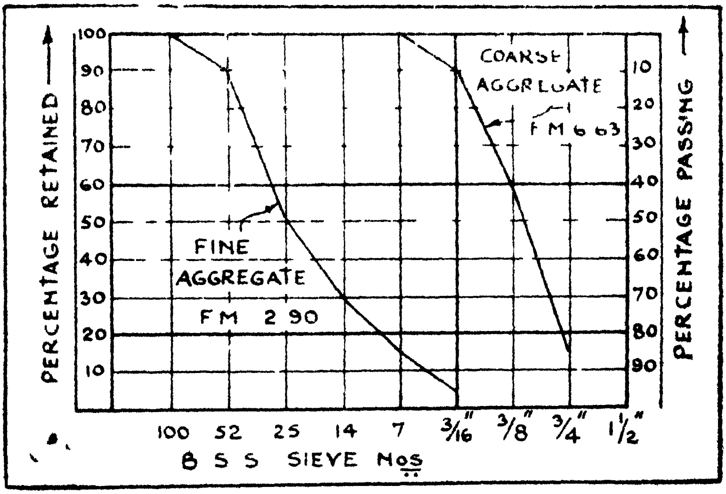


Fig 48 Sieve analysis of fine and course aggregates

In the above example where F_c = 6.68 and F_f = 2.90, if it is required to obtain a fineness modulus F = 5.25, the above ratio x is given by :—

$$x = \frac{6.68 - 5.25}{5.25 - 2.90} = 0.59 \text{ ; expressing as percentage,}$$

$$x = 59 \text{ percent.}$$

i. e. the ratio of fine aggregate to coarse aggregate is 59 : 100

The above relation can also be written as,

$$x_1 = \frac{F_c - F}{F_c - F_f} \quad \ldots \quad (2)$$

which gives the ratio of the fine aggregate in the combined aggregate.

Art. 227. Type Grading Curves for Combined Aggregate—Type curves of aggregate grading for 3/4″ and 1½″ sizes to obtain good results are given in the graphs of fig. 49

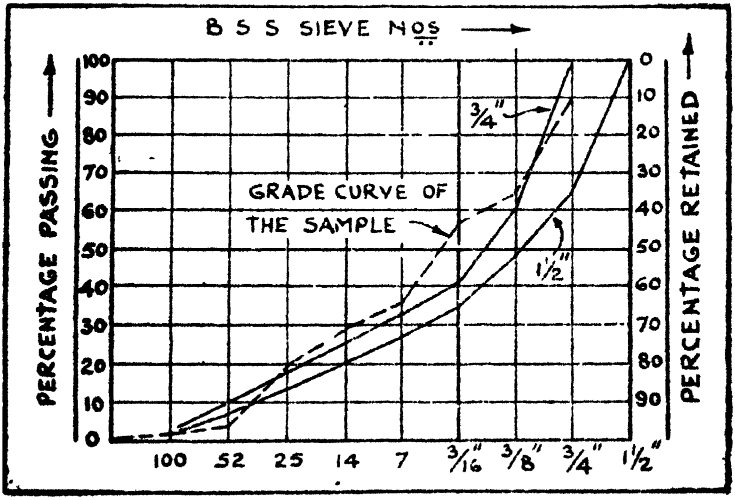


Fig. 49. Grading curves of combined aggregates.

for making concrete for general use. If it is desired to have a more workable mixture, about 10 to 15 percent more of the medium sizes particles should be used. The dotted line in the figure indicates the grading curve of combined aggregate in the above example where fine and coarse aggregates are mixed in the ratio of 59 : 100.

Art. 228. Volume of Combined Aggregate — When fine and coarse aggregates are added, the volume of the combined aggregate is not equal to the sum of their volumes. There is always a shrinkage in volume so that, if c is the shrinkage factor, then,

volume of combined aggregate

$$C = \text{Volume of fine aggregate.} + \text{Volume of coarse aggregate.}$$

$$C = V_f + V_c$$

The value of C has to be determined for the types of aggregates to be used for the required proportion of V_f and V_c, by actual observation. In the above case, V_f and V_c are taken in the ratio of 59 to 100 and filled to compactness in a container. The volumes before and after are measured and their ratio gives the shrinkage factor. If the shrinkage factor is 0.82 in this case, and if 5.5 cu. ft. of combined and well packed aggregate are required, the quantities of V_c and V_f could be calculated as follows:—

$$V_f + V_c = \frac{5.50}{0.82} = 6.75 \quad \text{cu. ft.}$$

Since, $V_f : V_c$ as $59 : 100$

We have, $V_f = \frac{59}{159} \times 6.75 = 2.5$ cu. ft.

and $V_c = \frac{100}{159} \times 6.75 = 4.25$ cu. ft.

This indicates that by mixing 2.5 cu. ft. of fine aggregate and 4.25 cu. ft. of coarse aggregate, we obtain a combined volume of 5.5 cu. ft. and not 6.75 cu. ft. after consolidation.

Moisture and Aggregate.

Art. 229. Effect of Moisture on Aggregate — The bulking effect of small percentages of moisture in fine aggregate or sand is already explained in Art. 198. An experiment on typical samples of sand and broken stone aggregate indicated the following results on their volumes, with varying percentages of moisture. See table No. 16 and the graphs in fig. 50. The bulking is less as the size of aggregate increase.

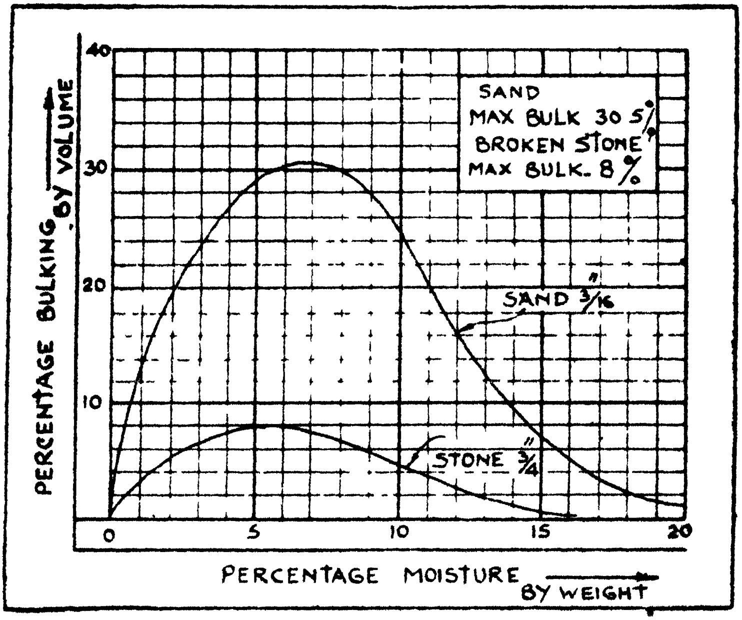


Fig. 50. Bulking effect of moisture on aggregate.

Table No. 16. *Bulking of Fine and Coarse Aggregate.*

Percentage of moisture	Percentage bulk of aggregate Fine	Percentage bulk of aggregate Coarse	Percentage of moisture	Percentage bulk of aggregate Fine	Percentage bulk of aggregate Coarse
1	13.5	3.5	7	30.5	7.5
2	19.6	5.6	8	29.5	7.0
3	23.5	6.2	9	28.0	6.0
4	27.0	7.5	10	26.5	4.8
5	29.0	8.0	12	16.0	2.8
6	30.0	8,0	15	7.0	0.8

Effect of Bulking on Volume -- It will be seen from the above table that the bulking in fine aggregate with 6.5 moisture, is 31.0 percent, so that if one cubic foot of dry material is required, we should take $1 + 0.31 = 1{\cdot}31$ cu. ft. of wet aggregate. Otherwise the concrete will be under sanded and the quantity of cement used is proportionately more The latter effect is less in the case of coarse aggregate which is wet.

Concrete mixes are designed on the assumption that the aggregates are dry. The ratios given are *Real Mix Ratios*. But in the field, generally they are wet, particularly when they are washed. Therefore, their moisture contents should be ascertained and due allowance should be made in their volumetric measurements, as explained later. Then the ratios are termed as *Field Mix Ratios*.

Art. 230. Water-Cement Ratio — *Effect on the Properties of Concrete* — We have seen that water in concrete does three functions.

(a) To wet the aggregate.

(b) To impart workability.

(c) To combine chemically with cement.

Enough water should be added to the concrete mixture to meet the above three demands, so that the homogeneous and plastic qualities are developed in it to impart necessary workability. As water acts like a lubricant, a deficiencing of it does not permit proper consolidation. Similarly a deficiency of water results in incomplete chemical reactions with cement. These two have a weakening effect on concrete.

On the other hand, if more water is added, it becomes difficult to maintain the homogeneous quality of concrete and an effect known as " segregation " or the separation of coarse and fine aggregate and cement takes place. Subsequently, the extra water will evaporate and a honeycomb concrete is formed. This has therefore, a bad effect on strength and durability.

From the above considerations, it is clear that only a requisite quantity of water should be added to each batch. The ratio of water to cement is termed as water-cement ratio. Generally this is expressed as the ratio of the weights of the two materials. If 5½ gallons of water are used for one bag of cement, then water cement ratio by weight is 0. 49. Sometimes the water cement ratio is expressed by volume. With some concrete designers, it is a practice to take cement-water ratio in their specifications and design computations.

Art. 231. Water-Cement Ratio and Strength— In fig. 51. .the relations between water cement ratio and strength at 7 days, 14 days, 28 days and one year are given.

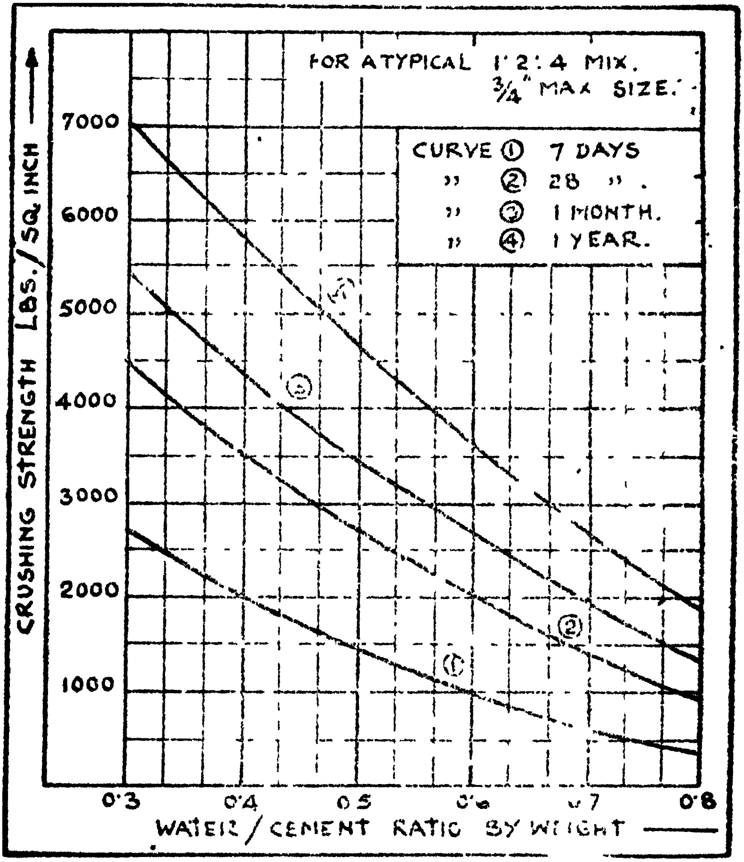


Fig 51. Water-cement ratio and gain in strength with age.

[*Note* — (i) Modified values of water-cement ratio by volume could also be derived from the values given in the above graphs and the relation could be studied on that basis.

(ii) The graphs for the cement-water ratios will be straight lines. They also could be drawn from the above graphs and studied.]

It is assumed that well compacted concrete is prepared. The crushing strength is expressed in terms of lbs. per sq. in. and the size of the test cubes is 6″ × 6″ × 6″.

Art. 232. Consistency of Concrete—Slump Test—To indicate the desired workability of concrete as required under different conditions of casting, it is a practice to express slump for concrete mixes. As the concreting is in progress, samples from ready mixed heaps are taken and tested for slump to examine that a uniformity of consistency is maintained throughout.

Slump depends upon the water cement ratio so that in a specification for concrete, either the slump or water cement ratio should be specified. Slump is tested with the aid of a slump cone shown in fig. 52. It is essentially a frustrum of a cone with top and bottom diameter of 4 ins. and 8 ins. respectively. The height of slump cone is 12 ins. It is provided with two handles for lifting after being filled with concrete,

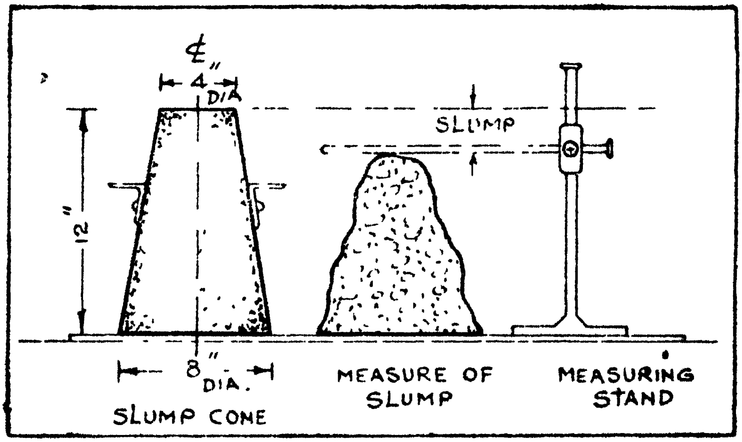


Fig. 52. Measurement of slump.

It rests on a steel plate and to facilitate packing of concrete a steel rod 5/8 in. diameter is used. When the mould is lifted, the concrete will slump or subside, and the depth of subsidence is a measure of slump.

A slump test also indicates the following :—

(i) Provided the grading of the aggregate and proportioning are correctly made, the slump is proportional to the water-cement ratio. But the amount of water to be added actually to the concrete depends upon the moisture content of the aggregate, particularly that of sand.

(ii) For a constant water-cement ratio and with a fairly uniform moisture content in the aggregate, any variation in slump indicates the corresponding change in the grading of the aggregate.

Slump Values — The values of slumps for different types of works are given below :—

Values of Slump for different concrete mixes.

Serial No.	Description of concrete	Slump values
(i)	For precast and vibrated concrete work in piles, and moulded work	1 in.
(ii)	For roads, slabs, foundation concrete	2 ins.
(iii)	For normal reinforced concrete work, in columns walls, etc.	3 ins.
(iv)	– do – with vibrations	1 to 2 ins.
(v)	– do – without vibrations, but in intricate positions.	4 ins.

The methods of disigning and making concrete are given in chapter X.

Batching of Materials.

Art. 233. Measurement of Concrete Materials — Concrete is prepared by mixing the various ingredients in batches or in small quantities of say about 4 to 12 cu. ft. each time in a serial order. Batching of concrete materials consists in measuring them individually in the designed proportions for purpose of mixing them to ensure that specified quantities of each are included in each batch.

(i) *Aggregate* — It is a very convenient practice to measure aggregate by volume with the aid of boxes of known capacity. For the moisture present in the aggregate, due allowance should be made in volume and in the quantity of water to be added as well. A better and a more reliable way of measuring the aggregate is by weights. But this requires the use of machinery for handling the materials and is more suitable for large works. Very often the weighing is arranged to work automatically.

(ii) *Cement*—Cement is measured by weight by taking 98 lbs. per cu. ft. and the backing is done on the basis of number of bags to be put in each batch of cement. This avoids the reweighing and rehandling of cement. Volume batching of cement does not give satisfactory results and there is every chance of getting less cement in each batch.

(iii) *Water* — Water is measured and put by gallons. It is kept in small tanks at a slightly higher level than the mixing platform and each time, the specific quantity is made to discharge from the tank.

Measurement by weight — Though measurement of the aggregates by volume is by far the most common method of batching concrete mixes on various jobs, it becomes very difficult to say that under different field conditions, the specified absolute volume of these materials are included in the finished concrete. A more reliable method is masurement by weight. To measure the aggregates by weight appears to be a tedious job at the outset; but with the aid of different types of machines which are now being put on the market, this work will be very much simplified. Portable types of batchers are very convenient to use. As such equipments are rather costly, unless the work is of a greater magnitide, it becomes difficult to install them.

Thus the measuring equipment should be so selected that the extent of the work should be always kept in view. If the aggregates are measured by weight, no allowance need be made for bulking. The only allowance to be made is for the weight of the moisture content; but even if this is not made, the discrepancy in the quantities is much less.

Other devices like " Innundation " method based on the principle that the saturated aggregate has a constant volume, and " submerged weighing " are also recommended for use. Cement and Water are measured as detailed in the previous article.

Art. 234. Elasticity and Plasticity of Concrete — *Creep* — In the case of elastic materials, under the effect of a load, there is deformation which is proportional to the load upto a limit known as elastic limit. If the material is loaded beyond the elastic limit, the deformation is more than the proportionate load, and ultimately there is a failure in the material.

But under the effect of a constant sustained load, the deformation is more than what it would be under temporary load. It will be the sum of elastic deformation, and plastic flow or creep. The former disappears when the load is removed while the latter continues for some time and causes a permanent deformation. Thus the plastic flow or creep is a factor of time and is also influenced by the temperature.

Concrete behaves more as a plastic material as against metals which are more as elastic materials. This is indicated by the stress-strains curve which is a straight line for a perfectly elastic material and is slightly a parabolic curve for plastic materials. Creep is an important property and helps the members to accommodate themselves under high loads lasting for a shorter period that may cause failure in perfectly elastic materials. Creep prevents the formation of cracks in the material.

CHAPTER VIII

Wood - Growth and Seasoning

Introductory.

Advantage of timber construction.

Timber Trees.

Forest grown and garden trees. Exogenous and endogenous trees. Hardwood and softwood.

Tree and its Structure.

Growth of tree. Annual rings. Spring and summer wood. Sapwood and heart wood.

Felling of Trees.

Age of tree; season in a year. Methods of felling. Conversion of filled logs.

Water Soaking.

Purposes. Storage of logs.

Sawing of Timber.

Shrinkage and distortion. Wastage. Methods of sawing. Tangential or plain; quarter sawing; radial or rift; ordinary. Combination sawing.

Drying and Seasoning of Wood.

Moisture in wood. Equibrium moisture content. Objects of seasoning.

Methods of seasoning. Air drying or natural seasoning. Log piling. Piling of sawn sections. Drying sheds.

Artificial or Kiln Seasoning.

Advantages over natural drying. Types of kilns. Compartment kiln and progressive kiln. Process of seasoning.

Water seasoning. Chemical seasoning. Electric seasoning. Two stage seasoning.

Measurement and weight of timber.

Timber Construction.

Art. 234. Introductory — Wood has been one of the most used material and probably the first material to be employed, in the construction field. Apart from its fuel value, its use is almost indispensible in the building up of structures,

(i) Temporarily during their construction; and

(ii) As a permanent component part of the completed ones.

In order to understand the individual characteristics exhibited by different kinds of wood, with regard to their durability and methods of preservation, strength, and the uses to which each variety could be put with advantage, it is necessary to study about the wood material and its structure. Such a knowledge helps to understand the various processes adopted for a study about its employment in the manufacture of modern materials like reconstructed wood and other utility products.

Art. 235. Advantages of Timber construction — Timber has several distinctive advantages over other materials of construction. The following are some of them :—

(1) It is stronger than other materials commonly used when considered in proportion to weight.

(2) It can be easily worked with tools to any size.

(3) Structural connections are easily made in timber work.

(4) In structures it admits itself of being employed universally for both load bearing and non-load bearing members with equal ease,

(5) Its use for preparing furniture and such other decorative and attractive interior fittings of artistic design, is accepted without doubt.

(6) The economy of timber construction in general can be recognised from the fact that even a smallest piece can be utilised in one way or the other, thereby minimising the wastage.

(7) It is a common observation that heavy timber construction is less liable to be damaged by fire than steel.

(8) The houses built of timber are warm in winter and cool in summer, due to non-conductive property of wood. Wood is also used where a sound proof construction is desirable.

(9) The durability of wood is unquestionable, if protected from direct exposure to atmospheric variations, and to alternate wet and dry conditions.

(10) A rare combination of lightness, strength and durability, commonly aimed at in the manufacture of modern materials of construction, can be seen in reconstructed wood of different types.

(11) The value of timber can be easily recovered owing to its resale value when not required.

Wood Material.

Art. 236. Timber Trees in General — It is obvious that wood once formed an integral part of a living tree, and the formation of wood material is a natural conseqence of the growth of a tree. Air, light, food and space are the essential requirements on which the growth of a tree depends. It may be noted that timber is obtained from the trunk of a tree and a tree with a long, straight and bulky trunk is the most useful one. Therefore the timber trees should have a long and a bulky trunk, and very few branches.

Forest Grown and Garden Trees — From the above considerations it is clear that the trees which yield timber are those grown in a forest, since :—

(i) they have to necessarily grow straight for want of side space; and

(ii) They have to grow tall in search of light and air.

The branches formed in the earlier stages of life wither away. As pointed out above such straight and long trunks are essential for yielding a maximum bulk of timber from a tree. On the other hand, the trees grown in a park or garden have ample side space for their branches to spread laterally, which is unfavourable for a tall and straight growth. The trees therefore grow with a number of branches from their early ages, and these branches persist during the life time of a tree.

Art. 237. Exogenous and Endogenous Trees — According to the manner of their growth, trees may be divided into two main classes, viz., (i) exogenous trees; and (ii) endogenous trees. Exogenous trees increase in bulk by the formation of successive annular rings on the outside under the bark. The timber that is used for building belongs to this variety and is described in this and the following chapter.

Endogenous Trees — On the other hand, the class of trees belonging to the endogenous variety grow inward by depositing each fresh layer internally instead of on the exterior, thus the older formations of wood material are on the outside. The vertical growth of an endogenous tree is in the fashion of links placed end to end, with a knot connecting two adjacent links. Endogenous trees are found generally in tropical countries and the most common varieties are, bamboo, coconut and palm. They have their own limited applications for temporary construction.

Art. 238. Hard Wood and Soft Wood — Trees are also classified into two main groups for commercial purposes–viz., broad-leaved, and needle leaved or conifers. Characteristically, broad leaved trees yield hard woods and the conifers yield soft wood. Generally hardwoods are dense and have narrow and well-defined annual rings. They are heavy, strong and hard. Softwoods are comparatively less dense, lighter in colour and more elestic. They are not very strong but are soft with straight grains and more uniformity of structure than hard woods. The classification of wood into hard and soft varieties is mearly a commercial one and very often it is found that in tropical regions this is not always true.

Art. 239. The Tree — Its Structure — Wood is built of individual units called cells which are tube-like bodies resembling bundles of fibres. The cells are brickshaped and have blunt or pointed ends. They differ considerably in size, varying from 0.001 to 0.02 inch in diameter and ¼ to ½ inch in length. The cells are formed of organic tissues with a cavity and a *Nucleus* in it. The nucleus forms the living part of a cell and constitutes what is termed as *Protoplasm*.

Functions of Wood Cells — The wood cells have four primary functions to perform :—

Starting from *the root system*, the mineral salts from the soil are taken in dilute solution in subsoil water. They anchor tree in the ground to hold it firmly. The vertical fibres mentioned in the previous article extend from the ends of tips of the branches through the trunk, and provide a continuous channel. The mineral solutions from the ground flow

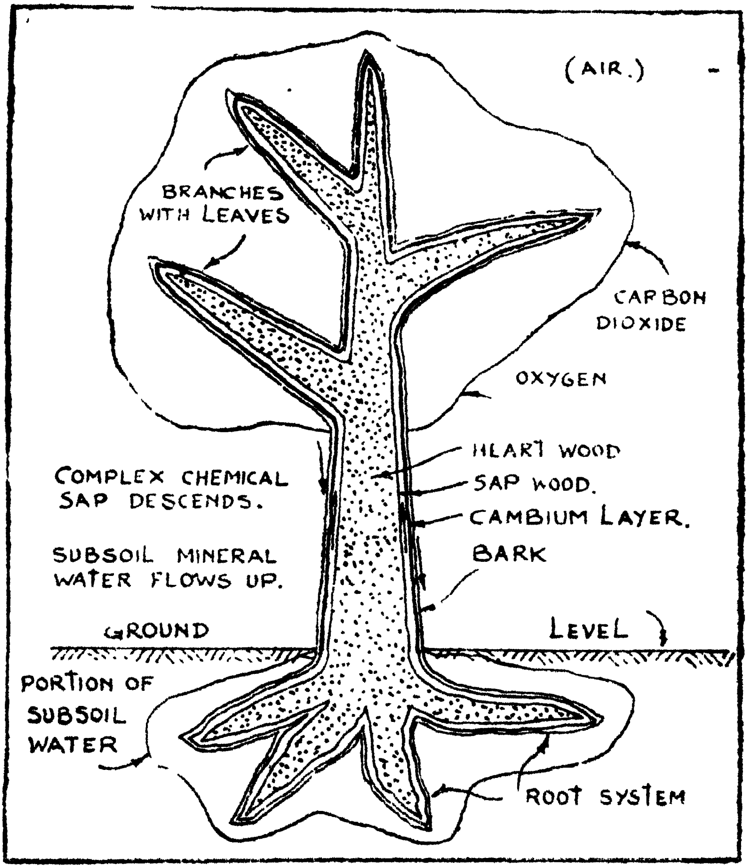


Fig. 54. Growth of a tree.

upwards through these channels and proportionately a very large quantity reaches the leaves.

✓ *The leaves* absorb carbonic acid (Co_2) from the atmosphere and with the help of solar energy in the form of sun's rays, a complex chemical compound, resembling a thick solution, is manufactured. The solution then descends to reach the growing regions under the bark. The mineral solutions flowing upwards and the complex chemical solution descending downwards are termed as *Sap*. It may be noted that sap is essential for carrying on the life process or plant metabolism.

The trunk of stem of a tree supports the branches and leaves and imparts rigidity and strength to the tree structure as a whole. In addition, it also does the function of conducting and storing the food materials for the formation of wood in itself and elsewhere in the plant.

Art. 242. Annual Rings, Spring and Summer Wood—An exogenous tree grows by the formation of fresh cells under the bark, at the ends of the roots and the tips of the branches. The growing region, which is in fact a thin film of duplicating or cambium cells under the bark, is termed as the *cambium layer*. See fig. 53 The bark does the function of protecting the newly formed cells of the cambium layer. In a thin form, bark or covering is also present on the outside of the roots and the branches. The bark of some trees is very thick in the trunk and on the inside contains rich chemicals. It is clear that if the bark of a tree is stipped off, its life is terminated. In the process of growth the cambium cell swells and duplicates and the new cell formed is closer to the bark. This action is more active in the growing seasons of summer and spring and the cells are inert in the cold weather of winter. The warm weather of summer and the subsoil water of spring through the cambium cells into activity. The growth is more rapid in spring on account of abundance of subsoil food material, but due to high water contents of the sap, the wood formed is lighter in colour. On the other hand, the summer wood is formed slowly and is usually darker in colour and denser in texture than spring wood. This difference in growth draws a line of demarkation between the annual rings of two consecutive years as shown in fig. 53 and makes the cross section of tree appear like a number of concentric circular rings packed together. Annual rings are more prominently visible in places with distinct seasonal climates.

Sapwood and HeartWood

Art. 243. Wood Material, Sapwood and Heart-Wood — The cell walls of plant life are very complex in their composition. The wall of a young cell is very plastic and expands rapidly. It is essentially cellulose, being composed of carbon, hydrogen and oxygen. Certain chemical changes take place in the course of time as the cell grows old, and the chief substance then formed is lining which imparts rigidity to cell walls. From what is explained in the previous article, it will be seen that the younger and the living cells are near the bark and the sapwood, and the older and the dead cells are in the interior or the heartwood. Some of the outstanding characteristics of sapwood and heartwood are given below.

Characteristics — Sapwood is rich in plant food material such as sugar, starch and albumen, which is in a putricible form and sets up decay in wood by fermentation. It attracts wood–rooting fungus and insects which reduce the life of timber. On the other hand, the cells of heartwood have stronger cell walls and contain substances like tanin, resins, gums, latex, calcium oxilate and deposits of silica which are poisonous to fungus and insects. The presence of the above materials imparts natural immunity and durability to heartwood. This does not mean that sapwood should be discarded from use for constructional purposes. The contents of the sapwood could be greatly reduced by various seasoning treatments such as water soaking, drying, and impregnating with preservatives, accompanied by protective coatings of oils and paints. Generally heartwood is darker in colour, has more compact annual rings and is denser and more close grained in texture than sapwood. The cell walls of sapwood are more absorptive and thus admit of thorough soaking with preservatives easily.

Sapwood contains a proportionately higher percentage of moisture than heartwood and this has an effect of reducing its strength and durability.

Sapwood is lighter in colour than heartwood. In fact, this change in colour takes place gradually as sapwood changes to heartwood in a living tree. It may be noted that heartwood is heavier and less permeable to moisture than sapwood.

Proportions — The proportion of sapwood varies from 15 to 60 percent of the total contents of a log, depending on the type of tree from which the log is obtained. Since the sapwood is on the outer portions of a log, a certain thickness of sapwood will indicate a smaller percentage of that wood in a log of bigger diameter than the same thickness does in a log of smaller diameter. For example, a 1½ inch ring of sapwood represents 37 percent in a log of 15 ins. diameter, and only 10 percent in a log of 30 ins. diameter.

Felling of Timber Trees

Art. 244. Felling the Trees for Timber— (i) *Age of a Tree for Felling.* For the purpose of obtaining timber, a living tree is cut and subsequently treated to impart durability and strength to the green wood material. The cutting of a tree has to be done systematically and this process is known as felling. The fact that whether a tree is fit or otherwise, for felling, depends on its age and the season of the year. Every tree must be in a full grown condition or just matured before it is felled, so that maximum wood material is obtained from the 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. If the tree is allowed to remain after it is fully grown, the heartwood is liable to *shakes and cracks*. These are radial cracks extending from the pitch towards the sapwood, and from the general appearance of these carcks in a cross section of the trunk, the defect is termed as *star shake.* As this defect is often found in the heartwood of the trunk of a living tree, it is also known as *heart shake.* The appearance of these cracks is mainly attributed to the evaporation of the oils and such other volatile contents of the cells of heart wood and the consequent drying of the cell walls.

(ii) *Season in a Year for Felling.*

Equally important as the age of a tree, is the proper season when the tree should be felled. we have already seen that in the spring and late in 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 the growth of fingus. During winter and early parts of summer, the growth of the tree is dull and the cambium layer is inactive. The sap and the moisture contents are also less. Therefore, this part of the year is favourable. Moreover, the trees felled in winter have to face the drier summer months which though favourable for fungal growth, have much practical importance in the subsequent conversion process. It is necessary that the logs should not be exposed directly to the sun's rays and their ends should be protected by cresote or some other preservative, to prevent splitting and checking and infection from fungi.

Stripping the Bark and Cutting Branches — In the case of trees which contain a larger proportion of water, and where there are no distinct climatic variations, sometimes the branches are cut and the bark is stripped off one season earlier than the actual felling operation. The tree should be felled as near the ground as possible with the aid of axes, saws and wedges. It should be properly tied with the aid of anchor ropes and carefully brought to the ground after cutting.

Girdling — In the case of trees like teak and such other varieties having natural resistance to the attack of fungi, it is sometimes a practice to cut round the trunk of the trees to be felled, a chase of 2 to 3 inches size, at about 6 to 9 inches height above the ground. This is done 2 to 3 years earlier than the tree is actually felled, and is known as *Girdling*. By this, the moisture gradually evaporates and the shrinkage and warping of timber during seasoning is much less.

Art. 245. Conversion of Felled Logs — The bark of the tree after felling is removed and the round logs are roughly squared. For facility of transport, they are further cut into smaller sizes according to market requirements. Lumber is the general term applied to cut sections of a log manufactured by sawing. The various gradations of timber as required for general purpose, factory service and structural use, are marked on the logs to be cut and sawn.

Art. 246. Water Soaking — As the bark afforded natural protection, the felled logs, after the removal of the same are particularly liable to be attacked by fungi which set up rot and decay, The sap ferments and the wood tissue decomposes very rapidly. It is observed that for the fungal action, a certain amount of air is necessary. The logs are, therefore, stored under water in log ponds, out of contact with air. Log ponds may be either artificial or natural. Complete submergence of the logs is necessary as the portions floating above the surface of water are liable to deteriorate. To ensure this the logs are tied down to girders placed across the pond. If this is not possible, the floating logs are successively turned on their sides once in a week or so.

Apart from the effect of preservation, water soaking also dilutes the sap and also partly eleminate it in solution.

For the manufacture of *veneers*, logs of uniform dryness are essential. They should be kept in wet condition for a long period to facilitate the process of peeling and slicing. Wet storage affords ideal conditions for this purpose.

Art. 247. Storage of Logs–As only a particular part of the year is suitable for felling timber trees, and since the saw mill work, and the other conversion processes are to run for all the year round, some sort of storage of the felled logs is essential. There are two types of log storages in general; *wet storage* and *Dry storage*. The method of wet storage of logs in log ponds is already mentioned above. In a dry storage, a yard is specially prepared on a firm and well drained ground from which all vegetation is removed. The floor of the yard is covered with clinker and gravel and the logs are preferably kept about a foot or so above this floor. See fig. Sometimes water is prinkled with the aid of sprays from a system of pipes, to keep the logs in a wet condition when they are kept in a dry storage.

Sawing of Timber

Art. 248. Swing of Timber - Shrinkage and Distortion–The roughly squared logs of timber from the log ponds and drying yards are further sawn into different sizes either by manual labour or by mechanical power. Large quantity of moisture is present in logs before sawing and consequently the cut sections, after sawing, lose this moisture and dry. This results in the shrinkage of timber and if this does not occur uniformly in all directions, the shape of the cut sections is distorted. It should be noted that circumferential shrinkage is greater than the radial shrinkage. The former is usually two to three time the latter. The longitudinal shrinkage along the fibers is the least. See fig. 55 for shrinkage and distortion characteristics. In addition to the distortion effect on the cut sections due to subsequent drying and release of the internal strain in the wood fibers, if any, the actual use to which the sawn section is to be put; also needs to be kept in view, while sawing.

Art. 249. Wastage During Sawing—In the conversion of timber by sawing, there is a great wastage which often approximates to well over 40 percent of the log weight. The refuse from the saw mills may be classified generally as follows:—

Saw dust	12 percent.
Side slabs and trimmings	18 percent.
Bark, loss of moisture and miscellaneous	10 percent.
Total	40 percent.

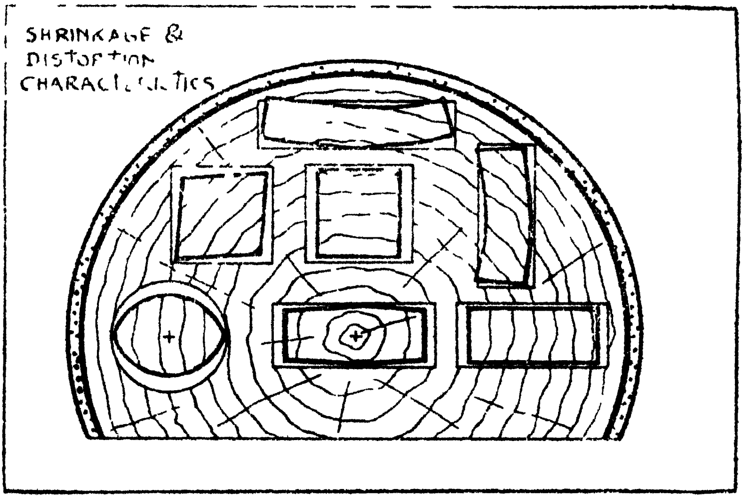


Fig. 55. Shrinkage and and distortion characteristics

Though the above refuse fetches some value as a by-product, much of it could be minimised by marking deligently on its cross section, the various sections into which the log is to be cut. Only experienced sawyers, who could exercise their best judgement, are capable of doing this job in order to get the maximum quantity of highest quality of wood.

The time required for sawing and the labour involved in handling during sawing, a given quantity of timber by one method or the other are also an important factors to be kept in view while sawing the logs, specially in sawmills by machine.

Art. 250. Methods of Sawing Timber — Principally there are four methods of sawing timber and the adoption of one or the other in any particular case depends on the factors mentioned above. These methods are,

(i) Tangential sawing.
(ii) Radial sawing.
(iii) Quarter sawing.
(iv) Combination of the above three.

These are described in the following articles.

Art. 251. (i) Tangential Sawing — The log is sawed tangent to the annual rings and at right angles to the medullary rays. This method is cheap to work and involves less wastage and minimum handling of the logs. As the radial or medullary rays, which impart binding and unity to the longitudinal fibers, are cut, the sections obtained by this method are weak and the timber does not wear well. It is also termed as plain sawing.

Plain sawn timbers warp more on drying and seasoning, usually in a cup shape manner. The strongest and the most durable timber is always obtained by radial sawing as explained later. It does not take an even polish and is easily splintered. In the following figures, the slabs or sides of logs are cut and sawn tangentially in a plain fashion. The timber obtained by this method is called '*flat grained*'. See fig. 56.

(ii) **Radial Sawing of Timber** — In radial sawing, the principle is to cut parallel to the medu llary rays and perpendicular to the annual rings. This produces timber with end grains which wears more uniformly and smoothly than the plain sawn sections. Timber sawn by this method shrinks and warps less and is generally distorted to a minimum. The annual rings make an angle between 15° and 90° to the broad surface of the board. The main disadvantage of quarter sawn timber is in its increased cost in manufacture due to more wastage and more time and labour required for sawing as the logs have to be turned several times during sawing. But, this methon gives wood more suited for high class work and fetches also more price.

Quarter Sawing is a term applied to the method of sawing timber by first cutting the logs in quadrants of circles. Generally quarter sawn timber can be:—

(a) *Simple or plain sawn,* in which the central portion is truely or correctly radial sawn and the two side portions of the quarter piece are partly radial and partly tangential cuts. See fig. 58 (B).

(b) *Radial Sawn* — This method requires the shifting of the position of a quarter piece each time, on a sawing platform to obtain radial cuts. See fig. 59 (C).

(c) *Rift Sawing* — The quarter sawn pieces mentioned above, are cut by a further modified method known as rift or the true radial sawing. See fig. 57 (A) The shrinkage in this method is the least but the manner in which the timber has to be cut involves much wastage and labour so that only the best variety of wood required for high class work such as cabinet making, special flooring, wall lining and decorative work, etc, is obtained in this way. Radial sawing costs

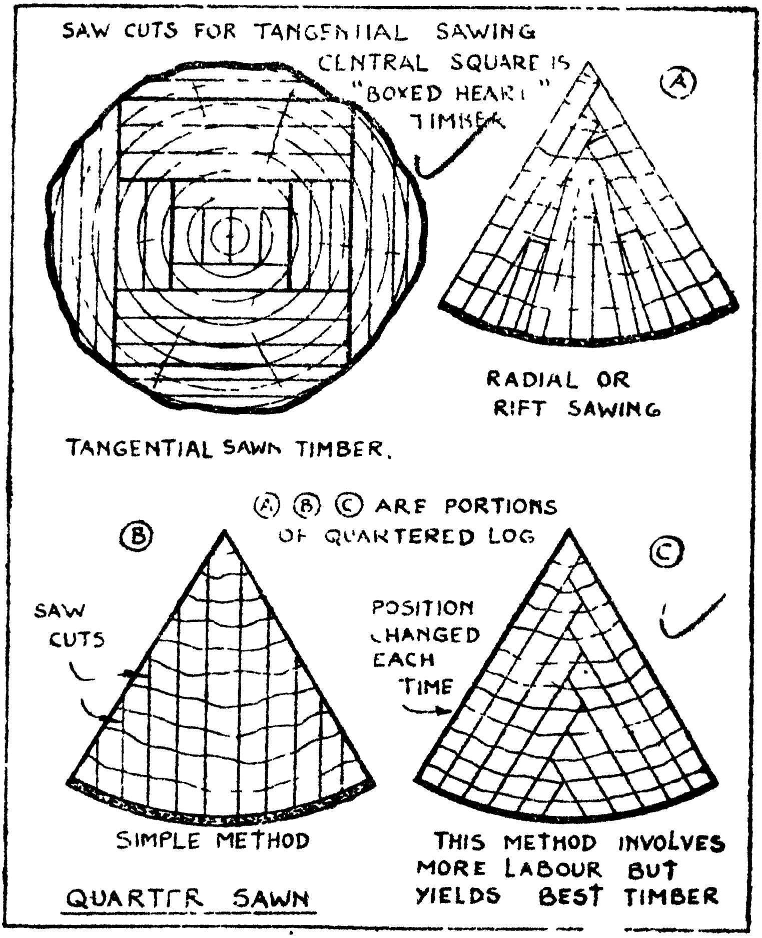


Fig 56 Saw cuts for tangential sawing of logs

Fig 57 , 58 and 59 Quarter sawing of timber.

(A) Radial or rift sawing for best results

(B) Simple quarter sawing

(C) Quarter sawn timber with radially cut planks.

almost twice as much for plain sawing. But the high price fetched by the quarter sawn timber in general, is much more than what is spent in excess during sawing.

Art. 252. (iii) Ordinary Sawing--This is a very economical method so far as the out-turn of timber and the cost of milling is concerned. The log is moved forward and backward in the same position on a sawing platform, resulting in a number of parallel slices as shown in fig. 60. But unfortunately, the cut pieces are liable to distortion by shrinkage and warping on drying. See fig. 61. Small size and unimportant logs are sawn quickly and cheaply by this method. It may be noted that the planks and scantling cut by ordinary sawing, near the centre are cut radially and contain mostly heartwood.

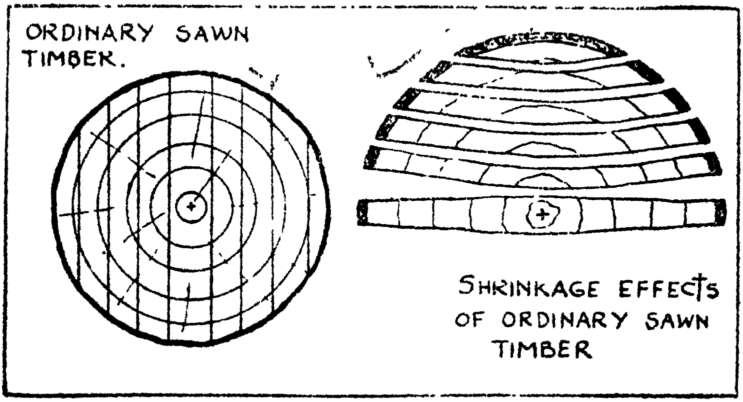


Fig 60 Ordinary sawn timber.
Fig 61 Shrinkage effects of ordinary sawn timber.

Art. 253. (iv) Combination Method — In fig. 62 and 63 are shown the method of sawing timber by a combination method. In fig. 62 the central portion is cut at right angles, by the ordinary sawing method to get the best advantage of that method, while the outer quadrats are again cut by the method of radial sawing, as shown. In fig. 63 the slabs are cut out along the lines a b c d to obtain a square cut pice form the log. Planks and scantling are again cut out from this section as shown. The outer slabs are cut out by the method of plain sawing. The central slices yield timber of maximun strength since the medullary rays are not cut.

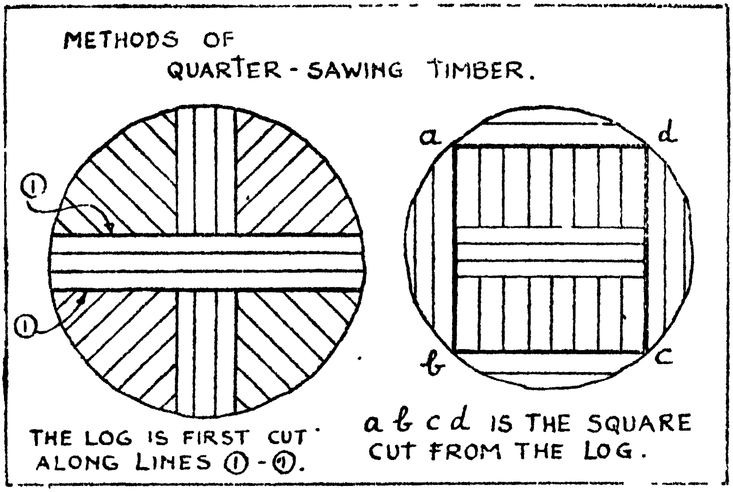


Fig 62 and 63. Combination method of sawing.

In figs. 64, 65, and 66 are shown the various methods of sawing timber for maximum strength, wear and tear and durability, respectively, on the principles explained hitherto.

Art. 254. Moisture in Wood — Living trees and freshly felled logs contain large amount of water in the form of moisture. The amount of this moisture is calculated on the weight of the oven dry or absolutely dry wood. As the strength, durability and economic properties of wood depend upon the amount of moisture present in it, is necessary to know how much water is present in the sample. Expressing the moisture content of wood as a percentage of its oven-dry weight, we have,

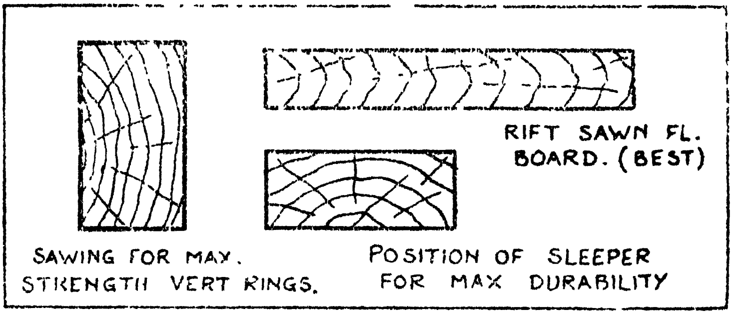


Fig. 64, 65 and 66 Sawing timber for strength, wear and tear and durability.

$$\text{Moisture Content.-Percentage.} = \frac{\text{Wt. of moisture in sample}}{\text{Oven dry wt. of sample}} \times 100$$

This is determined by weighing a sample of wood and drying the same in an oven until its weight becomes constant. If the initial weight of a sample is 62.58 grams and the weight after oven dry is 51.24 grams, then the moisture content of the sample is,

$$\frac{62.58 - 51.24}{51.24} \times 100 = 22.1 \text{ per cent.}$$

Moisture content can also be determined by the distillation method or with the aid of moisture meters.

Art. 255. Presence of Moisture—Moisture is present in wood in two forms:—

(i) The cell cavities are filled or partly filled with water.

(ii) The cell walls of which the wood is composed are saturated with water.

In the former case, water is held in the cell cavities in a similar manner as in a bottle or a cup, and has almost no effect on the properties of wood except in increasing its weight. It is termed as *free water*. It may be noted that the latter water in the cell walls, has an influence on changing the properties of wood. Usually the strength is doubled if the moisture content is requded *to* about 10 to 12 percent and tripled if reduced *to* 5 percent. The cell cavity water could be removed easily by evaporation, but it is difficult and takes a long time to remove the water absorbed by the cell walls, as it is held in capillary and molicular form.

Drying Phenomena — When legs and freshly cut surfaces of timber are exposed to air, or are kept in an open shed, the free water present in the cell cavities gradually evaporate. After all this free water evaporates and only the water absorbed by the cell walls remains, a state is reached which is known as the *fibre saturation point*. It is estimated that this state is reached when there is about 30 percent of moisture in wood. But actually, before all the free water is removed, the cell walls also start losing their water content so that the fibre saturation point is only a theoretical state.

Equilibrium Moisture Content — Depending upon the atmospheric conditions of humidity, temperature and air movements, the free water and the absorbed water of the cell walls evaporate until a state of equilibrium is reached between the moisture in the wood and that in the atmosphere. If the atmosphere is more humid or damp, the wood which is hygroscopic in nature, absorbs moisture, to lose it again when the atmosphere is dry. In a state of equilibrium, there is no interchange of moisture between wood and air. For any change in the conditions of the air, the state of equilibrium, once attained is upset and after a subsequent exchange of moisture a new one is reached.

It may now be said that, in the process of seasoning wood is dried to a moisture content which is in equilibrium with the conditions of the local atmosphere. For a further reduction in moisture, artificial methods are employed for drying.

Drying and Seasoning of Wood

Art. 256. Objects of Seasoning — All timber before use has to be air-dried or seasoned. It is possible to partially dry the sap and to reduce the moisture content from about 20 to 8 percent of its oven dry weight. The principal reasons and the objects sought for in air seasoning timber are the following :—

(i) The weight of timber is reduced and the consequent cost of transport and handling is minimised.

(ii) To bring timber to a state of equilibrium moisture content which is essential for all its subsequent conversion and manufacture.

(iii) It becomes stable as most of the movement in wood fibres takes place before this state is reached.

(iv) To make timber resistant to decay. Dry wood is more resistant to the growth of rot and fungus than green logs. This increases its durability.

(v) Green or unseasoned timber is weak and soft. Seasoning imparts strength, hardness and stiffness to timber.

(vi) Reduction of moisture to a certain degree is essential for effective preservation treatment, when adopted. Dried timber is more suited for painting and polishing.

Art. 257. Methods of Seasoning Wood — Seasoning of wood is accomplished in the following ways :—

(a) Natural or Air Drying.
(b) Artificial or Kiln Seasoning.
(c) Water Seasoning.
(d) Chemical Seasoning.
(e) Electric Seasoning.
(f) A Combination of two or more of the above.

By whichever method the green wood or lumber is seasoned, certain drying defects creep in timber if the process is not carefully carried out. In the process of drying, the moisture from the exposed surface evaporates and that in the centre of wood diffuses out to the surface to evaporate in its turn until the state of equilibrium is reached.

Art. 258. Air drying or Natural Seasoning -- By the combined effect of girdling and stripping off the bark with certain spices, a part of the moisture is driven off when the timber is in the tree form alone. Sometimes the logs of felled trees are allowed to remain in a stored condition to lose some more moisture. These stages are included in Preliminary Seasoning of timber.

Though natural seasoning is a very economical method and does not require any complicated installation, it is rather a slow process and there is a limit to the reduction of moisture contents if that is alone resorted to. It ensures uniform drying and lessens the amount of deformation in the process of drying. But on the other hand, it may be remarked that the invested capital is virtually locked up until the air seasoning takes place and the timber is sold.

Art. 259. Method of Stacking and Drying — Air Drying or natural seasoning consists in stacking the sawn timber to expose the surfaces of planks, boards and scantling of various sizes to enable them to dry. The site for piling should be level and dry with proper drainage. It is necessary that all grass and weeds should be elimitated from the site. A layer of cinder and ashes if available, or sand, should be spread on top of the prepared ground. In general, the foundations should be firm and strong. The supporting members over which the sections to be air-seasoned are piled, should be creosoted and in their turn should preferably rest on masonry or concrete pillars. The stacking platform should be at least one foot or so above the ground level.

The stacks should be so formed and located that there is a free movement and circulation of air around them. There are two methods of piling timber sections for air seasoning :–

(a) *Piling in Log Form* — All boards and planks with their edges untrimmed are stacked in this form shown in fig. 67. The timber has more space about it and therefore, dries quickly. But this method requires more space in the drying yard, since great heights of stacking could not be reached.

(b) *Piling in Rectangular Stacks* — All rectangular sawn timber are stacked in this manner, shown in fig. 68. Each layer of board is separated by three or four narrow strips to allow more surface for drying and for free circulation of air.

To facilitate this, stacks also should be oriented with respect to wind currents in the locality.

Drying Sheds — To prevent the timber from direct exposure to sun, rain and frost, seasoning sheds are provided with open sides and a covered roof. The results of air drying depend much on the conditions of the weather. The time required to season the boards and planks from the green condition of a log to an air-dry state depends on their thickness.

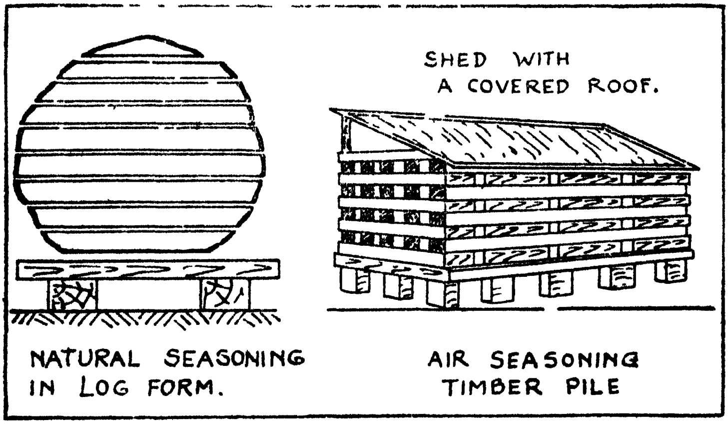


Fig 67 Piling timber logs for Air Drying.
Fig. 68. Timber drying shed for cut sections

Usually timber is dried to about 20 percent or slightly less of moisture content by this natural method in about 2 to 3 years. Soft woods and thinner sections require lesser time than hard woods and thicker sections. During the first few weeks of drying, timber is most liable to be attacked by fungi, and to warp and check as well.

Art. 260. Artificial or Kiln Seasoning — Timber can also be dried in closed chambers called kilns, under artificial conditions. By this process, the timber is not mearly dried but is also sterilized. Consequently the term " Kiln-Seasoning of Timber " is used in preference to " Kiln drying ". The following points are applicable to this process :—

(1) In the seasoning of timber with the aid of a kiln, it is possible to control and regulate the circulation of air, humidity and temperature, which are the principal factors of the atmosphere and on which the success or the failure of the process depends.

(2) The percentage of the moisture is reduced to any desired value, usually upto round about 5 to 6 percent by this artificial method. In fact, the timber could be brought even to the bone-dry state, but this is not desirable from the practical point of view.

(3) The main advantage of using a kiln lies in shortening the period of drying and to increase the outturn of timber.

(4) Owing to controlled drying conditions, the defects due to shrinkage, warping and checking are minimised.

(5) The insects and fungi are killed and the consequent losses and wastage are reduced. The kiln process almost sterilizes the timber.

(6) Hard woods require initial drying by natural process upto a moisture content of about 18 to 20 percent when they are said to be fit for kiln seasoning, whereas soft woods could be sent into a kiln almost immediately after felling.

(7) The weight of timber is further reduced with the consequent reduction in the fright charges and increase in the ease of handling.

The time required for drying depends upon the following factors :—

(i) The quality of timber that is put in and that is required; (ii) The efficiency of the kiln and its operation; (iii) The initial and final moisture contents desired.

Air-dried hardwoods of about 2 ins. thickness require 2 to 5 weeks and freshly felled ones required 4 to 12 weeks to dry them to a moisture content of 8 to 10 percent, whereas softwoods require 1 to 2 weeks under identical conditions in the above two cases respectively.

Art. 261. Types of Kilns — There are principally two types of kiln :—

(1) Compartment kilns with natural draught or formed draught; and

(2) Progressive kilns.

These are briefly described belog.

(1) *Compartment Kiln* — A compartment kiln is in general a closed airtight chamber fitted with appliances for heating and for supplying sprays of water and steam. The circulation of air through the kiln is secured either by a natural draught or by a forced draught. The walls are built with a cavity to minimise the heat losses, as shown in the figure. Air is heated by passing it over the surfaces of steam pipes, and is humidified by further passing it through a system of steam sprays or water jets. See fig. 68.

Process of Seasoning — In the initial stage of seasoning, timber is heated with air at 100° F, and fully saturated with moisture. The circulation of air is effected either with the aid of difference in temperation of the incoming and outgoing air, or by means of a fan. As the air is fully humidified, evaporation from the surface of timber is almost stopped. After the timber is sufficiently heated, the humidity is

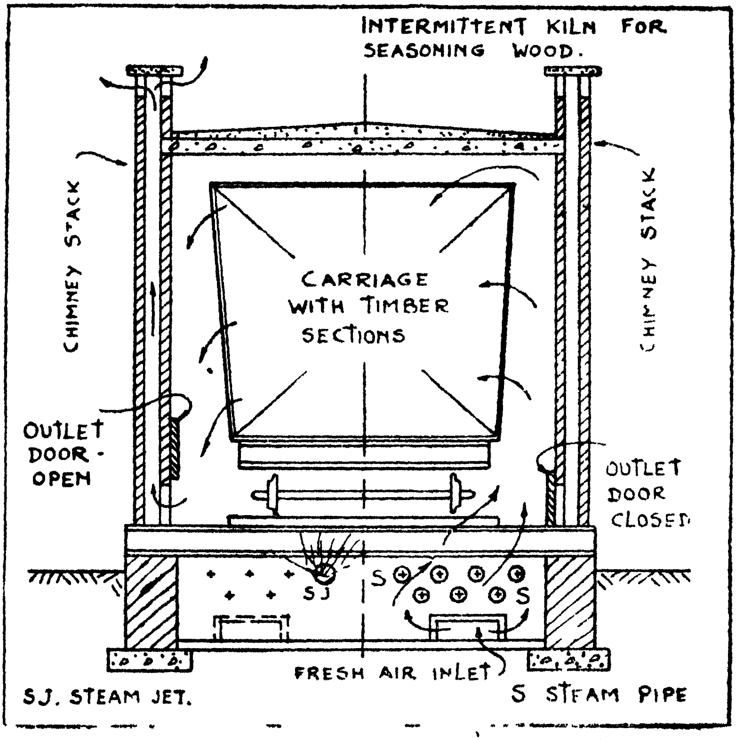


Fig 68. Compartment kiln for Artificial seasoning of timber.

gradually reduced and the air temperature increased, until the desired moisture content only is retained in the seasoned timber. After the treatment is over, the timbers are taken out of the kiln to admit of a fresh load to be sent in for seasoning in their turn.

(2) *A Progressive Kiln* — This Kiln is designed in such a way that the timber travels progressively from the charging end of the kiln to the discharging end gradually and as it does so it gets successively dried. Hot air is supplied from the discharging end. The entire process is kept continuous.

The loaded green timber stacks or carriages are pushed in the kiln from one end, and as timber is dried and seasoned they are withdrawn from the other end.

Art. 262. Water Seasoning — This is not much different from the process of Water Soaking, described under article 246. The term seasoning is used here to indicate that sap is diluted and is partly removed. This reduces the possibilities of decay and increases durability. Water seasoned timber also dries out more quickly. Sometimes the logs of freshly cut trees are conveyed through the streams and rivers, if they are in the neighbourhood. Alternatively boiling and steaming processes are also adopted mainly for two purposes,—viz. (i) To dilute the sap and to make the subsequent drying process easier and quick; and (ii) To impart immunity to wood. The use of superheated steam is also made to accelerate the drying process.

Art. 263. Chemical Seasoning — This is also known as salt seasoning. The economy of operation of a kiln lies in the rapidity with which the timber is dried in it. This results in the rapid drying of the surface of wood and if carried beyond a certain rate, drying stresses are set up and surface splits and irregular cracks occur in timber. Green timber is, therefore, soaked in an acqueous solution of a suitable chemical salt before it is made to pass through the seasoning processes. The vapour pressure of the chemical salt is less and as it is only a surface dipping that is effected, the interior moisture is drawn out so that the drying of wood from the centre to the surface is at a uniform rate, though the drying process is accelerated. The chemical frequently used is *urea,* which is a good dehydrating agent and does not cause the treated timber to sweat subsequently.

Art. 264. Electric Seasoning — Electricity is also used for drying and seasoning timber at extremely rapid rates. High frequency alternating currents are most suitable for drying purposes. It should be noted that green timber offers less resistance to the flow of an electric current and the resistance increases as the wood dries, resulting in the production of heat.

Two Stage Seasoning — A combination of natural or air drying and artificial or kiln seasoning is employed in a majority of cases. The green logs are first air-dried to a moisture content of about 25 to 30 percent. They are further cut to smaller sections of plank boards and scantlings and subsequently dried in a kiln to the required moisture contents.

Art. 265. Measurement and Weight of Timber — The weight of round poles and round piles is calculated by determining their volume and knowing their specific gravity. The following are the methods generally used :—

(i) If d_1 and d_2 are the two end diameter of the pole in inches and l its length in feet, the volume of this piece is given by the cone-frustum formula, as follows :—

$$\text{Volume in cu. ft.} = 0.2618\ \frac{(d_1{}^2 + d_2{}^2 + d_1d_2)}{144}$$

(ii) The approximate cubic contents of round or squared logs can also be determined by measuring their girths at the middle and at the two ends. Thus if g_1 and g_2 are the quarters of end girths, and g the quarter of the middle girth, the volume of a log L feet long is given by,

$$\text{Volume in. cu. ft.} = L\left(\tfrac{1}{3}\cdot g_1 + g_2 + g\right)^2$$

The girths are measured in feet.

(iii) It may be noted that the square of the girth at mid-length also gives the volume of the log per unit length of the log.

CHAPTER IX

Timber and Its Products.

Defects in Timber.

Natural defects – knots, twisted fibres, shakes, etc. Seasoning defects – shakes, case – hardening, honeycomb. etc.

Defects due to Fungal Action.

Factors affecting. Sap stain and wood rooting fungi. Attack by insects.

Causes of Decay.

Factors affecting decay.

Durability and Preservation of Wood.

Types of preservatives. Their qualities. Tar Oils. Water soluble and organic solvants.

Pretreatment of timber. Preservative application, Methods – surface treatment dipping and pressure processes.

Preservation of wood from fire.

Characteristics of Good Timber.

Durability and strength. Uses of timber. Structural work. Decorative use. Temporary use. Industrial use. Common tests on timber.

Veneers and Veneering.

Cutting, drying and edging.

Adhesives.

Natural and synthetic, organic adhesives. Their varieties. Adhesives and plywood. Thermoplastic and Thermosetting adhesives.

Resin bonded Plywood.

Manufacture, Laminated wood. Uses.

Reconstructed wood.

Manufacture and uses. Insulating boards. Miscellaneous building board.

Important varieties of Indian timber.

Natural and Seasoning Defects.

Art. 266. Defects in Timber — As timber is a product of natural growth and has to be converted before put to use, it is always associated with defects which are usually imperfections in their growth, manufacture and use. These defects may be classified into two corresponding main divisions :—

(i) Natural Defects or defects due to abnormal growth and rupture of tissues.

(ii) Deffects arising during conversion and use.

Considering the natural and practical difficulties of getting timber free from these defects, usually limitations are specified so that even the best variety of timber includes some of them. Defects in timbers have a general effect in reducing their strength and durability. Economically such timbers fetch a very low price in the trade and are unsightly in appearance.

Art. 267. Natural Defects —(a) *Knots* — See fig. 69. Knots in timber are indications of the branches that once existed in a living tree. As the branches withered away, with the increase in the diameter of the tree, the surfaces of their withered bases are enveloped by the deposition of the subsequent annual rings. The portions of these branches left behind in the wood are termed as knots. Structurally, the knots are classified as " live or tight knots " and " loose or dead knots ", according as the portions of the branches left behind were alive or dead. Knots may be either round or oval. A pin knot is 1/2" in diameter. A standard knot is usually accepted at 1″ diameter. In any case loose knots weaken a timber and are not permitted where structural strength is mainly required.

(b) *Twisted Fibres* — This defect is developed in a tree owing to its peculiar position where the prevailing winds turn the tree constantly in one direction. The fibres of such a tree are twisted longitudinally and if planks or any sections are cut from it, many of the fibres would be cut through and the strength of the piece is reduced.

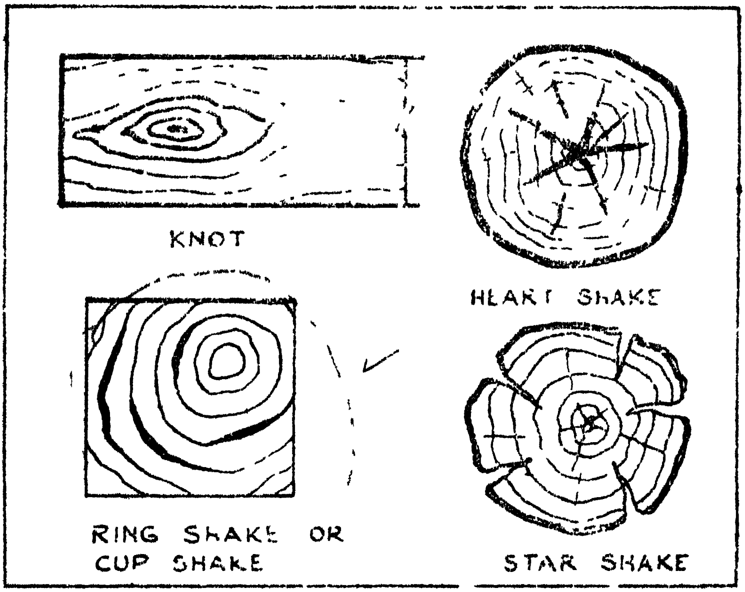


Fig 69 Knot. Fig 70. Heart shake.
Fig. 71 Ring shake or cup shake Fig. 72. Star shake.

If a tree is growing on much sloping ground, the deposition of the annual rings will not be symmetrical around the pith. The same ring will be denser on the up-hill side than on the down hill side.

(c) *Burls or Excrescences* — These are remnents of unsuccessful outbreaks for the formation of branches, and exist as superfluous parts in the trunk of a tree. They are particularly formed if a tree receives an injury when it is young. A large number of buds grow, which rarely develop. An injury to a young, growing tree upsets its development and leaves behind a shock.

(d) *Shakes — Heart or Star Shake* — See figs. 70 and 72 respectively. If a tree is allowed to remain past the age of maturity, the oils, rasins and gums and also the moisture present, in the heartwood cells are lost by evaporation and the wood starts drying from the pith outwards. This causes radial ruptures in the successive annual rings. Usually more than a single rupture take place and by the shape these splits and cracks take, this defect is commonly known as star shake. It is also termed as heart shake as it occurs in the heartwood. A living tree should therefore, be felled just past the age of maturity to get the maximum quantity of timber of the best quality, any particular tree could yield.

Radial Shake — If the outside of the wood dries quicker than the interior, radial cracks will appear, extending from the sapwood towards the heartwood and the pith. In fact, these cracks appear more in seasoned wood as explained later,

(e) *Cup and Ring Shakes* — As against the radial ruptures mentioned above, there are also circular ruptures extending vertically in a tree, between two consecutive annual rings. They are also termed as checks. On account of the curved shape of the defect, it is also called cup shake. Cup shakes are commonly found in the trees growing on the windward side of a forest where they have to swing against strong winds. The force of the wind is sometimes enough to overcome the adhesion between the two newly laid annular rings and thus to cause separation. See fig. 71.

(f) Defects of the type of " pitch pockets ", " Resin and mineral streaks ", " gum veins " and " latex canals " are also found in certain trees; but they are more familiar with particular spices only.

Art. 268. Defects Arising during Conversion and Use — *Seasoning Defects* — If the seasoning of the freshly felled logs of wood is not properly carried out, several defects creep in, as already referred to in the previous articles. The common defects due to non-uniform drying of the exterior and the interior sections of timber are the following :—

(a) *Radial Shake and Cup Shake* — the exterior drying more quickly than the interior, which remains comparatively wet. Radial shake extends from face to face of a timber section whereas cup shake causes only the separation of annual rings circumfarentially.

(b) *Case-hardening* — On account of the phenomena explained above, the more rapidly drying surface tissues shrink and contract quickly causing drying stresses to be set up in them. The surface of such timbers is hardened. Case-hardening also takes place in the bottom sections of the heavily loaded stacks kept for seasoning. The planks and boards which are in contact with the narrow strips, do not get free movement and their surfaces are, therefore, case-hardened. See fig. 75.

(c) *Twisting and Bowing* — If the unevenly dried timbers are subsequently sawed into smaller sections, some of the stressed are released and the defects such as, twisting, cupping, bowing and end splitting, appear quite prominently in them. See figs. 73 and 74.

(d) *Honey - combing* — Under controlled drying conditions of seasoning timber by chemical method, the hygroscopic substance on the surface tissues, sometimes allows the interior to dry out quickly, keeping the surface still wet. The internal stresses thus set up, cause radial and circular splits which, due to intersecting each other, impart a honey -comb texture to the wood interior.

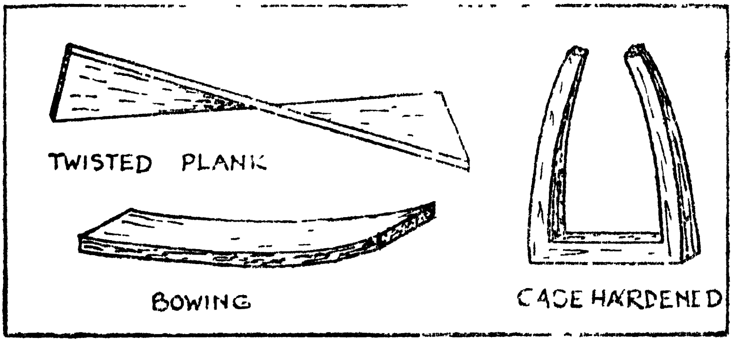


Fig. 73. A twisted plant.
Fig. 74. Defect due to bowing
Fig. 76. Case hardening.

To eleminate the above defects, the entire wood should be brought to the fibre saturation point at the same time and the rate of drying of the exterior and the interior should be kept the same. This rate is faster before the fibre saturation point is reached and is slowed down when wood is dried beyond that point.

Art. 269. Defects due to Fungal Action — Fungi are microscopic or lower form of plant life or plant organisms that attack and live on wood tissues and their cell contents, which belong to the higher form of plant life. Rotting is the general term applied to the disintigration and distruction of wood material by fungal action. The factors which promote the attack by fungi are the following :—

(i) Requisite amount of moisture;
(ii) Enough air;
(iii) Suitable temperature;
(iv) Adequate food material.

All these are necessary for the fungal action to take place.

(i) *Sap Stain Fungi*; and (ii) *Wood Rotting Fungi* — These are the two principal catagories of fungal organisms. The former live only on the plant food materials contained in the cell cavities. They leave the cell walls in tact and hence the strength of wood is not affected. But it may be said that the action of sap stain fungi prepares a receptive condition for the attack of wood rotting fungi. On the other hand, the wood rotting fungi attack the wood tissues and cause their disintegration and final decay in timber.

(i) *Sap Stain Fungi* — The sap wood of both hard woods and soft woods are affected by sap stain or blue stain. The ends of logs and the surfaces of freshly cut boards and planks are attacked. Sometimes stains are also caused by the fermentation of sap. Mould-like growths also appear on damp timber. These defects could be eliminated by a proper circulation of air and creating dry conditions in general.

(ii) *Wood Rotting Fungi* — These are either wet rot fungi or dry rot fungi. Though about 20 to 25 percent moisture is essential for fungal activity, wet rot fungi require a higher percentage of moisture and general wet conditions around their region of growth. Dry rot fungi require comparatively a lower percentage of moisture and does not require damp conditions to bring about disintegration and final decay. The wood is reduced to almost a powdery state from which the term " dry " rot is used. It may be noted that wet rot is commonly found in living trees through their wounded parts into which water gains access.

Art. 270. Defects due to Insects in Timber — Insects and worms which cause defects in wood are mainly of two types. One class of insects like *Beetles* and *Termites* living on the wood material whereas in the other class like *Marine Borers* boring holes in wood for themselves to live in, without eating it. The action of insects is to make tunnels in wood in various ways and thus to reduce it to powder and impart a honey comb texture to it. Timber is discoloured and loses its strength and finally falls into decay.

In lumber yards and in living trees, bark beetles are found to exist. Powder post beetles do much damage to the seasoned woods. The cracks in timber are usually enough for their eggs to be deposited. Usually beetles are found in temperate regions. But in tropical and subtropical countries termites, commonly known as *White Ants* are found in great number. They live in a colony and cause serious damage and loss to timber every year. They attack seasoned timber in position and in a short period reduce it to a hollow shell.

Marine borers are found in salt waters. They do not feed on wood but bore tunnels for themselves to take shelter and to live. Holes to the extent of 1" diameter and 2" to 3" long are bored by these insects.

Causes of Decay.

Art. 271. Improper use of Timber and consequent defects — In the process of life, like all organic matters, when a tree is felled, its life is destroyed and decay sets up in the natural course. The various agencies which accelerate this decay and cause disintegration are the following :—

(a) Careless handling of unseasoned timber after felling.

(b) Presence of sap and moisture in timber due to improper seasoning.

(c) Stacking timber in a timber yard or using timber in a building, in a place where there is no free circulation of air and there are constant damp conditions prevailing.

(d) Using timber in an exposed place in a building where it is constantly subjected to alternate wet and dry conditions.

(e) Decay of fence posts in their portions burried in the ground, without any preservative treatment, is not uncommon.

(f) If timber is used in structural work without an application of paint or some type of protective covering, it is quite susceptible to decay.

(g) Similarly, if paint is applied when timber is wet, interior decay sets in due to the fermentation and decomposition of the wood cells and their contents. It is important to note that moisture is the prime cause of decay in timber.

(h) The actions of fungal life on the wood cells and their contents, as in the case of sap stain fungi and wood rotting fungi — dry rot and wet rot fungi — set up decay in both unseasoned and seasoned timber, as previously pointed out.

(i) Insects and worms like beetles, termites and borers also bring about decay in timber in their own way as explained in the previous article.

(j) Mechanical wear and tear limits the life of timber but does not bring about decay in timber in the real sense of the word. It is sometimes termed as weathering, when the mechanical wearing away of wood is due to exposed and outdoor conditions.

The decay of wood is a progressive process, and the detection of decay in timber should be made in its early stages. The results are sometimes desastrous specially when the timber is used as a load bearing member as in the case of beams and girders, columns and joists if these members collapse. Economically also, early detection of decay, saves much in replacement. Specially with termites and dry rot fungi, great damage is done to timber before their ravaging work is discovered.

Durability and Preservation of Timber

Art. 272. Durability of Woods — Properly seasoned wood under ordinary conditions of atmosphere, gives a fairly long serviceable life. With certain types of wood like teak, this life is much long owing to their natural durability. Their cells contain mineral substances which are poisonous to fungi. These substances make the wood material unfit as their food. Under favourable atmospheric conditions prevailing in suitable places where timber is located, the durability of such woods is also increased.

Preservation of Wood —But the term preservation of wood indicates an increase in resistance to insect attack and fungal infection imparted to timbers. The life of timber is also increased thereby though it is put sometimes to unfavourable conditions during use. In modern construction, in the building of ships, aeroplanes and railway couches, etc. where strength has to be combined with durability and lightness, the reduction of moisture even upto 5 per cent is sometimes specified. Such highly dried wood is very hygroscopic and the tissues have to be soaked with some type of a preservative, to prevent the reabsorption of moisture.

Art. 273. Types of preservatives — There are several types of wood preservatives put in the market. But the following three are the main classes :—

(a) Preservative tar oils.

(b) Water soluble chemical salts.

(c) organic solvent chemicals.

The choice of one preservative or the other is very much governed by the following characteristics which are expected to be present in it :—

(i) A required amount of toxity towards wood destroying organisms.

(ii) Permanancy in the treated wood.

(iii) It should be easily available at low prices.

(iv) It should not be injurious to wood tissues, nor should it react chemically with them.

(v) It should penetrate wood to the required extent.

(vi) It should be safe to handle.

(vii) It should be possible to give the required decorative effect, if necessary, after the preservative treatment.

The three types of preservatives mentioned above and the methods of treating timber with them will now be considered.

Art. 274. Preservative Tar-oils — Creosote — The most important and widely used oily preservative is *Creosote*. There are three types of creosotes, coal-tar creosote, water gas-tar creosote and wood-tar creosote, depending upon their origin whether it is from coal, petroleum or wood. Creosotes are obtained by the distillation of these substances, and satisfy many of the characteristic requirements given in the above article. Out of the three creosotes, coal-tar creosote is the most important one. Creosotes should not contain more than 3 percent of water. Pure coal-tar creosote " sweats " in hot sun and as such, petroleum oils and waxes are sometimes used as dilutants with the crosotes, specially for the preservative treatment of railway sleepers. The creosote is thereby fixed in timber and does not come out of the surface. Creosotes have an undesirable odour which often limits their use. Coal tar is also used as a preservative but not so effectively as the creosotes, as it is more suited for surface application only.

Art. 275. Water Soluble Chemical Salts — Certain chemical salts are toxic in nature and are soluble in water. They are odourless and on drying admit of being painted. Where appearance is the main factor in wood, preservatives of this type are most suitable. Wood treated with water soluble salts requires to be re-dried and does not possess the same degree of moisture repellent qualities as when treated with the oil types.

Zinc chloride is the most familiar and common type in this class. The treatment process constitutes what is usually known as *Burnettizing*. Potassium dichromate is also sometimes mixed with zinc chloride.

Mercuric chloride is also extensively used and the process is known as *Kyanising*. Copper sulphate, sodium flouride and arsenic are the other types of water soluble preservatives.

Art. 276. Organic Solvant Chemicals — This is the third type of preservative in which toxic chemical substances such as naphtol and phenol, are dissolved in a non-aqueous solvant which is a volatile oil or spirit. The organic solvant evaporates after treatment, leaving behind the toxic chemical in the wood. Wood after this treatment can be painted. These preservatives have better permeability and are best suited for surface application. They are rather costly.

Art. 277. Treatment of Timber for Preservative Application — *Selection and Sizing* — As the application of preservatives involves great expenses, only sound and strong timber, free from defects, as far as possible, should be selected. Small sections are preferable to ensure a uniform treatment and a thorough application. In the case of small size poles, the bark should be peeled of invariably.

Drying and Seasoning — After the preliminary selection and the sizing of timber as mentioned above, is over, the next important requirement is that the various members to be treated should be seasoned to the required stage, by natural drying and kiln seasoning.

Incising — In the case of hard woods which are resistant to penetration by preservatives, their surfaces require to be *incised*. A number of incisions or cuts of the required depth are made, preferably by passing the piece through a specially designed machine. Sometimes the incisions are 2 to 3 inches deep. Incising also helps penetration across the grains. It is necessary to ensure that the fibres of wood are not crushed, or severely injured, as this would imparc their strength.

Sapwoods are much easier to impregnate than heart wood. Similarly axial penetration for preservative is much more than radial or circumferential.

For special treatments, cutting and framing of the sections is done prior to the preservation process, so that even the joints are proof to fungal action. This is also economical as every inch of treated timber is utilised and there is no wastage of treated timber.

Art. 278. Methods of applying Wood Preservatives — The various methods of applying preservatives to timber fall into three main catagories. They are the following :—

(a) Surface treatment by brushing and spraying.

(b) Dipping or steaping process.

(c) Pressure Treatment.

These methods will now be described in detail

Art. 279. Surface Treatment. *Brushing and Spraying* — This method is suitable when the preservative has to be applied to wood at interval of 2 to 3 years and also when timber is exposed to damp conditions only for a short time. It is also employed when timber is not expected to last for a long period. Brushing is the simplest method of applying a preservative. Usually two to four coats are enough and the treatment lasts over two to three years. Spraying by a machine is definitely better than brushing and gives a uniformity of application. As the preservative fluid is automized, spraying should be carried out in closed chembers to avoid injury to operators.

Art. 280. Dipping process — *Open Tank* — This is better than brushing and spraying. Better penetration can be obtained with a hot preservative provided it does not decompose. The pieces to be treated are actually given a hot preservative bath in an open tank by dipping. ½ hour to 4 hour duration of dipping at a temperature of 150° F to 200° F gives goad results. This method is also known as the steeping process.

Art. 281. Pressure Treatment — This is the most effective method of treating timber with preservatives and gives reliable results. The process consists in loading the steel cars with the timbers to be treated and pushing them in retorts or long steel cylinders, called autoclaves, the doors of which could be hermetically closed. The retort is then filled with the preservative under pressure until the desired quantity is absorbed by the timber.

There are two types of pressure processes in use :— (i) Full Cell process; and (ii) Empty Cell process.

(i) *Full cell process* — The cell walls and the cell cavities of the treated wood are both filled with the preservative. After the steel cylinder is charged with timbers, 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 cylinder and the desired pressure usually ranging from 125 to 200 lb. per sq. in. is applied for a specified period. The pressure is then reduced to atmospheric, and the preservative is then withdrawn from the cylinder. After a short time, the cylinder is unloaded. Thus the cell cavities also get filled up with the preservative. It is argued that the preservative injected in the cell cavities is a waste. But this method is most suitable to water soluble type of chemical preservatives.

(ii) *Empty Cell Process* — In this process, an initial air pressure of about 50 to 100 lbs. sq. in. is applied to the timbers in the loaded cylinder and subsequently hot preservative is pumped at a still higher pressure even upto 200 lbs. By this the air in the cell cavities is locked up and subsequently, after the pressure period, the preservative is drained away and a final vacuum is also applied to remove the surplus preservative from the timbers. This process is most suitable to oil type of preservatives.

Usually full cell treatment requires 1.5 to 2 times the preservative than required by the empty cell process. The quantity of preservative e. g. coal tar creosote, required varies from 6 to 15 lbs. per cubic foot depending upon the process employed and the type of work the treated timber is expected to perform.

Art. 282. Preservation of Wood from Fire — Considering the combustible properties of wood, it is necessary that it should be safe guarded against fire. Very often the term " fire proofing " of timber is used. It is not possible to make timber fire proof, as when it is heated to about 500° F, it does decompose, giving out inflammable gases. What best can, therefore, be done is to impart it fire resisting properties so as to retard the action of fire. The construction should be so adopted that fire stops are introduced at important points to block the spread of fire. This gives sufficient time for adopting measures of extinguishing the same. Upward draft of gases should be stopped. VerX thick and heavy timber sections are self-resistant to fire, since when surface combustion takes place, a layer of charcoal is formed on the outside which retards further inflamation. In addition timber has a low thermal conductivity.

On method of fire retardant treatment for wood is to apply a coating of paints of insulating and non-combustible type such as sodium silicate or ammonium phosphate. In another method, fire retardant chemicals are impregrated into wood upto a depth of at least 2″ to 3″. The chemicals commonly used are, ammonium sulphlate, ammonium phosphate, ammonium chloride, sodium arsenate, borax and boric acid. Dilute solutions of 2 to 3 percent strength only are recommended. Zinc chloride also gives some effect of fire retarding action. These chemicals decompose on heating and give out non-combustible gases and water vapour which dilute the inflammable gases and retard the combustion of wood. They also form readily, a dense layer of charcoal and a fused viscous mass and protect the wood from flames and radiant heat. The surface of wood is thus cut off from the supply of oxygen.

Properties and Uses.

Art. 283. Characteristics of Good Timber — The primary cheracteristic of good timber are (a) Durability and (b) Strength. Good timber is always obtained from a fully grown tree with straight and regular girth.

Freedon from Defecs — It should be free from branches and natural defects such as shakes, checks and twisted fibres, It should not be affected by wood rotting fungi. The trunk of the tree should be thick, long and straight.

It should be free from large and loose knots, and should be obtained from the heart wood of a sound tree. If from sapwood, the sap must be removed.

Sawn Sections — Radial sawn sections of timber are always preferred to tangentially sawn ones for better service.

Annual Rings, Colour, Sound and Weight — The annnal rings should be regular and uniform and as dense as possible. The colour should be uniform and lustrous. There should not be any sudden change in colour as this would indicate a disease in timber. Dark colours usually indicate strength and durability.

When struck, timber should give a clear sound, A dull sound indicates decay in timber.

Among the same species, the heavier the timber the stronger and more reliable it is.

Dried and Seasoned Wood — Good timber is always obtained from a thoroughly seasoned wood, dried sufficiently below the fibre saturation point. It is necessary that seasoned timber should be free from decay, sap stain and rot of any type. There should be no surface cracks and honey comb interior.

If necessary, it should have receised some type of preservative treatment suitable to its use.

Structural Properties — The following structural properties are also characteristics of good timber. Strength under direct and transverse loads; elasticity; resistance to shocks;

resistance to shear; hardness and ease of workability. Good timber does not split when nail is driven into it.

The chemical composition of all woods when dry is the same. The approximate percentage composition of the various components can be taken as follows,:— carben 49, hydrogen 6, oxygen 44 and ash 1. Weight of seasoned wood ranges from 30 to 60 lbs. per cu. ft. depending on the type of wood.

Art. 284. Uses of Timber — On account of abundence in nature and ease with which it could be obtained and converted, combined with its facility of working, there is practically no limit to the use of wood. Wood also has a great commercial value as a raw product in the manufacture of various utility products. Some of the most important uses of wood are given below. Timber is used as a material is used as a material of construction both as a load bearing member and a non-loadbearing member. It is used as a permanent componant part of a structure and also as a material of temporary use during construction.

(i) *For Permanent Structural work — Light Structural Members :—*

Building timber for beams, joists posts, floor boards and roofing timber, etc. Frame work for buildings and mill construction.

For doors and windows and wall linings. Lath work base for plaster.

For railway sleepers and bridge floorings. For fencing poles, gates, electric poles and poles for transmission lines.

Use of bamboos and canes for cheap and simple construction.

For Heavy Timber Construction.

Timber trestles, - foundation, bents and super-structure. Bridge members—heavy trusses and floorings.

Piles and pile driving frames. Timber spires, domes and vaults.

For conduit pipes and wooden flumes.

For Decorative Use — In the making of furniture, cabinets partitions and interior decorative work. For veneering and plywood construction.

For Transportation Work — Timber is used for boats and ship building; body building of railway coaches and omnibuses; for air - craft work. For wharves, jetties and landing platforms. In the making of carriages and buts for guns.

(ii) *Por Temporary Use During Construction* — Scaffolding and general centering work of walls and towers. For providing shoring and strutting to support the sides of soft soil excavation. For form work in R. C. C. construction.

Timber is very conveniently employed for heavy centering work of bridge arches, for derric poles, cranes, gantries and staging work. It is also used for packing boxes and crate work in general and pattern making in foundry castings.

(iii) *Reconssructed wood* — In the making of fibre boards insulation boards, hard and soft building boards, linoleum, etc.

(iv) *Industrual Use* — Some of the industrial uses of wood are—as pulp in the manufacture of paper, card boards, *box boards, and wall paper. Artificial silk and rayon silk. Wrapping twine. Roofing felt. Agricultural and farm impliments. Wood is used for the manufacture of preservatives for its own use.*

Art. 285. Common Tests on Timber — The following are the tests commonly applied to timber specimens to determine their mechanical properties :—

(i) *Tensile Test* — The type of specimen to be used for the purpose is a rectangular piece 2″ × 2″ and 8″ log. The method of applying load is in two ways, parallel to the grains and perpendicular to the grains.

(ii) *Compression Test* — A rectangular specimen 8″ × 2″ × 2″ is used for this purpose and the load is applied along the grains. Compressive strength is also tested perpendicular to the grains. Sometimes a cylindrical specimen of $1\frac{1}{8}$ - in. diameter and $3\frac{5}{8}$ - in. long is also used and the test is carried out on that pieec.

(iii) *Bending Test* — shear test, test for toughness and cleavability are also employed to study the behaviour of timber under such loads.

(iv) *Moistutc Content* — This has been explained in Art.... Moisture content should be ascertained since the various mechanical properties mentioned above, depend upon it.

Veneers and Veneering.

Art. 286. Cutting, Drying and Edging of Veneers — *Veneers* are thin layers or sheets of wood of varying thickness from 1/16 in. to ¼ in. They are used in construction where lightness, strength, durability, stiffness, non-shrinking and non splitting properties are expected of timber. All these properties are difficult to be found in combination in a solid wood in its natural form. Veneers are mainly used in the manufacture of plywood, batten board, laminated board and for decorative facings. For such work, the veneers are jointed with adhesives such as glues. Veneering requires only an excellent veriety of solid timber selected from the cutting platform in a saw-mill.

The following are the various stages in the process of paking out veneers from the flitches or cut timber sections, and their logs :—

(i) The thin veneer layers or slices are cut as successive thin sheets with the aid of circular rotary saw or a veneer slicing machine, or a rotary peeling machine, as continuous sheets from the timber which is made to rotate on its longitudinal axis against a very sharp knife.

(ii) The veneers are then conveyed for the removal of all knots and unsound portions from them.

(iii) They are subsequently dried in kilns where the moisture contents are reduced to the required value for satisfactory gluing.

(iv) After the classification of veneer is done the slices are joined at their edges with the aid of an adhesive. This is termed as edging.

(v) Thus a continuous sheet or veneer is formed and from this sheet the desired sizes are cut out. The process of preparing such long and continuous sheets is called *veneering.*

Adhesives.

Art. 287. Adhesives — Adhesives are the materials used for bonding the surfaces of wood, metal, plastics and glass. Their binding properties are partly due to mechanical interlocking of their molecules with the poures in the surfaces of the articles adhered but chiefly due to condensation and settig reactions and inter–molecular forces and bonds. Various theories are recently put forward to explain the existance of the adhesive force.

There are different types of adhesives now put on the market. The following are their main varieties :—

(i) *Natural Organic Adhesives :—*

- Animal protein glues.
- Blood albumin glues.
- Casein adhesive.
- Vegitable starch adhesive.

(ii) *Synthetic Organic Adhesives :—*

- phenol formaldehyde
- Urea formaldehyde
- Products of cellulose.
- Vinyl glues.

A brief description of these adhesives is given in the following articles.

Art. 288. Natural Organic Adhesives — *Animal Protein glues* — Glues of this catagory are obtained from the hyde trimmings, bones and fleshings by boiling them in hot water. They are commonly used for wood construction. On cooling when the water dries the glue hardens.

Animal glues give hard and strong joints but on exposure to atmosphere and under damp and moist conditions, they become soft and decay in the course of time. They are natural thermoplastic adhesives, softening by heat and becoming hard when cold and dry. The process of becoming hard and soft at cold and hot temperatures are reversible with thermoplastic adhesives.

Albumen and Blood Glues — Natural Thermosetting Adhesive — Raw blood is dried into a powder and when using, it is mixed with hot water at about 150° F. It coagulates and hardens to gain strength. It does not soften at high temperatures and exhibits a high water resisting properties. But in recent years, due to the advent of synthetic adhesives, natural ones are fast disappearing from the construction field.

Casein Adhesive — These are made from skimmed milk as it becomes curdled and sour. It is dried, powdered and ground, and is mixed with small quantities of alkalies. Casein is a protein organic adhesive and while using it is mixed with water and mechanically pressed to become hard on drying. Casein does not require heating for using it. It has a good moisture resisting properties.

Glues and caseins require the addition of some preservative material to impart them the resistive properties to the attack of insects and to fungal action.

Vegetable Starch Adhesives — The starch obtained from the roots, grains and corn is treated by acids, ground and powdered. While using, it is mixed with water and an alkaline preservative. The glued articles are kept under a press for several hours to harden.

Art. 289. Synthetic Organic Adhesive —

(i) *Thermosetting Adhesive* — Synthetic adhesives of this class are made commonly with *phenolic* and *urea* compounds. They exhibit thermosetting properties and become hard by forming a series of condensation products, when heated to about 200° to 250° F.

It may be noted that, certain proprietory adhesives are also now available for bonding metal to metal. A thermosetting adhesive therefore, hardens by heating alone by setting up the reactions. This process is not reversible. The common varieties of these resins are phenol formaldehyde and urea formeldehyde. They are unaffected by changes in weather and moisture. Phenol fermaldehyde is the most durable of all the adhesives and is immune to fungi, bacteria and insects, while urea formaldehyde is not so durable and cannot stand moisture and high temperatures.

Synthetic resins are used in the manufacture of plywoods, laminated wood and reconstructed wood. They are available in rolls of dry film, which are formed with thin porous papers soaked with resin solution, the paper acting as a resin carrier. *Tego film* is one variety of such form of adhesive. While using, the dry film is placed between the wood veneers which are then pressed and heated. Liquid phenolic glues are also prepared as against resin films, and could be applied to the surfaces to be jointed.

(ii) *Thermoplastic Adhesives* — Unlike the thermosetting variety, these are fusible at high temperatures and soluble in moist or damp conditions. They are, therefore, not employed where great strength and durability are needed.

Cellulose derivatives are the chief varieties of this class of adhesives, vig., Cellulose easters - nitrate and acetate, cellulose eathers - methyl and ethyl.

Venyl glues form another class of thermoplastic adhesives viz., venyl alcohol and vinyl acetate.

Latex-based Adhesives is another class of synthetic adhesives. They are formed with blood albumin, resine or starch with a base of rubber latex or rubber solution.

Art. 290. Adhesives and plywood — The art of making plywood is being practised from very early days. But the adhesives then commonly used were obtained from natural organic materials such as hyde glues, blood and albumen glues, caseins etc. as descrived in art..... The main draw back with them was their unstability under heat and damp conditions. They were not durable and were liable to be attacked by bacteria and insects, which distroyed the glues and delaminated the respective plys.

Subsequently to overcome the above deficiencies, alkalies in the form of sodium or calcium oxides were added as preservatives. The plywoods prepared from such adhesives were found to be hard and stable but they offered great abrasive resistance on the tools used while working with them.

By the introduction of *Synthetic adhesives* which are manufactured :—

(i) In the powdered form; or

(ii) In the glue form; or

(iii) In the form of films as resin impregnated or tissue coated paper, a new field has been opened out for the plywood industry. Synthetic adhesives have overcome all the three defects and possess the following advantages viz. —

(i) Stability under moist conditions.

(ii) Stability at higher and lower temperatures as well.

(iii) Durability or immunity towards insects, bacteria, fungi and moulds.

(iv) In addition they offer the necessary bond in the jointed members.

With the aid of synthetic adhesives, the wood veneers could therefore be used effectively for making the resin bonded plywoods, etc; and to mould them to any shape.

Art. 291. Plywood — The thin veneer sheets prepared as detailed above, are glued to the sides of a thicker and an inferior type of veneer similarly prepared so as to form a plywood with 3 plys. The longitudinal grains of the central veneer are placed at right angles to those of the outer ones. This gives a balanced plywood which is free from warping & shrinkage defects. The outer ones are termed as face plys and the inner one as the core. Sometimes two more plys are used and are termed as cross plys or cross bonds as in the case of thicker panels, where 5 or more plys are used. The extreme or outer plys are always from specially selected woods. See figs. 76 and 77,

The cementing materials used for edging and also for binding together the successive layers of a plywood are either Tego films or some type of glue films of synthetic adhesives. Sometimes only a coating of liquid resin to the surfaces of veneers is enough. The process of bonding together the various plys is known as the fabrication of plywood veneers, *Manufacture* — Plywood is generally made in two ways to obtain plain sheets :—

(i) By cold pressing; (ii) By hot pressing. In the former case, the adhesives are capable of setting at room temperature.

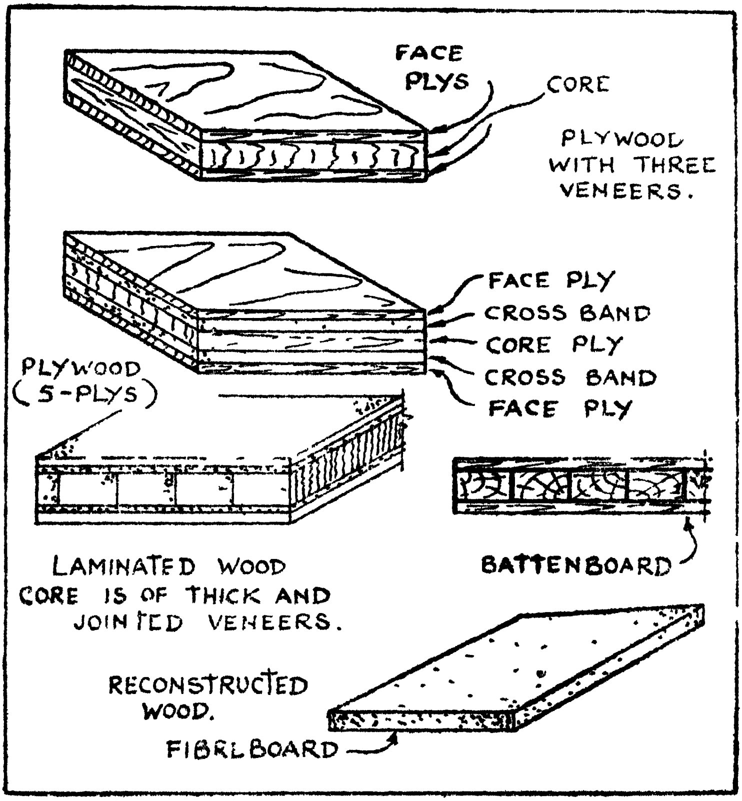


Fig. 76. and 77. Plywood with 3 and 5 plys.
Fig. 78 and 79. Laminated board and batten board.
Fig. 80. Reconstructed wood.

In the latter case, the glued veneers with the requisite number of plys are pressed in large hydraulic presses. The leaves of these presses are electrically heated. The high frequency method of heating is found to work satisfactorily. The usual range of pressure and heat applied for the fabrication of plywood veneers is 100 — 200 lbs. per sq. in. and 300° to 500° F. respectively.

Three dimensional plywood and articles with curved shapes and architectural figures, are manufactured by applying fluid pressure from inside a bag of thick blanket or felt. For higher pressures and better results, autoclaves with solid or ribbed moulds are used.

By employing the necessary type of top ply, the entire wood surface can be given a decorative effect at a very low cost. Large sizes with greater widths could be obtained with plywood as against the limited widths given by solid pieces of timber. Plywood can be bent to any curve and hence it could be used for any veneer construction work. The thickness of plywood is usually varying from 1/16″ to 3/4″ and over, and the plys range from 3 to 9 in odd numbers. All veneer construction plywoods are thinner than the laminated core construction plywoods, explained in the following article.

Art. 292. Lamin boards or Laminated Wood — They are also made on similar limes as plywoods. They may be of 3 plys or multi-plys. But the middle thicker veneers are of the cut and jointed type whereas the thin veneers are continuous sheets. See figs 78 and 79 In the case of *Battenboards*, the middle thick, sandwitched panel is replaced by cut wood battens and not the inferior type of single or laminated veneers as in the case of plywoods and lamin boards.

Art. 293. Reconstructed Wood — Several types of modified, hard or soft varieties of reconstructed wood products are now manufactured. They are available in panel boards of varying thicknesses from 1/8 in. to 1/2 in. They are fibrous in texture and range from a soft lighter and a porous variety, weighing only 2 to 3 lbs. per cu. ft. to a more harder, heavier and a compact variety, weighing 18 to 24 lbs. per cu. ft. Hard pressed and super hard boards weigh even more than 60 lbs. per cu. ft. Fibre boards are available in sizes of 8 to 16 feet long by 4 to 6 feet wide. The following are the principle standard varieties of fibre board:—

(i) *Insulating boards* — Building boards, roof boards, sheathing boards, plaster boards and interior boards. There are two types of insulations to be secured by an insulating body. Thermal and acoustical. From the practical point of view, usually both these properties are jointly required in a construction where insulation has to be provided. Therefore, an insulating body is designed to possess both these qualities. Thermal Insulating property of a material indicates the resistance of that material to the flow of heat or cold through it. Similarly sound insulation absorbs the sound energy by the insulating body.

Fibre insulating light boards possess both the above properties. They contain a large number of small dead-air spaces or cavities in them, which enable them to develop both thermal and acoustical insulating properties. Still air present in these cavities acts as a bad conductor of heat and also absorbs the energy of sound waves and thereby deadness the sound. Though insulating boards are mainly intended to serve as heat insulators, their use for lath base for plaster and sheathing and roofing boards of a thicker variety for outside surfacing is not uncommon. These boards are also employed for sound deadening and imparting acoustical properties to auditoriums and broadcasting stations in modern constructional design.

(ii) *Medium Hard Boards and Hard Boards* — These belong to the second type of boards which are hard pressed and hence are more compact, strong and durable. They are usually 1/4-in. thick and weigh about 60 lbs. per cu. ft. The primary purpose served by them is to impart internal appearance and finishing to a structure. They are not liable to warp and volume changes due to change in temperature and humidity of the surroundings. One face of the hard boards is a plane smooth finished surface. When properties of high non-absorbant nature are required, hard wood boards are impregnated with oil.

(iii) *Miscellaneous Building Boards* —

(a) Soft, flexible, semi-rigid and semi-stiff materials,—hair felt, linofelt, torfoleum, fibrofelt, cork board, Eureka and Celotex.

(b) stiff fibrous materials in sheet form,-Asbestos wood, gypsum wall board, Inso-board, Insulite, Masonite, weather-wood, Essexboard, fiberlic and venesta.

Art. 294. Bent Members of Wood — Bent wood members are prepared in various ways :—

(i) *Solid Piece cut Wood* — These are prepared by sawing out with the aid of a band, the members, out of one solid wooden piece. This yields weak members as the grains of wood are badly cut while sawing to the required curvature.

(ii) *Solid Piece Bent Wood* — To overcome the above defect, the solid piece of wood is bent to the required curve.

Wood could be compressed to about 20 to 25 percent without damage while it could not be stretched more than 1 percent. Therefore the deformation is effected on the compression side of bending, keeping the tension side unaffected. Only the best variety of wood with straight fibres is suitable for the purpose.

(iii) *Laminated Curved Members* — Solid pieces of wood could not be bent to a greater curvature nor could they be conveniently given reverse curvature. These difficulties are overcome by laminated wood members. The various laminations are glued together as already mentioned.

(iv) *Veneered Curved Members* — The solid piece cut wood members with the required curves are covered with a face of wood veneers to import strength and appearance. The gluing could be done with the grains at right angles to each other.

(v) *Curved Member of Plywood* — The plywood could be bent to the required curved figure before manufacturing or after it is glued. It is necessary that the wood must be held in the required curve form till the glue sets and the wood is dried.

Art. 295. Manufacture of Reconstructed wood — *First stage* — In the initial stage, well selected wood is broken into small sizes and converted into chips with the aid of a hog or a suitable machine. The chips are then cooked for a few hours, either in hot water boilers or in retorts through which superheated steam is passed. The lignin or the wood gum is thereby softened and partially plasticized. This enables the wood fibres to be separated in the subsequent process.

Second stage — The softened and plasticized wood fibres are then filled in an air tight steel cylindrical vessel called " gun " into which is admitted steam under great pressure. The steam pressure usually varies from 500 to 600 lbs. per sq. in. The pressure is then suddenly increased to 1000 lbs. and maintained for only a few seconds in the vessel. The bottom valve of the cylinder is next quickly opened and owing to the sudden expansion of steam, the fibres blow out from the cylinder in a manner similar from a gun

Third stage — The separated fibres are further washed in a refining process to remove of excess lignin and spread to form a loose blanket on wire screens. This is a very important stage as it allows the fibres to rearrange and construct a new type of desired texture, which is altogether different from that of natural wood. The blanket mats such formed are of the required thickness and are pressed between steel plates with the necessary pressure to yield soft and hard boards.

Indian Timber Trees

Art. 296. Common Timber Trees in India — The following is a brief list of the trees commonly used in India, giving their weight, properties principal uses and the locality where found,

(i) **Ain or Aini** — Weight, seasoned with about 15 percent moisture, 50 lbs. per cu. ft, Used for general structural work. Furniture, and boat building. Sleepers, Locality-Bombay and Madras provinces.

(*ii*) **Babul**—55. Strong and hard wood. Structural work, Impliments. Bombay, Madras, C. P. and U. P,

(iii) **Benteak** — 55. Strong wood. More suitable for furniture, doors and windows and such fine work. Bombay, Madras, Kanara.

(iv) **Champa** — 45. Strong and durable wood. Yields good posts and planks. Carriage building. Furniture. Bombay and Madras. C. P. and U. P.

(v) **Deodar** — 40. Soft wood. It is light and strong. used for general structural work, packing boxes, etc U. P. and Punjab.

(vi) **Dhamani** — 45. Very strong and hard wood. Tool handles and sports materials. General turning work. Bombay, Madras and C. P.

(vii) **Dindal** — 60. Strong and hard wood and has the same uses as *Dhaman* wood. Splits very badly. Bombay and Madras.

(viii) **Heddi** or **Haldu** — 45. Moderately hard and strong. Yields good planks. Furniture and general building work. Bombay and Madras. C. P. and Bengal.

(ix) **Jambul** — 45. Moderately hard and durable. Sleepers and implements. Used for boat making. Bombay, Madras, C. P. and Bengal.

(x) **Mango** — 45. Moderately strong. Yields very fine planks. Used for general building works. Doors and windows. It has a wide general use. Bombay, Madras, C. P., U. P., Bengal.

(xi) **Mushwal** — 60. A good variety of wood; hard, strong and heavy. Quite suited for furniture, cabinet making and ornamental work. Bombay and Madras.

(xii) **Phanas** or **Jack** — 40. Moderately hard and strong. Yields good planks and sleeper for general use. Suitable for furniture. Bombay and Madras.

(xiii) **Rose wood** — 60. Very strong and hard wood. Quite suited for high class furniture, cabinet making and ornamental work. Bombay, Madras, Mysor, C. P.

✓(xiv) **Sal** — 60. Very strong and durable wood. It is difficult to work with. Used for general structural work. U. P. Bengal, C. P. and Madras.

(xv) **Siras** — 50. Strong wood, used for common construction work, and furniture. Bombay, Madras, C. P., U. P. and Bengal.

✓(xvi) **Sissoo** — 50. Strong and durable wood; commonly used for furniture making. Very reliable for construction purpose. Bombay, Mysore, U. P. and Bengal.

✓(xvii) **Teak** — 45. Moderately hard and strong. Very commonly used for different kinds of works. Sleepers. Possesses good natural durability. Bombay, Madras, C. P.

Common Foreign wood used in India are :— Hickory; Douglas; Ash; Burma Teak; etc.

CHAPTER X

Concrete Making

Proportioning of Mixes.

Ratios. Real mix. Nominal mix and field mix.

Design of Concrete Mixes.

Sieve analysis and fineness modulus method. Minimum voids method. Trial mixture method. Arbitrary method.

Mixing of Concrete.

Hand and machine mixing. Transporting and placing of concrete. Joints in concrete work.

Consolidation of concrete – by hand and machine. Curing of concrete.

Formwork for Concrete.

Concrete surface finishings — form finish; dressed finish; granolithic finish; and plastered finish.

Rainforced Concrete.

General principals and making.

Water-proofing Concrete.

Preliminary precantions. Porefillers; water-repellants and proprietory compounds.

Breeze and Cinder Concrete.

Coke breeze, cinder and blast furnace slay as aggregate.

Artificial Stone.

Cast stone or precast concrete. Principles of making and procedure.

Proportions of Ingredients.

Art. 297. Types of Proportions — The various principles governing the making of *" Good Concrete "* and the factors affecting the same, have been explained in Chapter VII. In the following articles are given the design of *" Concrete Mixes "* and the methods of making good concrete. For the purpose of obtaining concrete with the requisite qualities to serve any specific purpose, the first step is to design a suitable mix ratio, and then to mix the various ingredients, etc. in the second step.

There are three ways in which any particular ratio of a mix is expressed. They are given below :—

(i) *Real Mix* — This is the ratio expressed on the bases of dry materials as obtained in the design procedure, to give the necessary strength. This is in fact the theoretical ratio, giving the exact quantities of the aggregate and water.

(ii) *Field Mix* — The real mix has to be modified to suit the field conditions such as moisture in aggregate, state of atmosphere, exact value of slump, etc.

(iii) *Nominal Mix* — Concrete is generally classified on the basis of certain nominal ratios as suitable for different types of works, such as 1 : 1½ : 3 ; 1 : 2 : 4; 1 : 3 : 6 and 1 : 4 : 8. See Art. No. 224. The actual ratios used for purpose of measurement of aggregate per unit quantity of cement depends upon the real and field mixes. The nominal mix ratios give a basic distinction between the different grades of concrete.

Art. 298. Design of Concrete Mix — The design of a concrete mix consists in specifying the ratio in which the available types of coarse and fine aggregates should be mixed per bag of cement, to develop a given strength in concrete. There are four different methods used for the purpose :—

(i) Fineness Modulus Method.

(ii) Minimum Voids Method.

(iii) Design by Trial Mixes.

(iv) Arbitrary Method.

Art. 299. Fineness Modulus Method—Fineness Modulus Curves : Relation with strength of concrete.

Considering the combined behaviour of the various ingredients of concrete, the design of concrete mixes for a specific strength could be based on the following four factors :-

(a) *Fineness modulus* of combined or total aggregate.

(b) *Volume of combined* or total *aggregate* to unit volume of cement.

Since the strength of concrete depends upon the quantity of cement used, in general, for a unit volume of aggregate and that since richer mixes are required with the smaller size of the aggregate, relations are established between the size of the aggregate and ratio of cement to aggregate volume, with respect to strength. Thus,

(c) *Size of aggregate* also plays an important part.

(d) *Slump value**— for concrete, also has to be considered since the water cement ratio directly influences the strength.

In figs. 81. and 82. are shown two types of graphs, one for vibrated concrete and the other for concrete consolidated by hand, to explain the relations between the above four factors and strength. This is illustrated in the following example by using the above design graphs.

Fineness Modulus Method

Art. 300. Design of Concrete Mix — It is required to produce concrete of strength 3000 lbs. per sq. in. after 28 days, using 3/4" aggregate for normal, machine mixed and hand compact concrete in R. C. C. work.

Fine aggregate : 3/16 to 1/4" size F_f - 3.18; river sand.
Coarse aggregate : 3/4" size F_c - 6.15; broken stone.

Cement used is " Normal Setting Cement,"

Satisfactory control is exercised on the field conditions.

Applying the above data to the graph in fig. 82, the Fineness modulus for combined aggregate is 5.0 and the volume of compact combined aggregate is 4.67 for 1 cu. ft. of cement.

Ratio of sand to broken Stone

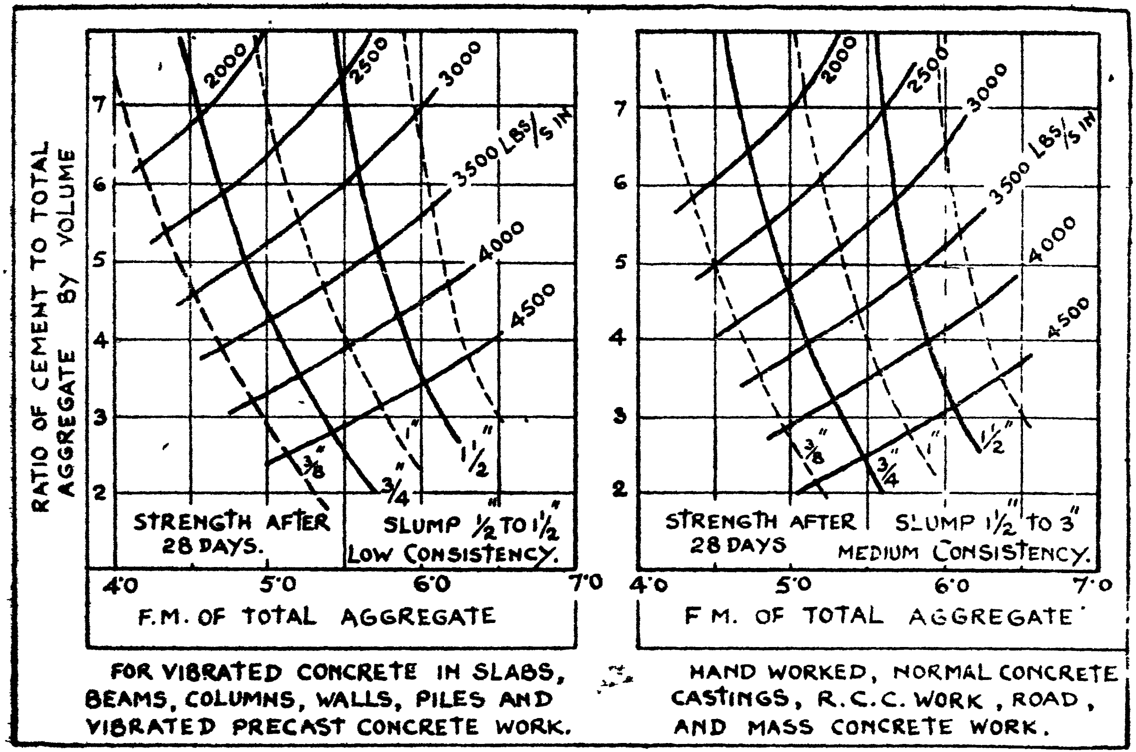
Real Mix. The quantity of sand, x is given by—

$$x = \frac{6.15 - 5.00}{5.00 - 3.18} = \frac{1.15}{1.82} = 0.63$$

i. e. If crushed stone = 100 c. ft. then the quantity of sand = 63 c. ft. or in every 100 cu. ft. of the sum of combined aggregate, 38 5 c. ft. is sand and 61.5 cu. ft. is crushed stone. After testing, the shrinkage factor for this ratio is found to be 0.8. Then the compact volume of 4.67 c. ft. of combined aggregate equals 5.84 c. ft ; of which 2.25 c. ft. is sand and 3.57 is crushed stone.

∴ Real Mix ratio is given by:—

Cement	Sand	Crushed stone.
1	2.25	3.57



FOR VIBRATED CONCRETE IN SLABS, BEAMS, COLUMNS, WALLS, PILES AND VIBRATED PRECAST CONCRETE WORK.

HAND WORKED, NORMAL CONCRETE CASTINGS, R.C.C. WORK, ROAD, AND MASS CONCRETE WORK.

Fig. 81 and 82. Design of concrete mix Fineness Modulus method.

This falls into the catagory of 1 : 2 : 4 Nominal mix concrete.

To calculate the Field Mix—If the sand and coarse aggregates are wet, the percentage of moisture in each should be determined, and from the graph, due allowance for bulking for these moisture contents should be made. The ratio has to be then modified. Thus, if for 4 percent moisture in sand and for 3 percent moisture in crushed stone, the respective bulkings are 22 and 8 per cent, then the Field Mix Ratio is,

Cement	Sand	Crushed stone.
1	2.75	4.00

Ratio for a batch of 1 bag of cement :—
One bag of cement : 3.3 cu. ft. wet sand : 4.8 cu. ft. wet stone.

The quantity of water required for the mixture could be determined from the relations between the water cement ratio and slump. Due allowance should be made for the moisture present in the aggregate. The quantity of water is expressed in gallons per bag of cement.

Art. 301. Minimum Voids Methods—This method 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 the fine aggregate. In this case it is generally necessary that about 5 to 15 percent of more fine aggregate and cement should be used than that indicated by the voids in each, to ensure a proper filling and a dense concrete. The higher values are to be allowed for smaller size metals.

The voids in the aggregates are measured by filling them in a water-tight container of known volume. Water of known quantity is poured in to fill in the container upto the surface of the aggregate.

In a particular case the voids in the coarse aggregate amounted to 44 percent and those in the fine aggregate to 37 percent. The size of the aggregate is 1-in. as determined by the sieve analysis. Allowing an excess of 12 percent for cement and 9 percent for fine aggregate, the required ratios are :—

Coarse aggregate.... = 100 c. ft.
Fine aggregate = 44 × 1.09 = 48 c. ft.
Cement = 48 × 0.37 × 1.12 = 20 c. ft.

This can be written as the values expressed on the basis of 1 cu. ft. of cement :—

Cement	Fine aggregate	Coarse aggregate
1	2.4	5.0

The quantity of water required is determined on the basis of the actual quantity required for the necessary slump and workability. The strength has to be tested by making test cubes.

Art. 302. Trial Mixture Method — Fine aggregate and coarse aggregate are mixed in different proportions and the mixture is filled in a vessel of known volume. After it is thoroughly consolidated, its weight is noted per cu. ft. for each proportion. Then the proportion which yields the heaviest mixture is taken, as it is expected to form a dense concrete. Test cubes are then made to determine the strength at 7 and 28 days.

Art. 303. Arbitrary Standard Method — This is in fact the method where the nominal ratios are used. The quantities of the materials required per bag of cement are worked out, and water is added on the basis of slump and consistency. This method could be modified by measuring the voids as explained before.

Art. 304. Mixing Concrete — Concrete can be mixed either by mannual labour or by machine known as " Mixer. " In either case, the mixing should be done thoroughly.

(i) *Hand Mixing* — The general procedure for mixing concrete by hand, is the same as that given under mortar. The various stages are :—

(a) Dry mixing of aggregate and cement.

(b) Semi-wet mixing with half the quantity of water.

(c) Wet mixing with the remaining quantity of water.

A clean, non-absorbant and hard platform is selected and coarse aggregate is first spread on it as required per batch. Fine aggregate is then spread on it and finally cement. But in the case of lime and surkhi concrete, lime mortar is spread on the coarse aggregate.

(ii) *Machine Mixing* — A common type of a concrete mixer is shown in fig. 84. The capacity of the mixer depends upon the size of the drum. The revolving drum has paddles fixed inside it, to ensure thorough mixing. The drum has to make about 50 to 60 rotations for each batch of mix. The drum is capable of being tilted on either side of the frame, - on one side it receives the raw materials and on the other side it delivers the ready made concrete. The mixing is done intermittently for each batch, but ensures a continuous supply of concrete. There are other types of concrete mixers in which the loading, mixing and delivery are all kept in a continuous operation.

Art. 305. Transporting and Placing Concrete — Concrete should be transported and Placed in its final position

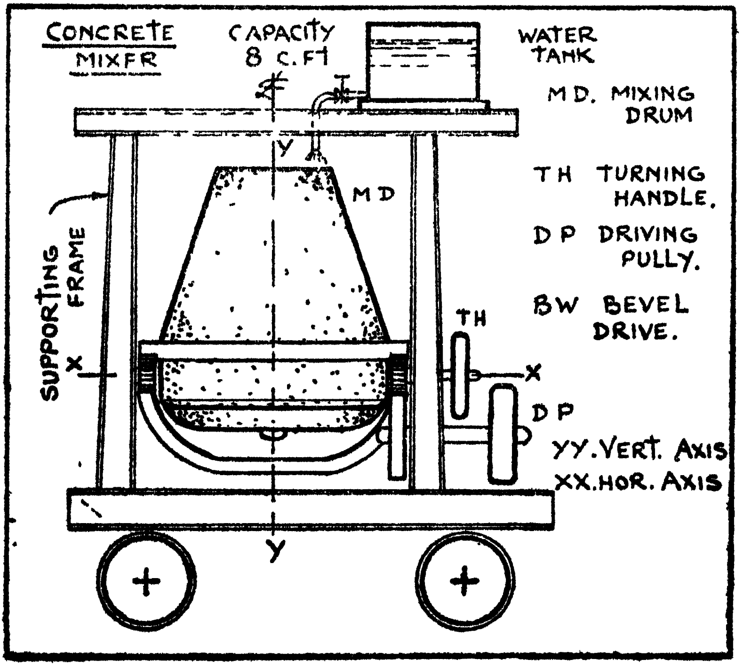


Fig 84 Concrete mixer.

including complete consolidation, before the initial setting of cement commences. Wheel barrows and hand carts are convenient to carry ready mixed concrete. On small works, iron pans are not uncommon. But for depositing concrete on a very large scale, chutes, belt conveyors and concrete pipe lines with concrete pumps are necessary. In any case, care should be taken to see that the homogenous nature of concrete is not disturbed during this operation.

Similarly the placing of concrete requires proper attention. It should not be dumped from a height as this would cause *Segregation* in concrete owing to heavier particles falling down quickly. Concrete should be deposited in horizontal layers. Badly designed concrete shows a tendency of "Bleeding" by allowing water to come up to the surface.

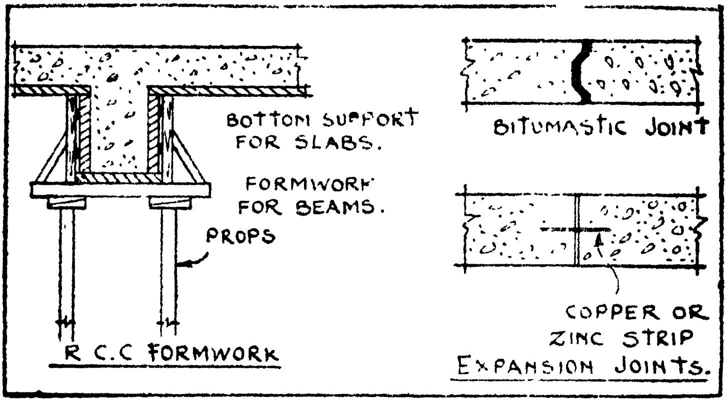


Fig. 85. R. C. C. formwork for beams and slabs.
Fig 86. and 87. Joints in concrete work.

The formation of "Laitence" or a crust of squeezed out mortar on the surface is an indication of bad or weak concrete. While preparing water-tight concrete, *segregation*, *bleeding* and *laitence* formation should be very carefully avoided.

Art. 303. Joints in Concrete Work— The joints between the portions of concrete laid continuously on two consecutive days are formed by a rich mortar of about ½-in. thick. The loose concrete from the surface of the previously laid concrete is removed. The method of providing expansion joints in concrete between two independent portions of concrete is shown in figs 86. and 87.

Art. 304. Consolidation of Concrete — This forms an important stage in the manufacture of concrete, to secure maximum density and strength. Consolidation removes the air bubbles from the body of concrete; and in the case of reinforced concrete, it ensures proper contact between the surfaces of reinforcing rods and concrete to develop necessary adhesion.

(i) *Consolidation by hand* — This is a very simple method of compaction of concrete. It consists in rodding, tampering the placed concrete to induce gentle movements in its ingriedients. A pointed steel rod of 5/8" diameter and 2 to 3 feet long is ordinarily enough for hand consolidations.

(ii) *Consolidation by Vibration* — This is a mechanical method of consolidation. Different types of vibrating machines are in use, such as,

(a) Vibrators attached to form work.
(b) Surface vibrators.
(c) Internal vibrators.

Vibrated concrete gives best results with respect to density and strength. But it is slightly costly due to extra equipment required and also due to the form work which has to be disigned for extra strength and rigidity to take up the vibrations. the vibrations are usually of the order of about 2500 to 3500 per minute. Vibrated concrete requires a slightly lower value for the slump than that required for hand compaction. Once the concrete is placed in position and consolidated, it should never be disturbed, as already pointed out.

Art. 305. Curing Concrete — Concrete has to be kept wet for a period of about 21 days to 28 days after it is placed in position. During this period, it gains strength by setting and hardening. The effect of temperature on curing has been already explained under cement. The following are the common curing methods adopted :-

(a) Spraying of water either by hand or by a pump on a small scale

(b) By covering the surface by wet gunny bags, straw, etc. This is more suitable for vertical faces.

(c) By forming small bunds to enclose water on the surface of horizontal castings.

Art. 306. Form work for Concrete — This is also sometimes known as shuttering. Concrete being a plastic material when freshly made, requires to be held in a specially designed form work or shuttering during the curing period. See art· 220. One type of form work is shown in fig. 85. Form work should be rigid and strong. It should be so designed that it could be easily erected and easily dismantled. It should admit of being used several times. It should be non-absarbant. Though timber is the most common material used for shuttering, the use of steel plates and rolled sections is not uncommon.

Art. 307. Concrete Surface Finishings — Concrete surface could be finished in various ways depending upon the purpose to be surved. The following are some of the types

(i) *Form finish* — In this case no other treatment is given to the surface after the form work is removed. If the form work is very correctly made, true to size and with plain surfaces, this is the best type of finish and carries the marks of the form work, which when arranged in a systimatic order yield a very good appearance.

Pre-cast concrete sections could be simply jointed at their sides, with their surface left in the same condition as when cast, this is specially suited in the case of slabwork.

(ii) *Dressed form finish* — In this case, the surface is given some form of dressing with dressing tools. This finisning is termd as tooled finish similar to stone work.

(iii) *Granolithic finish* — In the case of floor for dwelling house and ware houses, the surfaces of concrete are finished while green. Trowel finish with neat cement, and slightly rough finish with a wooden float, are very common. To increase the resistance to wear and tear, small quantities of ironite, or silicate compounds of sodium and magnesium or silicoflouside are used for warehouse floors. The surfaces are there-by hardened.

(iv) *Plastered Finish* — This is a very common finish. There are several varieties of plasters in use,—from smooth or rough, to rough cast ar pebble dash. Sometimes plastered surfaces are also sand rubbed or sand blasted. They may be given a treatment with stucco or cream of lime.

As concrete is essentially an artificial stone, it is also subject to weathering action in a manner similar to such kinds of natural stones.

Art. 308. Reinforced Cement Concrete. R. C. C. — Concrete is very strong in compression, but comparatively very weak in tension. And when steel rods are enbedded in concrete, the latter adheres quite well to the surfaces of the former. Advantage is taken of these facts to design a material in which compression is taken by concrete and tension is taken up by steel. Such a composite material is termed as *Reinforced cement concrete.* Some of the sections of R. C.C. members such as beams, columns, footings, etc. are shown in figs. 88 to 98. After the form work is prepared, the reinforcement is placed in position and is tied or welded. The subsequent operations of placing concrete, consolidation and curing, are the same as detailed in the previous articles.

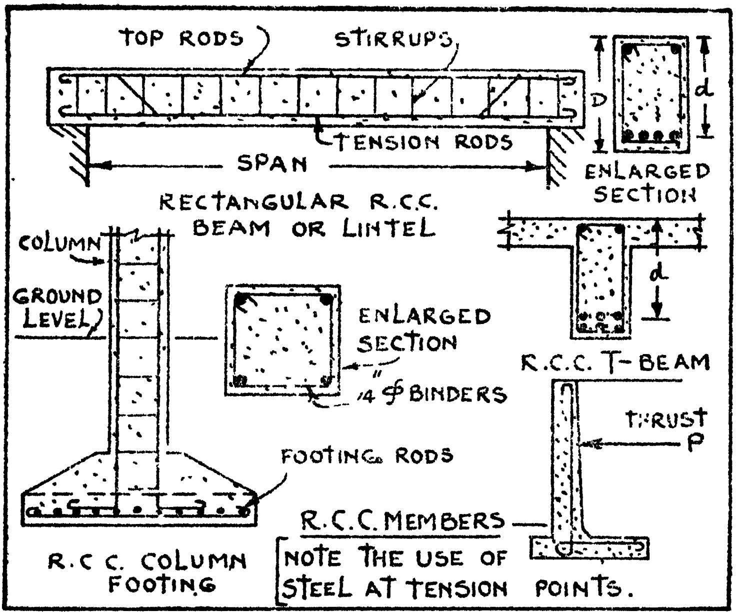


Fig. 88 to 93 Typical R. C. C. Section.

Art. 309. Water-Proofing Concrete—Concrete required for tanks and reservoirs, roof slabs of terraces should be designed to possess water proofing qualities. The following measures are adopted for the purpose—

(i) Selection of hard and strong aggregate which should be very carefully graded to obtain maximum density in concrete.

(ii) To adopt a water cement ratio as small as possible, consistent with workability, and to use mechanical means of consolidation such as vibrators so as to produce a dense concrete.

(iii) To add certain compounds which either act as inert pore-fillers or chemically react with concrete ingredients. Chalk, talc, magnesia, fuller's earth, gypsum and fat lime, act as pore-fillers, while ammonium chloride, calcium and aluminium chlorides, zinc sulphate and iron filings belong to the second class of chemical compounds. Iron filings rust, and expand to fill in the pores in concrete.

(iv) There are several proprietory preparations in the market. They are mixed in a specified proportion with concrete. They are either pore-fillers or chemical reagents. Some of the common types are :—sika; pudlo; impermo; Rainex ; etc.

(v) Applications of coats of bituminous materials, paints and varnishes, are given to concrete surfaces, very often as protective coatings. They are chemically inert and mainly act as water repellants.

Art. 310. Breeze and Cinder Concrete – Light weight concret can be made by using coke breeze and cinder aggregate with cement and water. Coke breeze is a porous material produced in the manufacture of coal gas from coal. It is sufficiently hard and gritty and very light in weight. Precast slabs also could be prepared out of this type of concrete, and could be conveniently used for floors and light weight partitions. They take nailing very easily without splitting.

Blast furnace slag also could be used for making concrete, where it acts as an aggregate. Feather-crete is another type of concrete where rice husk is used as an aggregate. Sometimes wood shavings and saw dust are used to make a type of concrete material known as Indianite. These are essentially manufactured by firms in the form of precast slabs and pressed into moulds of standard sizes.

Artificial Stone.

Art. 311. Cast stone or Precast Concrete — Various units such as plain or moulded stone blocks, beams, lintels, fence-posts, and sleepers are now manufactured and used on a large scale as artificial stone products. The main advantage is that similar articles could be manufactured on a mass scale in a central concrete workshop very cheaply. They can be satisfactorily consolidated and cured to attain the desired strength and density. For artificial stone or cast stone used for architectural work, the face-work can be given any desired treatment or finishing. Such stone products usually have an interior of 3/4″ concrete materials of 1: 2: 4 ratio, while a thickness of 1 to 2 inches from the exposed face is made up of a rich mix of 1/8″ to 1/4″ size. Desired pigments could be added with cement in the surface layer to give the appearance of a natural stone. The other details about the various steps in the making of concrete, placing, vibrating and curing are the same as those hitherto described.

The use of silicate of soda, with stone dust and portland cement is common in making these stones. Sometimes marble chips are used for the face work and such a type of finish is called "Mosaic" finish. "Terrazo" is another name given to such a finish, if it is cast in situ. Terrazo finish takes very fine polish.

Art 312. Concrete Block Work — *Dense Concrete and Light Weight Concrete* — Just as bricks are made by preparing clay and burning it, cement concrete blocks are made by preparing a suitable, fine concrete mixture and casting it molds and subsequently curing then under wet conditions for 28 days. They need pressing in a machine in mold. Both solid and hollow blocks of concrete are made, their sizes are :—

(i) Building blocks ..	15 ¾″ × 7¾″ × 8″.
(ii) Thin partition ..	15 ¾″ × 7¾″ × 5″.
(iii) Solid works or facing slabs ..	18″ × 9″ × 3″.

In the case of hollow blocks, the hollow portion varies from 30 to 40 percent of the volume of the block.

Some concrete blocks are made in two pieces, either in the form of 2 - angles or 2 - channals, to be jointed to form a rectangular block. Concrete blocks are quite suitable for making hollow, and cavity walls.

Light weight concrete (L. W. C.) blocks are also made from the light weight concrete as described in art. 310. The weight of each block varies from 12 to 25 lbs, each, as against 40 to 50 lbs. each for the dense concrete blocks. Hollow concrete blocks are largely used for filling the praels of framed structures; but their use for constructing load bearing walls of simple buildings is not uncommon.

For mass production work of simple buildings the concrete blocks are the most suited ones.

CHAPTER XI

Ferrous Metals

Pig Iron, Cast Iron and Wrought Iron

Pig Iron,

Ores of metals and preliminary treatment. Ores of iron. Reduction of iron ores factors influencing. Other impurities of iron ores.

Blast Furnace.

Component parts. Additional equipment. Hot blast stoves and feeding equipment. Smelting the iron ore. Flux and fuel.

Composition of Pig Iron.

Ferrite; carbon, -free and combined; silicon; manganese; sulphur; phosphorus. Varieties of pig iron - gray, white and mottled.

44 E, M.

Cast Iron.

Remelting of pig iron – materials added and their functions. The Cupola,– working and reactions. Properties of cast iron.

Composition of Cast Iron.

Iron and carbon; silicon ; manganese; sulphur and phosphorus. Classification of cast iron – gray, white and mottled varieties.

Molding and Casting.

Foundry work. Pattern making. Molding. Casting,—ordinary, centrifugal and die casting. Cooling and finishing; defects.

Wrought Iron.

Cast iron to wrought iron. Puddling furnace. Description and working. Melting, balling and shingling. Reheating and rolling, effects of.

Properties and uses of wrought iron. Tests.

Occurrence of Metals

Art. 313. Ores of Metals — Metals generally do not occur in nature in a pure metallic state. They are found chiefly in the form of oxides, carbonates and sulphides. These compounds of metals as they occur in nature are termed as ores, and are often associated with some other impurities. From the industrial point of view, the ores should contain a sufficient quantity of the metal. Ores are found in nature as surface deposits or underground deposits and require to be obtained either by quarrying or by mining respectively in the two cases.

Ore treatment — After the ores are brought to the factory, they are *dressed* to separate the loose earthy matter and impurities and then broken up in crushers for proper sizing.

Calcination is the next treatment of the ores and consists of roasting or preliminary heating to remove the water and carbon-di-oxide from them. The heat required is very moderate.

After receiving the above preliminary treatment, the ore is now fit for *smelting* in furnaces where intense heat is generated to enable the metal to melt and sink down in a fluid state. The common metals used are iron, copper, lead, aluminium, tin, magnesium, zinc, nickel, chromium and tungstan.

Art. 314. Ores of Iron — (1) *Hematite* (Red oxide Fe_2O_3) This contains 70 percent of iron, but owing to impurities yield about 55 percent only. This is generally found to be the most important ore in the manufacture of iron.

(2) *Hematite* (Brown oxide $Fe_2O_3.nH_2O$) also known as Limonite. This is a hydrated oxide ore of iron and contains 60 percent of iron. This is reduced to about 45 percent due to impurities.

(3) *Magnetite* (Black oxide Fe_3O_4) — This is the richest and hardest iron ore and contains 73 percent of the metal. It seldom contains any impurities.

(4) *Siderite or Spathic Ore* — (Crey or brown iron carbonate, $Fe.CO_3$) — It contains 48 percent of iron, and can yield commercially about 40 percent of the metal.

(5) *Pyrite* (Yellow sulphide FeS_2) — It contains 42 percent of iron. But this form of iron ore is very seldom used for the manufacture of iron.

Art. 315. Reduction of Iron Ores — *Factors Influencing* — CO; C; Temperature; and hot blast of air. The general principal of obtaining iron in the metallic form is that of reduction. The substance which is used to eleminate oxygen from the iron oxides should be the one which has more affinity for oxygen than iron has for oxygen. For this purpose, carbon in the form of CO is employed as an agent. CO is therefore made to come in contact with iron oxide and since carbon monoxide has a greater binding force for oxygen than iron has for it, it liberates the oxygen from iron oxide to form CO_2.

Temperature — also plays an important part in the reaction since the strength of carbon monoxide as a reducing agent increases with temperature. Since the metallic iron has to be separated from the other impurities in a molten condition, it is necessary that a temperature of about 3000° F has to be attained in the furnace. At this temperature CO is extremely active as a reducing agent and the liberation of iron from the ore is very rapid.

Carbon monoxide is derived from coke. CO_2 is first formed and in the presence of excess of carban, it is suddenly reduced to carbon monoxide. The possible reaction of carbon- monoxide as a reducing agent could be written. as follows :—

$$Fe_2O_3 + 3\,CO = 2\,Fe + CO_2.$$

In the above equation, it is estimated that the carbon monoxide first reduces all the oxide of iron Fe_2O_3 to FeO and further reduces only a part of FeO to Fe. The remaining of FeO is reduced to Fe by the fine particles of carbon C which come into operation as shown below:—

$$FeO + C = Fe + CO$$

A blast of hot air through the materials has an accelerating effect on the above reactions.

Art. 316. Impurities in Iron Ores — *Silica and Alumina* — The common impurities with which iron ores are associated are, *Silica* and *Alumina*. Methods should also be employed to eliminate these from the ores to obtain metallic iron. We have seen under limes and cement that lime CaO, becomes chemically active at about 3000° F and shows great affinity for silica and alumina to form calcium silicate and calcium aluminate which are the basic compounds of clinker and cement.

Flux — Advantage is taken of the above property of lime, and limestone is added to the ore along with coke, as it is put into the furnace for smelting. The silicates and aluminates of calcium and magnesium as formed from the impurities

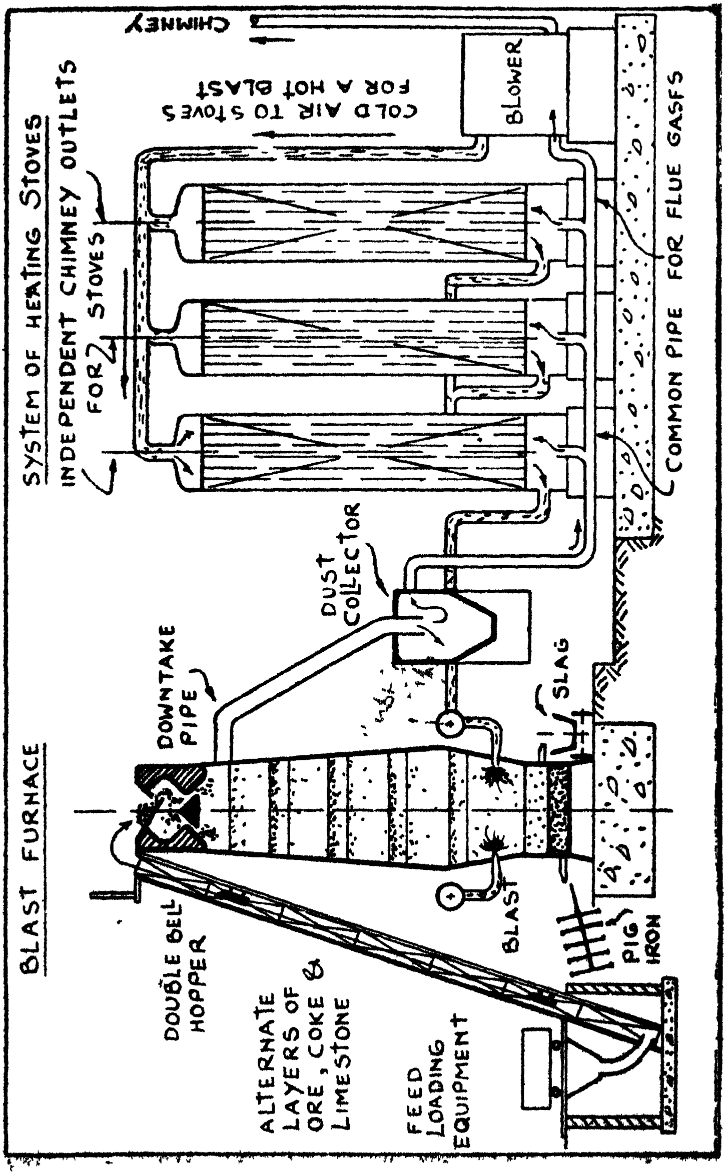


Fig. 94. Blast furnace with heating stoves.

of iron ores are termed as *slag*, and being lighter than iron, collect on the top of the molten metallic iron. This gives a natural device of extracting the molten iron separately from the slag. It may be noted that the blast furnace slag when finely ground exhibits cementicious properties.

Other impurities in the ore are magnesia, iron sulphide and alkaline phosphates. They are oxidised and show a greater tendency to enter into combination with the slag than to remain with iron and are therefore partly removed also. Thus the various important impurities in iron ore are, silica, manganese, sulphur and phosphorus.

Pig Iron

Art. 317. The Blast Furnace — The function of the blast furnace is to separate the metal from various impurities. This is done by smelting ores with other materials in it. The furnace is essentially a cylindrical steel shell about 100 ft. height and 20 to 25 ft diameter. It is provided with a refractory lining of silica bricks. Fig. 94. shows the details of a blast furnace. The various reactions that take place in a blast furnace at different heights and their corresponding temperatures are also shown in fig. 95. A modern blast furnace yields about 500 to 700 tons of steel per day.

The total height of 100 ft. of the blast furnace is made up of :—

Hearth or Crucible is the lowest part of the furnace where the molten iron and slag collect for being drawn out through a tap hole. The hearth extends to a height of about 8 feet.

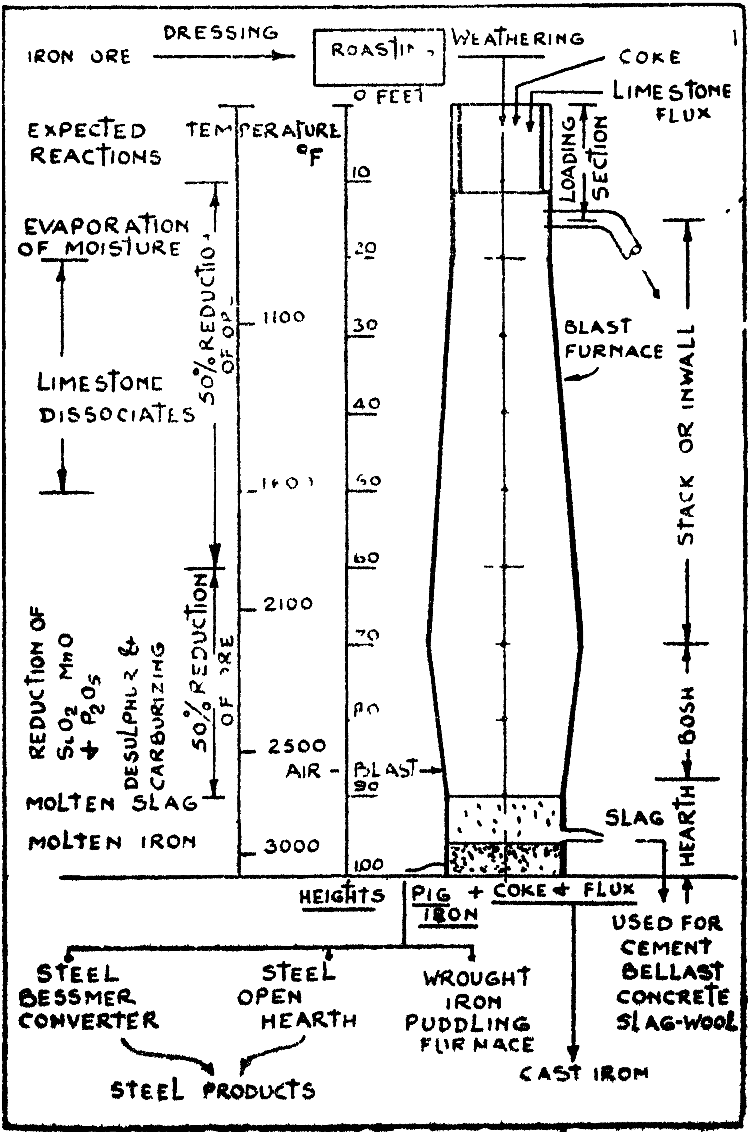


Fig 95. Reactions in a blast furnace.

Bosh or the Burning Zone is the next portion above the hearth and is the hottest part of the furnace. It is about 12 ft. high. Special cooling arrangements with the aid of cold water pipes, are provided around the bosh. A blast of hot air is forced into the furnace just below this portion. To enable this a circular bustle pipe runs round the furnace and several nozzle pipes called tuyers are taken from it to blow in the air. Around the hearth and the bosh a refractory lining of firebricks is provided. The entire blast furnace is supported on columns at the base.

Inwall or stack— The portion above the bosh and extending to a height of about 60 feet is termed as "Inwall" or stack through which the feed gradually descends and gets heated.

Feeding zone or Mouth - This is the top part of the blast furnace and covers the remaining part of the height of 20 feet. It consists of a hopper and a double cone or double bell arrangement. The upper bell receives the feed and opens out automatically when a sufficient quantity is deposited on its back. The feed then falls on the lower bell and a similer operation takes place to admit it into the " Inwall."

Downtake Pipe — The chimney for the blast furnace consists of a downtake pipe connected just below the lower bell of the feeding zone. The hot waste gases from the furnace are drawn out through this downtake pipe for further use as explained in the next article.

Art. 318. Additional Equipment To Blast Furnace— (i) *Hot Blast Stoves* — These are tall structures of the size of " blast furnace ", with their outer shell of steel lined with a refractory material. The inside of each stove is filled with firebricks arranged in a criss-cross fashion, leaving sufficient space between adjacent bricks, for flue gases or air to pass. Usually 3 to 4 units of such heating stoves are arranged in a row for each blast furnace.

The function of a hot blast stove is to extract with the aid of firebricks arranged in it, the heat from the flue gases as they come out of the down-take chimney from the blast furnace, and then to give out the same heat stored in the fire-bricks, to heat the air to be blasted into the furnace through the bustle pipe and tuyers as described before. Between the hot blast stoves and the bustle pipe, are fitted up blowing engines for handling the hot flue gases and the heated air.

(ii) *Feeding Equipment* — This includes a pair of inclined tracks and haulage cars to convey the feed from the platform at the ground level to the unloading platform at the mouth of the blast furnace, 100 feet high, as shown in the figure. The trucks which bring the feed, empty their contents directly in the haulage cars. See Fig. 94.

Art. 319. Smelting the Iron Ore — *The Feed* — The feed into the blast furnace consists of :—

(i) A properly dressed and roasted ore.

(ii) Coke to act as fuel and also as a reducing agent. Sometimes coal, and charcoal are also used.

(iii) A flux, generally lime, $CaCO_3$ which combines with the impurities of iron ore and forms a fussible slag. Lime-stone is a basic flux.

Reactions — The iron ore, coke and limestone are added in the ratio of 6 : 8 : 1. The necessary hot air for combustion which is preheated with the aid of hot stoves as described above, to about 1200° F, enters the furnace through the tuyers and combines at once with the white hot coke at about 8000 F to form CO_2 and CO at once. The carbon monoxide and the fine particles of carbon rrom coke act as reducing agents and help to form metallic iron. Similarly lime combines with the impurities and forms molten slag. The two materials collect in the hearth but in two different layers, with molten iron in the lower portion. It takes about 4 to 6 hours for the feed to descend form the mouth of the furnace to the hearth and to collect into a sufficient quantity for tapping.

Art. 320. Pig Iron — The molton iron is tapped from the hearth once in 6 to 8 hours and is allowed to flow out on a bed of sand moulds, called pig moulds. Similarly slag also flows out separately. For this purpose two independent tap holes are provided at different levels in the hearth. The iron solidifies in the pig moulds and is taken out for further use. Alternatively the molton iron from the blast furnace could be cast into regular moulds after conveying it into large laddles, of about 30 to 50 tons capacity. The metal moulds are mounted on an endless chain and are filled successively each time. They then pass through a water tank to get cooled or water is sprayed on .them. This solidifies the iron in the mould. Pig iron is the raw material for the manufacture of ferrious metals such as, wrought iron, steel, cast-iron, etc. Molton pig iron is also used directly for making steel by different processes.

Art. 321. Composition of Pig Iron — *Carbon In Iron* — From the fact that molten iron has to remain for sometime to collect in sufficient quantity in the hearth, before it could be tapped, there is a good chance for carbon to get dissolved and mix up with it. This is the reason why carbon enters iron.

The the pig iron from blast furnace contains 90 to 92 percent of iron. The various other elements percent in pig iron are, *Carbon* , *Silicon, Manganese, Sulphur* and *Phosphorus*

An average pig iron contains : —

Iron – ferrite, Fe,	..	92	to	94	%
Carbon C, uncombined and combined with iron.	..	4	to	5	%
Silicon, SiO_2	..	1	to	2	%
Manganese Mn	..	1	to	2	%
Sulphur S, and Phosphorus P.		1	to	2	%

The slag from the blast furnace has the following composition on an average :—

Lime CaO	..	45	%
Silica SiO_2	..	85	%
Alumina Al_2O_3	..	12	%

The remaining constituents are magnesia MgO, calcium sulphate $CaSO_4$; manganese oxide MnO_2 and oxide of iron FeO. All these together amount to about 8 percent.

Slag is used far various purposes. It is crushed to a suitable size and is employed for various purposes, such as,– in the making of blast furnace cement, ballast for railways, metal for roads, aggregate for concrete, etc. Since it contains sulphates and phosphates, it has a manurial value and could be also used as a furtiliser.

Art. 322. Classifications of Pig Iron — Carbon plays a very important part on iron. It exists in iron in two forms, in a free form as *Graphite* separately from iron and in a combined form as *Cementite* and *Pearlite*. Free carbon impart softness and a coarse crystalline structure to the metal, while combined carbon makes the metal hard and gives a fine grained crystalline structure. The presence of carbon in iron is influenced by silicon. In molten condition silicon throws excess of free carbon out of solution and precipetates it until the percent of carbon is almost the same as its own value. It has also a very powerful influence in decomposing the compound of carbon and iron.

Pig iron is classified on the contents of free and combined carbons as follows. These classifications are termed as grades.

(i) *Grey Pig Iron* — Grades No. 1, 2 and 8. These varieties contain almost all of free carbon or graphite. More than 8 percent is graphite carbon and less than 1 percent is combined carbon. The percentage of silicon is almost the same as that of free carbon. This is a soft variety and has a bigger size cristals. Gray cast iron is quite suited for foundry castings.

(ii) *White Pig Iron* — Grades No. 5, 6 and 7. These contain almost all of the carbon in a combined state less than 1 percent is free carbon and above 8 percent is combined carbon, and silicon less than 1 percent. The crystals are close grained. The metal is hard and strong and could be easily melted. The white variety is used for making wrought iron.

(iii) *Mottled Pig Iron* — In between the grey and white varieties, is mottled pig iron and is classified as grade No. 4, It contains equal proportions of combined and uncombined carbon. It has a mottled appearance and an average hardness.

Pig Iron also contains other impurities like magnesium, sulphur, phosphorus, etc. which influence the manufacturing processes for various products as explained later.

Cast Iron.

Art. 323. Making of Cast Iron — There are four distinct stages in the making of cast iron articles.

(i) Remelting of pig iron, with the aid of a fuel.

(ii) Refining of pig iron with the addition of scrap castings and flux.

(iii) Casting the molton iron in a suitable final mould.

(iv) Cooling down of the moulded article under controlled conditions.

Art. 324. Remelting of Pig Iron — Cast iron is obtained by remelting pig iron and applying some refining processes. It is then cast into the required final moulds to obtain the cast iron articles. We have seen that grey pig iron is more suitable for obtaining foundry casting fluid and is, therefore, used for the purpose. Sometimes, the molten pig iron is also used directly for making cast iron.

The materials employed in the making of cast iron are, pig iron, scrap iron, coke and flux. The adding of *scrap iron* of broken and old castings with pig iron brings about the economy of the process. The remelting of such old castings with pig iron also improves the quality of cast iron prepared and makes it more strong and dense. *The Fuel* commonly employed is coke, to supply the necessary medium for the generation of heat to melt iron and flux. Lime is added as a flux. Lime is added as a flux in the form of limestone or shells. High calcium lime is better suited for the purpose. It forms a slag for removing non-metallic substances and the oxidised products of sulphur, phosphorous and manganese. The ash from the burning of fuel is also removed with the flux. The flux with all the above impurities forms a fusible slag at the high temperatures of the furnace and being lighter than molten iron, collects at its top. This facilitates its removal separately in the refining process.

Art. 325. The Cupola — The first two stages in the making of cast iron, viz., remelting of the pig iron and refining, are carried out in a special furnace called the Cupola furnace. This furnace has a great resemblance to the blast furnace. It is primarily intended for the purpose of remelting pig iron with the necessary refining to a certain extent while the blast furnace has to extract iron from the ore by reducing it and therefore, has it work at a very high temperature as explained before. In fact, the reactions in a cupola are mainly of an oxidising nature, since sulphur, phosphorus and manganese are removed from pig iron by oxidation. The blast of air which is forced into the cupola through the tuyers is cold as against the hot blast in the case of blast furnace.

The details of a cupola furnace are shown in fig. 96. The general features are the same as those of a blast furnace. The materials are put in the furance through the charging door near the top while the casting metal fluid and the molten slag are drawn from the hearth below. Sometimes a hot well is also provided as shown in the figure. A blast of cold air is blown through the tuyers at the level of the burning zone and there are no arrangements of regenerating stoves in this case

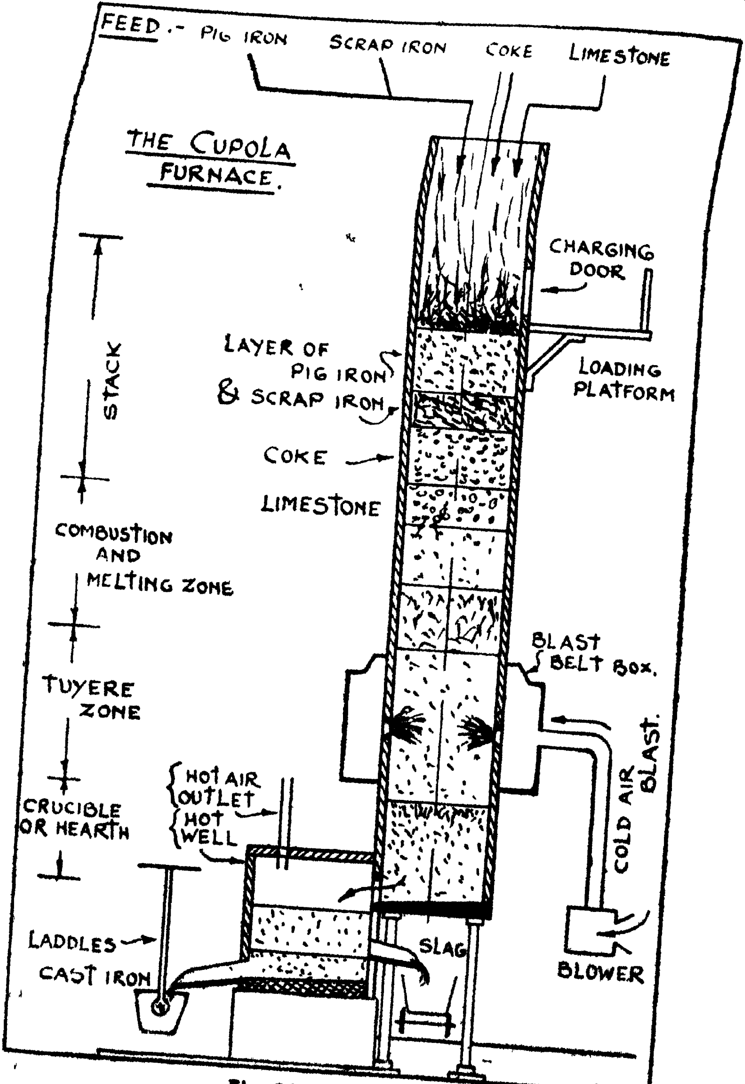


Fig. 96. The Cupola.

for heating the blast. The working of the cupola is not continuous and only the quantity of iron required for the day's castings are molten each time.

Art. 326. Properties of Cast Iron — Tensile and Compressive Strengths — Cast iron is strong in compression but weak in tension. Out of 4 to 5 percent of total carbon, at least 0.8 to 1.2 percent should be in the combined state to impart the necessary tensile strength. The remaining of carbon is in the graphite form.

Cast iron is brittle and does not absorb shocks. It does not possess the properties of ductility and malleability. It cannot be welded, forged or rolled like steel. In recent processes of foundry practice, the above defects are partly overcome as required by the articles to serve different purposes. Gray cast iron is softer than white cast iron. The gray colour is due to the graphitic carbon while the combined carbon imparts white colour to the cast iron.

The specific gravity of cast iron varies from 7.0 to 7.5. The shrinkage of cast iron is a very important property which influences its casting into various shapes. Shrinkage is different with different types of castings and varies anything from less than 1 percent to 3 percent. Due allowance has to be made in the moulds to account for the shrinkage of the molten fluid on cooling.

Cast iron has a very low cost of production and can be cast to any convenient shape easily. It can be used cheaper than steel for making C. I. pipes for water mains and sewers, covers, columns with their caps and bases, brackets, fire gratings, etc.

Constituents and refining.

Art. 327. Composition of Cast Iron — A brief description of the parts played by the constituents is given below. The various common constituents are, - carbon, silicon, manganese, sulphur and phosphorous.

(i) *Iron and Carbon* — Cast iron contains about 92 to 95 percent of iron, 3 to 4 percent of carbon and upto 3·0 percent silicon and the rest are sulphur, phosphorous and manganese in very small percentages.

Combined Carbon — Cementite and pearlite — Carbon plays a very important part on the properties of iron. Pure or free iron is ferrite, Fe, and is soft. Structurally it is weak and tough. Ferrite occurs in combination with carbon as *Cementite,* Fe_3C and for 15 parts of iron there is one part of carbon, i. e. cementite contains 6.67 percent of carbon. Cementite is hard and brittle and has great strength.

Pearlite is another combination where ferrite and cementite occur together. It has properties midway between those of ferrite and cementite; i. e. it is stronger and more ductile than ferrite but slightly weaker and not so hard and brittle as cementite. Thus we have ferrite, cementite and pearlite as the main constituents of cast iron in different proportions.

Free carbon-Graphite— It may be noticed that free carbon also exists in cast iron as graphite either in the form of flakes or in the form of bigger sized particles as temper carbon. See next chapter for a detailed treatment.

We have seen that pig iron has to be remelted to obtain foundary castings. As it cools down graphite is separated in the form of irregular flakes. The size of these flakes, their uniformity of distribution and their quantity influence the properties of cast iron. The graphite flakes are found mixed up with ferrite, cementite and pearlite. To control the above formation of graphite, and to have a uniform distribution of it in iron, the molton pig iron has to be superheated which enable the graphite to dissolve in iron. The molton metal is then allowed to cool down gradually. This allows the graphite to separate out gradually in a rather crystalline form and the rate of cooling also is so controlled that the sizes of graphite nodules are small and well distributed in the iron casting. To add to this alloying metals like silicon carbide, and nickel are added in the powdered form at the casting temperature to help the formation of graphite in the above manner. This improves the structural properties of cast iron.

Coarse and irregular flakes of graphite give softness to cast iron. It does not weather well and wears in an uneven manner. In general graphite flakes reduce the strength and ductility of the metal.

(ii) *Silicon* and *Aluminium* prevent the graphite to remain in the dissolved condition in iron by causing its precipitation. The separation of graphite from iron solution increases with the percentage of silicon. This prevents the formation of cementite. Thus, to have a harder variety of cast iron with maximum cementite, the molton metal should have a low silicon content. However, silicon allows the molten iron to run freely. This property is desirable in a casting fluid to eliminate the formation of blow holes. Silicon is present in cast iron to the extent of 1.2 to 3.0 percent.

(iii) *Manganese* and *Chromium* — There are other elements which help to stabilise cementite in the molten metal. *These are Manganese and Chromium. The presence of these metals is usually less than 1 percent.*

(iv) *Sulphur* makes cast iron weak. Also such cast *iron becomes " red short " or brittle when red hot. The molten metal does not, therefore, flow freely. The castings made therefrom will have flaws,* blow holes and cracks. The desirable quantity of sulphur is taken as 0.3 to 0.5. However, sulphur shows tendency to combine with manganese to form maganese sulphide.

Sulphur has a stabilising effect on cementite, when not combined with manganese.

(v) *Phosphorus* — This has an effect opposite to that of sulphur. It makes cast iron " cold short " or brittle when cold. But cast iron containing phosphorus allows the metal to flow freely and is, therefore, desirable while making intricate castings. The permissible percentage varies from 0.5 to 1.0

Art. 328. Classification of cast iron — Cast iron is generally classified on the form in which carbon exists in it. From the discussion in the foregoing article, it will be found easy to follow the classification below.

(i) *Gray Cast Iron* — 92 percent iron; graphitic carbon 3.5 percent; combined carbon less than 0.5 percent; Silicon 3.0 percent. The gray colour is due to graphite carbon. This variety of iron contains more of ferrite and graphite, less of pearlite and very much less of cementite. Gray cast iron has a low tensile strength of 8 to 12 tons per sq. in. It can be easily machined due to the softness of ferrite and the graphite coming out in the form of flakes.

(ii) *White Cast Iron* — 94 Percent iron; graphitic carbon 0.5 percnet; combined carbon 3.0 percent, silicon 0.5 to 1.0 percent. The white colour is due to cementite. This variety of cast iron contains more of cementite and pearlite and very much less of graphite. Gray cast iron has a high tensile strength of 20 to 24 tons. per sq. in. It is hard and brittle and could not be easily machined.

(iii) *Mottled Cast Iron* — This is a mixture of gray and white cast irons, in composition, colour and general properties. It contains, ferrite, graphite, pearlite and cementite in the corresponding proportions. Its tensile strength is between 12 and 16 tons. per sq. in.

Molding and Casting

Art. 329. Foundry work — The art of pouring molton iron into the specially prepared molds so that on cooling the metal takes up the shape of the mold, is termed as foundry work.

Art. 330. Pattern Making — Patterns of the articles to be prepared by the molding process, have to be made first. They are made with the necessary increase in size to allow for the shrinkage of the molded article on solidifying. The pattern is made either of well seasoned wood, metal or plaster of Paris. Sharp corners and angles are avoided generally in the castings.

Art. 331. Molding — In the process of molding a core of hollow space is formed. Special foundry sand, usually green sand, dry sand or loam, possessing the necessary properties of adhesion and refractory nature is used for the purpose. Pure silica sand with very small quantities of *alumina, magnesium and lime, give best results.* The pattern is placed in the molding box and filled around with the foundry sand. To facilitate the removal of the pattern, the mold is made up of two or more parts called core boxes or flasks. The pattern is then taken out leaving behind a hollow core for the metal to be poured in. Feeding openings are provided in the mold to connect the core for pouring the metal.

Sand molds could be used once only and for the next casting another one has to be made. But where a number of articles of identical shape are to be cast metal moulds are made and could be used repeatedly. But they have their own disadvantages such as, sudden cooling, difficulty in allowing air bubbles to escape, etc.

Art. 332. Casting—After the core is ready in the mold the molten metal specially prepared to suit the requirements, is poured in, with the aid of ladles, until every part of it is filled. Pipes are cast in the vertical position and are then spun with a *centrifugal* motion. This gives a uniform dense texture to the material.

Injection Molding—In this case, the molten metal is forced under great presure into the mold. These are also called *Die Castings*.

Art. 333. Cooling of Casting and Finishing— After the casting is cooled and has solidified it is taken out from the mold. It is then cleaned with a wire brush or a sand blast, and water. The irregularities on the surface of the casting are removed by filing and sometimes by chipping. Any subsequent heat treatment to be given to a casting is treated in the next ehapter.

A defective casting is detected by a dull and a deadening sound when juntly struck with a small hammer. This indicates blow holes and air bubbles in the body of the casting. A good casting should not have anv cracks, or rough surfaces.

Wrought Iron.

Art. 334. Cost Iron and wrought Iron — Wrought Iron is made from pig iron by remelting it in the puddling furnace. It is the purest form of iron, and as the name implies the pig iron has to be worked with in order to obtain it. The whiter variety of the pig iron is used for making wrought iron. It contains about 1.0 % silicon, 1·0 % manganese, 0.5% sulphur, and less than 1·0 % phosphorus. The percentage of total carbon varies from 3 to 4 of which less than 1.0 % is in the free form. During the process of making wrought iron, manganese could be removed completely and the percentages of silicon, sulphur and phosphorus could only be reduced to a minimum. The carbon contents could be brought down to less than 0.15 percent. As a result of this the cast iron which was brittle and could not be bent either hot or cold, is converted into wrought iron which is very ductile. It admits of being bent when hot and when cold. Similarly it could be hammered conveniently to different shapes.

Art. 335. Puddling Furnace —See fig. 97. The puddling furnace belongs to the class of a " Reverberatory Type, " in which the flames from a side fireplace deflect and beat back on the hearth where the metal is being melted. For this purpose, a sloping roof is provided to guide the flames down on the molten metal. By this a higher temperature could be developed in the region of the hearth. But the fuel consumption in a reverberatory furnace is nearly double that of an ordinary direct heating furnace.

The Furnace—The furnace is built of refractory materials such as silica and magnesia bricks set in fireday, and consists of the following component parts :—

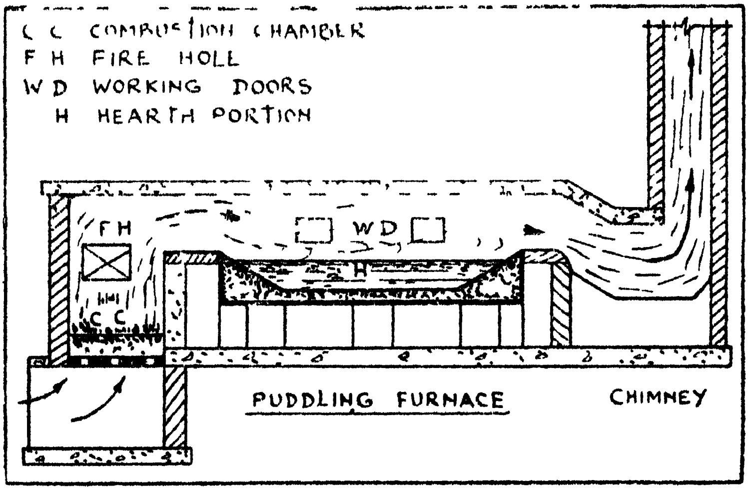


Fig 97 Puddling furnace

(i) *Combustion Chamber* with a fire place, gratings and a fire door, where the fuel is burnt and the flames are generated.

(ii) *The Hearth*—This is a shallow basin, next to the conbustion chamber where the puddling process and the melting of pig iron are effected. By the side of the hearth are provided the necessary working holes to work with the molton iron.

(iii) *The Chimney* is provided on the side opposite to that of the fire place to allow the flue gases to escape.

(iv) *The Roof* — A continuous roof with proper slopes for the purpose of guiding the flames and deflecting them as shown in the figure, is also provided.

Art. 336. Processes of making Wrought Iron — There are two distinct stages in making wrought iron from white pig iron. They are the following —

(a) The melting and the balling stage; and

(b) The shingling or the squeezing stage.

These are discribed below —

(a) *The Melting and the Balling Stage* — The feed consists of the type of pig iron as detailed in art... The lining of the hearth is made up of a material rich in iron oxide, such as red hematite ore. Mill scales are also added to the pig iron along with the feed. During the process of puddling, the lining and the mill scales act as oxidising agents upon the impurities in iron.

After the metal is melted, which takes place within one hour or so, it is stirred thoroughly with the aid of long rakes through the working door. By this the impurities, viz, silicon, sulphur, phosphorus and manganese are oxidised. They leave the iron and enter the slag. The fused slag with these impurities gets itself distributed throughout the molten iron, and makes the iron a spongy mass. During this stage the metal boils and gives a puddling appearance. It is simultaneously stirred and rabbled during this period. The oxide ore of the lining and the mill scales oxidise the carbon contents of the iron also and give out carbon-di-oxide. The gas bubbles through the molten mass and gives a boiling effect as described above.

The molten mass with the fused slag mixed up with it is highly porous and spongy as descrbed before. It is in the form of a thick viscous paste and could now be rolled up in the hearth in the form of a ball of about 100 to 150 lbs. weight. This completes the furnace treatment with the formations of the ball for the making of wrought iron in the first stage.

Art. 337. (b) Shingling Stage — The ball of spongy mass prepared as detailed above, is then taken out of the puddling furnace and is then put below a steam hammer. Here it receives blows to enable the fused slag to squeeze out from the body of the ball. This hammering action removes a greater part of the slag from the iron. Alternatively, the slag could be squeezed out with the aid of a squeezing machines consisting of ecentrically mounted rollers fitted in a casing as in a roll mill. The ball comes out in the form of a bloom at the other end. The squeezed iron is then conveyed to a rolling mill where some more slag is further removed from the iron during the process of rolling. The bars are then cut into pieces of uniform size.

Reheating and Rerolling — To improve the quality of wrought iron, the bars are reheated and rerolled, and each time more of the slag is squeezed out until there is almost 99.5 percent of iron. This produces different grades of wrought iron, such as B, BB and BBB. The wrought iron is now useful to make pipes, chains, boiler plates, sheets, grills, nails, wires, etc.

A very good variety of wrought iron contains the following percentages of its constituents 99.5 of iron; less than 0.1 of carbon; 0.1 of silicon; 0.01 of sulphur, 0.07 of phosphorus and 0.03 of manganese. The remaining is slag in miner quantities. Thus it will be seen that the impurities are almost negligible and that the wrought iron is the purest variety of iron, commercially put in the market.

The main defect in wrought iron is the presence of black streakes of slag and blisters with spots. This is mainly due to incomplete heating, squeezing and rolling.

Art. 338. Properties of Wrought Iron — Heat test and bending test are commonly employed to distinguish cast iron, wrought iron and steel. Cast iron cannot de bent when cold while wrought iron could be bent very easily and steel could be bent with difficulty. Cast iron gets wrotten and breaks very quickly when heated, while steel could be bent easily when hot. But wrought iron becomes pasty and very plastic at red heat and could be easily forged at about 1650° F. It melts at 2800° F, but it cannot be cast into moulds.

Wrought iron is very malleable and ductile. The presence of sulphur makes it "red short" and that of phosphorous makes it " cold short ". The tensile strength of wrought iron varies from 20 to 26 tons per sq. in. It is stronger in compression by about 25 percent. However it is not so strong as steel, and its high cost of production makes it difficult to use except in special cases. In modern constructions mild steel has replaced it greatly.

The properties of iron could be greatly improved in various ways. Carbon steels contain carbon upto about 1.7 or even 2.0 percent, and about 1.5 manganese and 0.5 silicon. These are termed as plain-carbon steels or unalloyed steels, The tensile strength of a plain carbon steel increases from about 25 tons per sq. in. to about 50 tons per sq. in. if the carbon content is changed from 0.15 to 0.6 percent.

The properties of plain—carbon steels could be greatly improved by introducing various alloying elements in it, such as manganese, chromium, nickel, tungstan, molybdenum etc. to form medium tensile and high tensile alloy steels. For example the tensile strength of a plain-carbon steel with about 0.33 percent carbon could be increased to more than double if chromium and nickel are added in suitable proportions.

The properties of plain-carbon steels and alloy steels could be again improved by suitable heat and mechanical treatments. They could be made to acquire great strength and durability under different conditions of use. Properties such as corrosive resistance, heat resistance, wear and abrasion resistance, etc. could be imparted to them. These are explained in the next chapter.

CHAPTER XII

Carbon Steels and Alloy Steels

Types of Steel Manufacture.

Low, medium and high carbon steel. Bessemer process of steel manufacture acid and basic. Bessemer converter details and working.

Open–hearth furnace,– details and working. Deoxidising and recarburizing agents. Tilting hearth.

Electric process. Crucible steel process. Cementation process. The Duplex process.

Milling Operations.

Ingot molds and castings. Reheating of ingots. Rolling; drawing; forging and pressing.

Heat Treatment

Critical points and structural changes. Equilibrium diagrams. Eutectic. Phases of steel transformation. Types of heat treatments.

Alloy Steel.

Principal types of alloy steels,— their composition, properties and uses.

Manganese, nickal, chromium, tungsten, molybdenum and silicon steels. Stainless steel. Tool steel.

Non-Ferrous Metals.

Principal types of non-ferrous metals,— their properties and uses.

Copper ; zinc; lead ; tin ; and aluminium.

Manufacture of Steel

Art. 339. Steel — Pig iron is the raw material for the manufacture of steel. The process consists in refining pig iron by oxidation so that only the requisite quantity of carbon will remain in iron to form steel. Steel contains carbon from anything below 0·25 percent to 1·5 percent. Carbon occurs in the form of iron carbide, Fe_3C, compound of iron and carbon. There are three grades of steel depending upon the percentage of carbon.

Low carbon steel or mild steel	Carbon; anything Upto 0.25 %
Medium carbon steel or medium hard steel	Carbon; between 0.25 % and 0.70 %
High Carbon steel, or hard steel	Carbon; between 0.70 % to 1.5 %

Steel is manufactured from pig iron in the following processes—

On a large scale by:—

(i) Bessemer Process.
(ii) Open-hearth Process

On a small scale for making special steel by:—

(iii) Crucible steel Process.
(iv) Cementation Process.

The fifth and the last process which is now coming into great use, is

(v) The Electric Process. These processes are described in the following articles.

The Bessemer Process

Art. 340. Bessemer Process of Steel Manufacture — The molten pig iron is a mixture of iron and carbon and contains silicon, manganese, sulphur and phosphorus as impurities. From the point of view of steel manufacture, the ore of iron or the pig iron made therefrom, is classified into two main catagories as shown in the accompanying table No 17. (i) The pig iron containing more of silicon and less of phosphorus and sulphur; (ii) The pig iron containing less of silicon and more of sulphur and phosphorus.

Table. No 17. Pig Iron for Acid and Basic Processes.

Contents.	Pig Iron Suitable for	
	Acid Process	Basic process
Silicon	2 to 2.5 %	0.1 to 0.2 %
Sulphur	about 0.05 %	Upto 0.3 %
Phosphorus	about 0.1 %	Upto 0.3 %
Carbon	3 to 4 per cent.	
Manganese	0.2 to 0.4 percent.	

The rest of quantity is iron.

The Bessemer process is really that of conversion, and there are two principal stages in the manufacture of steel by this process, namely :—

(i) The conversion of pig iron to pure iron, and

(ii) The conversion of pure iron to steel.

The above stages of conversion fall into two types, acid and basic, depending upon the nature of reactions in the converter.

Art. 341. The Acid Process — The pig iron suitable for this process is that containing more of silicon and less of sulphur and phosphorus, as shown in table no· · The molten pig iron obtained from blast furnace is stored first in a reservoir of about 1000 tons capacity and each time about 15 to 20 tons of it is drawn out into the ladles for being put into the converter. The reservoir is provided with arrangements to see that the pig iron is kept in the molton condition till it is taken out for making steel.

Fig. 98 shows a bessemer converter in the inclined or receiving position and fig. 99 shows the same in the vertical or the working position. A lining of 12″ to 15″ thick of silica material is provided inside the converter.

(i) *The Conversion of Pig Iron into Pure Iron* — After receiving a charge the converter is brought to the vertical position. This admits automatically a blast of air at about 10 to 20 lbs. per sq. in. pressure to bustle through the molten mass. The blast of air brings about the necessary purification of pig iron.

In the first few minutes manganese and silicon are oxidised and burnt. This is indicated by the brown smoke with a shower of sparks rising up through the mouth of the converter. When this is complete, carbon is the next to oxidise and bubble out as CO_2 gas. This is indicated by a

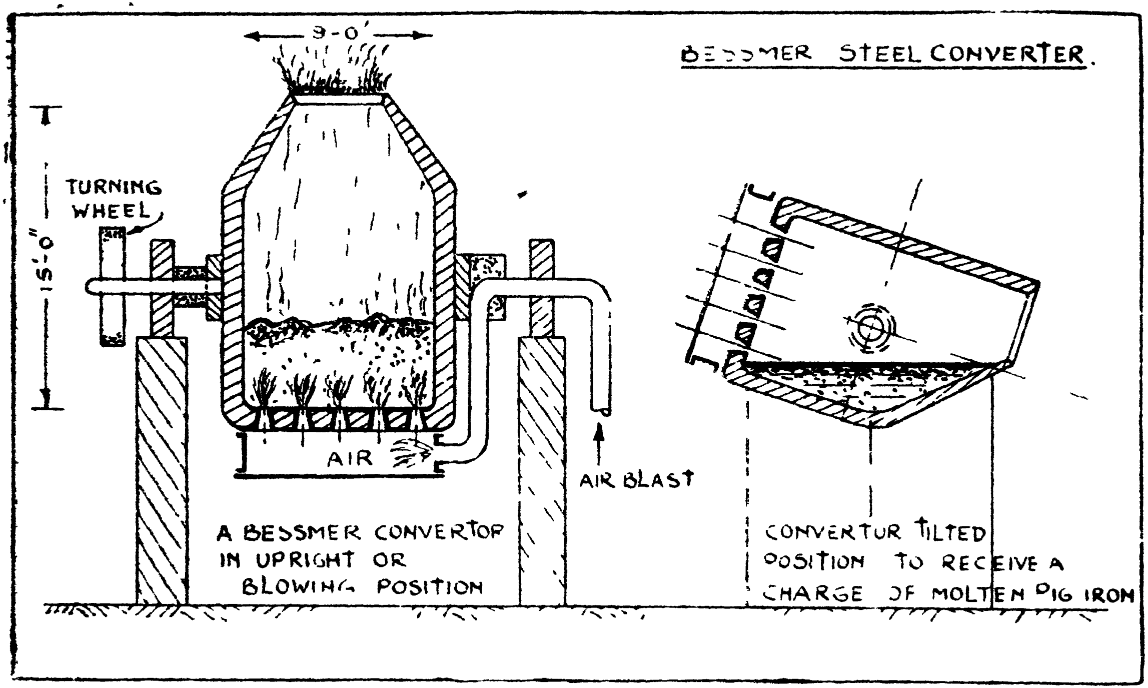


Fig. 98. Bessemer convertor in the working position.

Fig. 99 Bessemer convertor in the charging position clear brilliant flame shooting up to a height of about 25 feet. When all the carbon in the pig iron is burnt out, the flame suddenly drops down. The blast of air is then stopped and the converter is turned down to empty its contents. Thus silicon, manganese and carbon are completely burnt out and eliminated from the pig iron. If the blast is not stopped immediately after all the carbon is burnt out, the iron will be the next to oxidise and this should be prevented. The entire operation takes about 15 to 20 minutes and about 15 to 20 tons of steel could be prepared each time the converter is used.

(ii) *The Conversion of Pure Iron to Steel*— The addition of carbon to the pure iron so made is carried out, by putting " Spiegeleisen " into the converter after all the carbon is burnt and before the converter is tilted. Spiegeleisen contains carbon and manganese which get mixed up in iron with the aid of a blow of air to form steel. Sometimes steel scrap is also added. This stage is known as *"Deoxidisation* and *Recarburization,"* since manganese from the spiegeleisen combines with oxygen in the molten metal to form M_nO and Carbon combines with iron to form steel.

In the acid process the sulphur and phosphorus are unaffected and therefore pass into steel. This is a draw back of the process, but the manganese which is added subsequently improves the quality of steel by removing its red shortness due to sulphur and imparting it hardness and toughness. The lining for the converter in the acid process has to be necessarily of silica to prevent its corrosion.

Art. 342. The Basic Process — In this case the lining of the converter is of alkaline or basic materials like magnesite or burnt dolomite. This helps the removal of phosphorus and almost all of sulphur by forming slag. The pig iron should contain much less of silicon and a sufficient quantity of sulphur and phosphorus to enable the necessary reaction to take place for their removal.

The various stages in the making of steel by this process are the same as detailed above, viz., charging the converter with pig iron, giving a blast of air, adding of spiegeleisen and emptying out of the prepared steel. A small quantity of lime is also put to act as a flux and to maintain the basic reactions in the converter for the satisfactory elimination of sulphur, phosphorus and other impurities. It will be seen from the above that the Basic bessemer steel is of a better quantity than the Acid bessemer steel.

The Open Hearth Process.

Art. 343. The Furnace — The open hearth process of making steel is also known as " Simens-Martin process ", after the names of the two inventors of the process. The main disadvantage with the bessemer process was that only particular varieties of ores or pig iron were suitable for treatment. But with the open hearth process any kind of ore or pig iron could be employed to make either basic or acid steel. But it may be noted that generally acid types of ores are more suited to make steel by the Acid Bessemer Process, while the Open-Hearth Process is adopted in the case of basic ores. The latter is therefore often termed as " Basic open hearth process. " The steel obtained is of a better quality and could be produced on a large scale with a uniform grade.

The furnace is shown in fig. 100 and is built of chrome and silica bricks. The principle of working is the same as in the case of a reverberatory furnace.

The Hearth is a shallow, saucer-like *pan* of a capacity sufficient to melt about 80 to 100 tons of the charge each time. It takes about 9 to 10 hours to complete the process of making steel for every change. The refractory linings for the hearth consists of magnesite bricks. By the side of the hearth and along the longer side are provided charging doors and observation holes.

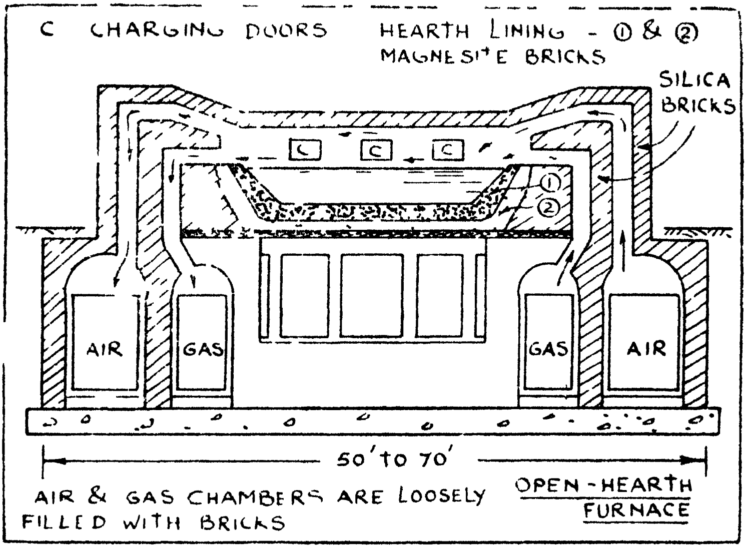


Fig. 100, Open-hearth furnace.

Preheating and Regenerative Chambers — The fuel used in the open hearth process is a mixture of preheated producer gas and preheated air. The heated mixture as it enters the hearth section catches fire and due to the sloping roof, the flames formed beat back on the molten metal. Due to this reverberatory action, it is possible to develop a temperature as high as 3000° F.

The flue gases are made to pass through two chambers on the other side. The chambers contain bricks arranged in a chequer fashion as shown in the figure. The bricks thereby get heated by the flue gases and the chambers thus act as regenerative chambers or as storage chambers for the heat extracted from the flue gases. The gases then pass on to the chimney. After about half an hour the direction of flow of the flue gases is reversed. The air and producer gas are now made to enter the hearth section through the above heated regenerative chambers and get preheated. After burning in the hearth the flue gases will then pass through the chambers through which the air and producer gas were passing previously. The bricks in these chambers will get heated; and the chambers will act as regenerative chambers after another half an hour when the direction of the flue gases is again changed. The use of the regenerative chambers, two on either side of the hearth, adds to the economy of the process by utilising the waste heat from the flue gases. The temperature in the regenerative chambers usually reaches 1600° to 2000° F. The chambers are similer to the hot stoves in the blast furnace.

Art. 344. Process of Making Steel in the Open-Hearth — For every charge in the initial stage, a certain quantity of scrap steel, ore and lime stone are put in the furnace. After these are heated, molten pig iron from the blast furnace is added. Within a period of 5 to 6 hours all the impurities, like silicon, manganese, phosphorus and sulphur are oxidised and pass into the slag. The soft iron produced thereby is almost pure, even to the extent of 99.9 percent.

Deoxidising and Recarburising

At this stage spiegeleisen in the form of ferro-manganese is added to act as a deoxidising and Recarburizing agent. As usual, the quantity to be added depends upon the type of steel required. Sometimes ferro-manganese is added after the soft pure iron is tapped into the ladles from the hearth. This gives a longer and a slower reaction to take place to form steel.

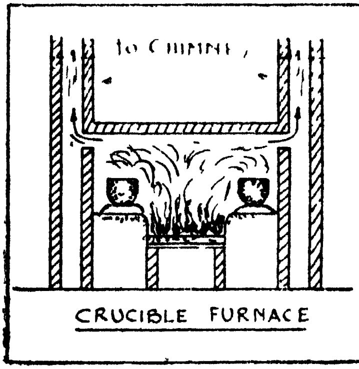


Fig 100 Crucible furnace.

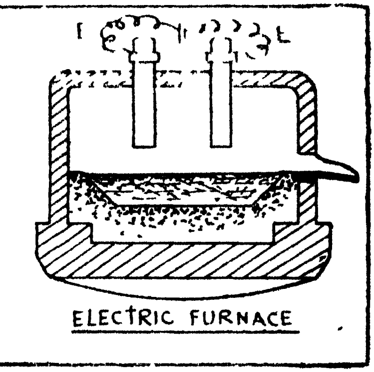


Fig 102. Electric furnace

Slag — The slag formed in the open hearth process collects on the surface of the molten soft iron. It has to be carefully collected, tapped and removed through the slaghole, before spiegeleisen is added.

Art. 345. Tilting Hearth Furnace — The hearth in some cases, is provided with a circular base which is mounted on rollers. This enables *it to be tilted for the purpose* of *emptying out, the slag and the molten metal. Particularly* the *tilting arrangement is suitable for the slag to be tapped out from the surface in the tilted position of the hearth.*

Art. 346. The Electric Process — An electric furnace operates on the same principles as those of the basic open hearth furnace. Instead of air and producer gas, electric current is empoyed as the heat generating medium. Air is not required to operate an electric furnace to generate heat, which is an advantage. An electric furnace is shown in fig. 102. It has a tilting base, the advantages of which are mentioned in the previous article for emptying out the contents. The furnace is about 12 to 15 feet in diameter and has a capacity of 12 to 15 tons of molten steel each time. With the aid of the electrodes, electric arcs are formed and supply the necessary intense heat. With the aid of the tilting base, the slag can be conveniently removed two to three times as it is formed. An electric furnace could be considered as an internally heated crucible. After the spiegeleisen is added, the molten metal is allowed to remain still in the furnace, until it reaches the pouring temperature as required for steel castings.

Wrought Iron to Steel

Art. 347. Crucible Steel Process — Steel is also prepared on a small scale in refractory crucibles. The crucibles are of 10 to 12 ins. diameter and of 18 to 20 ins. height and each crucible yields about 40 to 50 lbs. of molten steel at a time. They are made of fire clay, graphite and carborundum. About 4 to 8 crucibles could be placed in furnace in a circular fashion around the fire place. The crucibles are filled with pieces of high class wrought iron, to which are added some scrap iron. They are then covered with a layer of charcoal. Lids are then placed on then for being put in the furnace for heating as shown in fig. 101. The contents melt in 4 to 5 hours and a slag is formed on the surface. It is skimmed off from the surface twice or thrice. Owing to the slow and steady process of carburization, the quality of steel is also improved. The best variety of steel could be formed by this process.

The crucibles are then taken out and the molten metal is used for steel castings, or for forging into different shapes, or for making ingot molds. The steel from bessemer or open hearth is remelted in crucibles to make it homogeneous and crystalline. Crucible steel yields good "blister steel" which is suitable for making knives, razors, cutting tools, surgical instruments, springs, files, etc. The above advantages of the crucible process are now being derived by the electric process and the special types of steel could be manufactured on a larger scale.

Art. 348. Cementation Process— Steel is also prepared from wrought iron by the *Cementation process*. It is a very slow process and requires anything from 5 to 10 days to manufacture one variety of steel. Wrought iron flats of a very good quality, about 6 to 10 ft. long and ¼″ to 3/4″ thickness, are placed one over the other with layers of powdered charcoal in between them. They are well packed in refractory boxes and kept in a furnace for heating. They are gradually heated for the first two days and then the temperature of the furnace is raised subsequently. The lowering of the furnace temperature is also done under controlled conditions and very gradually. Good variety of blister steel with fibrous texture, specially suitable for axes, saws, springs, chisels and tools, is also made by the cementation process.

Art. 349. The Duplex Process— This is a combination of the Acid Bessemer process and the Basic Open–hearth process. We have seen that the bessemer converter with a silica lining is best suited to eliminate silica, manganese and carbon from pig iron, while the basic open–hearth is used for removing sulphur, phosphorus and other impurities from pig iron. The Duplex process is invented to take the advantages of the above two processes. Thus the molten pig iron after receiving treatment in the acid bessemer converter, is put in the basic open-hearth. This eliminates the various impurities in two stages. In the basic open–hearth, the slag formed is skimmed off from the surface, which is an additional advantage of that process. The recarburizer is then added in the form of ferro–manganese, either in the hearth or in the laddles as required. The economy of the process is effected by adding scrap iron in the open hearth as usual. There is much saving in time in the Duplex Process, and within 6 to 8 hours steel could be made. It is clamied that the steel produced by this process is of a better quality.

To obtain a very high quality of steel the Triplex Process is sometimes recommended, where the molten pig iron, after receiving treatment in the coverter and open-hearth, is further refined in the electric furnace, to get the advantages of the crucible steel process.

Milling Operations

Art. 350. Ingot Mold Castings — The prepared steel in the molten condition either from the hearth, converter or the laddles, is poured into metal molds called ingot molds. The molten metal can be also used directly to obtain steel castings as detailed under cast iron. The solidified metal from the ingot mold is termed as ingot. An ingot measures 7 ft. long, with square top and bottom of 15-ins. and 18-ins. square respectively. They are storred for further use into the various milling operations.

Art. 351. Reheating of Ingots — (i) *Rolling.* Before the ingots are used for milling operations, they have to be uniformly heated to working temperatures. The ingot is then passed through chilled roller to reduce its size. As a result of this the cristals formed in the ingot during cooling are drawn out into threads, and the steel gets a fibrous texture. The ingot is made to pass through the rollers many times, each time getting reduced in section. Rounds, flats, angles, squares, Tees, channels, and I-sections are all obtained by this method of rollings. Sheets are also rolled in the rolling mills.

(ii) *Drawing* — The round sections of the rolled metal could be further drawn into wire by making them to pass through holes of successively smaller diameters.

(iii) *Forging and Pressing* — Forging consists in shaping a hot piece of steel with the aid of a die or a series of successive dies, under a power hammer. The metal is kept in the die of the required shape of the article and is pressed into it under a hammer. The milling operations improve the quality of steel also. The steel becomes ductile.

Heat Treatment

Art. 352. Heating and Cooling of Pure Metals — From the condition of a fused liquid at high temperatures, as the metal cools down, it becomes more viscous until when it reaches the freezing point, it starts solidifying. At freezing point, the temperature of the freezing liquid remains constant so that a metal freezes at a constant temperature. After the whole of it has become a solid, the temperature drops further to that of the room temperature. The cooling curve of a typical metal with respect to time is shown by P. Q. R. S. in fig. 108. QR shows the *Freezing Point* or *Arrest Point* of the liquid, where the temperature is constant, even when there is a lapse of time. During this period important structural changes take place in the mass. These points are also termed as *Critical Points*.

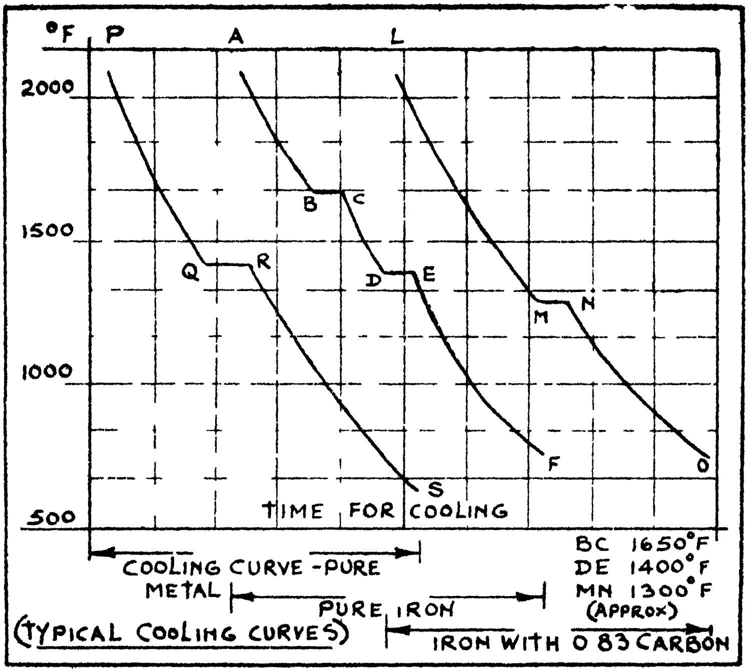


Fig. 103 Typical Cooling Curves.

On the other hand, the reverse happens when a solid metal is heated. At the melting point, the temperature is constant until all the metal is converted into a liquid or a molton state. The temperature then rises further. Regarding the highest temperatures usually attained in the metallurgical operations in industries, it may be noted that these temperatures just convert the metals into fused liquids.

The temperature at which the change of state from a fused liquid to that of a solid takes place is slightly lower than that at which the solid is converted into a fused liquid. In the former case, heat is given out and in the latter heat is absorbed when the above physical changes take place.

Art. 353. Effect of Heat on Alloy Metals — An alloy is formed by mixing two or more metals in their melted condition. The atoms of these metals get themselves intermingled in a homogeneous manner and are uniformly dispersed. Usually, this is possible with almost all metals except with a very few, such lead and aluminium.

Effect on Freezing point — When any two metals exist in a dissolved condition in a molten state, the freezing points of the two metals are affected, in fact they are lowered. The extent to which this lowering of the freezing point of the metal takes place, depends upon the percentage of each metal in the molten mixture. see fig. 104.

Consider Alpha & Beta as any two metals mixed to form an alloy at different proportions. Let P Q represent lead and R Q represent tin. Their independent melting points are 625° F and 450° F respectively. The effect of mixing tin at varying percentages with lead is to lower the melting point of lead until it reaches 360° F. Similarly, the effect of mixing with tin, lead at varying proportions, is to lower the melting temperature of tin until it also reaches 360° F. At this lowest temperature of melting of the alloy of lead and tin, their respective percentages are 62 and 38.

Thus it could be seen that when two metals form an alloy there is a lowest temperature at which the two will start freezing simultaneously, and to secure this they have to be mixed in a specific proportion.

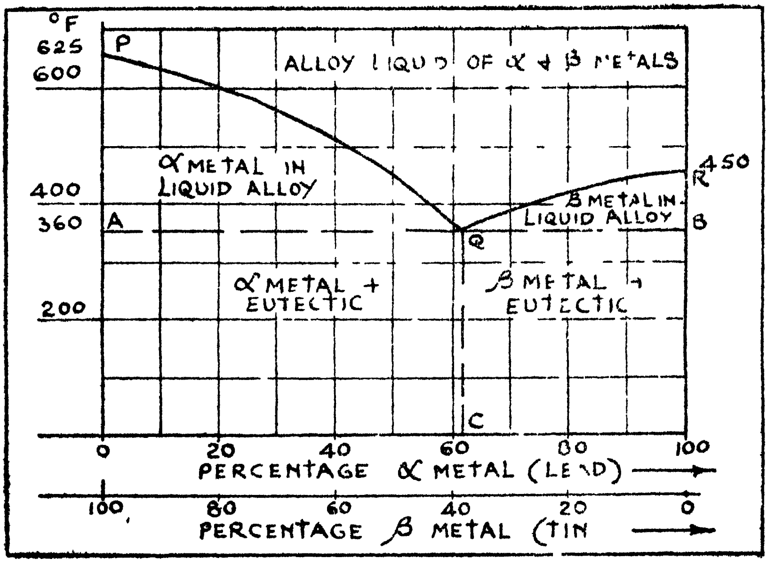


Fig 104. Equilibrium diagrams for lead and tin

The manner in which the solidifying or freezing temperatures of the two alloying metals are affected is shown by the " Equilibrium Diagrams ". In fig. 104 the equilibrium diagrams are P Q and R Q; P Q being the upper curve and R Q the lower one. Above the upper curve the alloy is all in the liquid state and below the lower curve it is in the solid state. Between the two curves there is differential freezing and one of the metals solidifies first and the other remains in a liquid state. This gives a " *Solid Solution* ".

The point of intersection of equilibrium diagrams gives the " *Eutectic Point* ". Thus if 62 percent of lead and 38 percent of tin are added to form an alloy, it will melt very easily at the lowest temperature of 360° F. This indicates that lead and tin form a " Eutectic Alloy " at the above percentage. Such an alloy crystallises easily from the eutectic solution state, giving a uniform fine granied structure to the solidified mass. Thus a eutectic alloy is one that melts easily at a lowest temperature.

Art. 354. Effect of Heating and Cooling on Pure Iron — *Ferrite* — This is shown in fig.108 by the curve A B C D E F for values less than 2600° F. The curve shows the effect of cooling from the fused liquid state, with two freezing points or arrest points at 1650°F and 1400° F approximately. When the pure iron is heated from room temperature, it will be found that the above arrest points or critical points are about 40 to 50° F higher than the above temperatures. The form of iron above temp. 1650° F is termed as Gama-iron and that below 1400° F is termed as Alpha-iron. In between these two forms, iron passes through an intermediate stage known as Beta-iron.

Face-Centred and Body-centred — cubic lattice for iron. The atoms of iron arrange themselves in the cubic system in two ways, which are structurally different. They are described below :—

(i) *Face Centred Gama-iron* where the atoms of iron arrange at the rate of one at each corner of the cubic lattice space and one at the centre of each face of the cube, i. e. there will be 8 + 6 = 14 atoms of iron in one cube. This form of iron takes one atom of carbon at its body centre by way of dissolution to form iron carbide Fe_3C or cementite. Thus theoretically 6.67 percent of carbon can dissolve in iron. It may be noted that at temperatures higher than 2000° F, cementite decomposes. It is most stable at 1300° F or round about that temperature.

(ii) *Body centred Alpha-Iron* — Where the atoms of iron are arranged at the rate of one at each corner of the cubic lattice space and one at the body centre.

Alpha & Gama are the only two important forms of iron to consider. For 0.6 percent of carbon or more Gama-iron changes directly to Alpha-iron at about 1400° F. The critical temperature is then gradually lowered until when the percentage of carbon is 0.83 or so, its value is 1300° F. See the curve L M N O in fig. 103.

The classification could be written as follows :—

Alpha-iron upto 1400° *F.*

Possesses magnetic properties. Has a body centred cubic lattice, for the arrangement of its atoms.

Beta-iron from 1400° *F to* 1650° *F.*

It is non-magnetic but structurally, it is the same as Alpha-iron and the difference between Alpha and Beta iron is not much. Beta-iron cannot be attracted by a magnet.

Gama-iron above 1650° F and upto 2000° F approx. It is a fused liquid and has a face-centred cubic lattice.

Both the forms of iron, viz., Gama-iron and Alpha-iron, which are free from carbon are called *Ferrite.*

Art. 355. Iron and Carbon Alloys–Antenite; Cementite and Ferrite — We have seen in the previous articles that when an alloy is formed of two metals, the freezing temperatures of either are lowered. A similar phenomenon takes place when alloys of iron and carbon also are formed. This is shown in fig. 105, where the equilibrium diagrams for iron and upto 2.00 percent of carbon are drawn to illustrate the principle. The face-centred Gama-iron which has a freezing temperature of 1650° F in its ferrite form, gets this

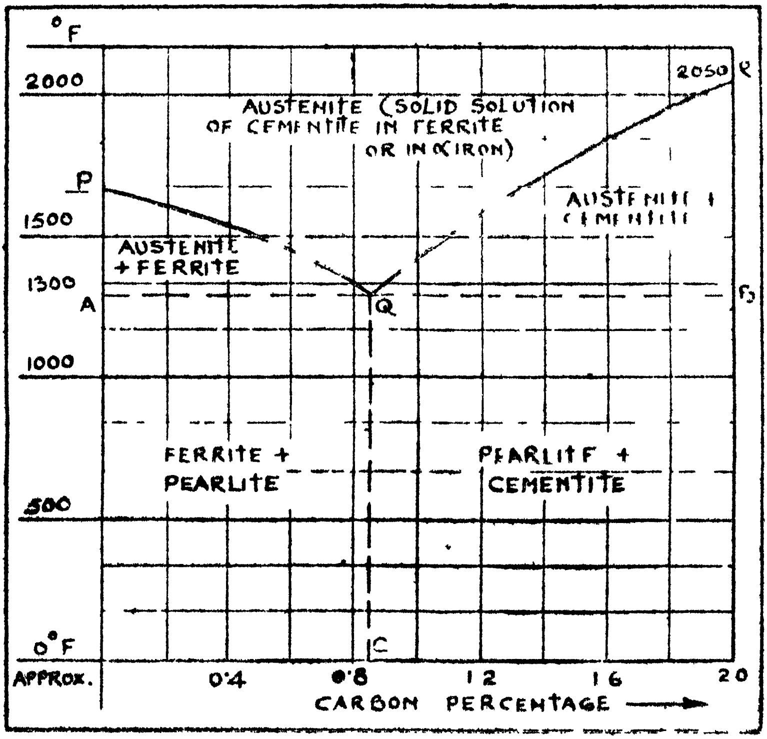


Fig. 105. Iron carbon equilibrium diagram upto 2.0 percent carbon and below 2000° F.

value reduced to 1300° F when 0.83 percent of carbon is added to it. The manner in which this reduction of freezing temperature takes place from zero percent carbon to 0.83 percent carbon is shown by the equilibrium curve PQ. This gives the values of the upper critical point for different percentage of carbon.

But beyond 0.83 percent of carbon and upto 2.0 percent, within the temperature of about 2000° F the equilibrium diagram is shown by the curve QR. Thus a eutectic point Q is obtained at 1300° F for 0.83 percent of carbon.

We have seen that ferrite combines with carbon to form iron carbide, Fe_3C or cementite at a temperature of about 1800°F and that iron could contain 6.67 percent of carbon dissolved in it. From the above also, it could be seen that since cementite decomposes at temperatures higher than about 2000° F i.e. when the contents of carbon is near about 2 percent, the maximum amount of carbon that can exist in a solid solution is also about 2.0 percent. Below this temperature and above the iron carbon equilibrium diagrams, we have a solid solution of cementite in ferrite (Gama-iron) which is known as *Austenite*.

Between eutectic temperature line at 1300° F and equilibrium diagram PQ, ferrite (Alpha-iron) cristals are deposited in austinite, while between this line and the equilibrium diagram QR, cementite crystals are deposited in austenite.

At temperatures lower than the eutectic point, i.e. 1300° F, on the left hand side where carbon is less than 0.83 percent, the Alpha-iron and the solidified mass of the Eutectoid known as " *Pearlite* ". On the right hand side where the percentage of carbon is more than 0.83 and less than

2.0, the solidifying mass below 1300° F, contains cementite and also pearlite as before. Thus the eutectoid containing 0.83 percent of carbon in austenite or the iron-carbon alloy formed of ferrite and cementite in fixed proportions, will start freezing at 1300° F approximately to torm pearlite through the stage of eutectoid transformation. The above formations are explained in the following classification of composition of steel :—

Serial No.	Percentage carbon –	Composition of steel.	Type of steel.
(1)	Upto 0.83	Ferrite and pearlite.	Low and medium carbon steel.
(2)	0.83	All pearlite	Medium carbon steel.
(3)	Above 0. 83 and upto 2.00	Cementite and pearlite.	High carbon steel.

Art. 356. Iron and Carbon — More than 2.0 percent of carbon at greater than 2000° F.

It may be noted that for carbon content of more than 2.0 percent a eutectaind is formed at about 2000° F when the percentage reaches 4.33. The mixture of iron with such high carbon contents yields cast iron. Similarly equilibrium diagrams for percentages of carbon higher than 2.0 and for temperature of higher than 2000° F could be drawn so that above these diagrams the mixture of iron and carbon is in a liquid state and below that temperature they are solids. Though theoretically 6.67 percent of carbon can dissolve in iron, it is not possible practically to go beyond [illegible] percent or so. Pure iron melts at 2800° F, and to obtain a casting fluid of steel or cast iron a suitable temperature between 2000 F and 2800° F should be attained.

The Effect of Heat — On the iron carbon alloy the effect of heat is to reverse the process of eutectoid transformation by changing pearlite to austerite at 1800° F and dissolving either ferrite or cementite as the case may be until the upper corresponding critical temperature on the equilibrium diagram is reached. Beyond this temperature the mixture gets completely transformed into austenite.

Art. 357. Effect of Rapid and Slow Cooling of Molten Steel —The above discussions regarding the structural changes in steel are only possible, if the cooling takes place under slow and controlled conditions. From very high temperatures of liquid solution of iron-carbide or cementite in Gama–iron, we pass on to solid–solution of cementite in Gama-iron i. e. austenite, which further changes to :—

(i) Ferrite and pearlite; or
(ii) All pearlite; or
(iii) Cementite and pearlite,
depending upon the percentage of carbon.

Again the structural transormation of austenite to pearlite on slow cooling takes place in four stages, so that steel assumes successively the following forms :—

Austenite, martensite, troostite, sorbite and pearlite. If by some means, instead of the slow cooling, rapid cooling or quenching is effected by adopting intensive measures for cooling austenite, the mixture will not get any time or opportunity to pass through all the above transformations. This transformation could be stopped at any of the above structural forms by adopting a suitable intensified rate of cooling.

Martensite — This is formed if austenite is cooled at a very intensive rate in cold water. The cementite does not get time to transform to pearlite. But though the cooling is extremely rapid, Gama–iron changes to Alpha–iron cementite will be found in a state of dispersion in Alpha–iron. Martensite has a needle like structure and is extremely hard. The hardness is due to the strains in the lattice space, which have to be removed by a second heat treatment.

Troostite — A slower rate or cooling will give rise to the formation of *Troostite*. The cooling is usually effected in an oil tank. The hardness of troostite is less than that of martensite. The softness is attributed to the formation of a greater proportion of Alpha–iron in it.

Sorbite is the next stage to that of troostite. For its formation, the rate af cooling has to be still slower. It is softer than troostite but harder than pearlite.

Pearlite is the final stage in the transformation of austenite. It is a stable form while the above three intermediate forms are unstable. pearlite contains about 6 parts of ferrite to one part of cementite.

Art. 358. Heat Treatment of Steel — In order to develop various properties in steel of different grades so that it could be used for different purposes, it has to be given a heat treatment. The properties of steel depend upon ;—

(i) The percentage of carbon; and

(ii) The heat treatment.

The manner in which carbon influences the properties of steel by forming iron-carbide or cementite has been already explained. A brief description of the different types of heat treatment and their effect on the properties of steel are given below —

Art. 359. Hardening — We have seen that steels with different percentages of carbon contain austenite above the temperatures of the iron–carbon equilibrium diagrams, and that the effect of quenching is to produce the various transformed stages from martensite down to pearlite. These forms exhibit different degrees of hardness. The quenching medium could be anything from ice–cold water to boiling water, or it can be oil. The hardness imparted to steel depends upon the medium used and also upon the rate of cooling. The articles are heated to just above the upper critical temperature for some time and then quenched.

The thickness of the material has an effect on the uniformity of the hardness developed in it from the surface to the interior. The surface of steel articles could be heated by a blow pipe and by subsequent quenching, its surface could be only hardened.

Case Hardening or Carburising — This is done by packing the articles in a box containing a carbon medium such as charcoal, etc. and heating them to a sufficiently high temperature so as to convert the Alpha–iron to Gama–iron. The Gama iron thus formed absorbs more carbon to the required thickness, depending upon the time of contact. Low carbon steels are selected for the purpose. Generally, the case hardened part contains about 0.88 percent of carbon to form a hard skin of eutectoid steel.

Nitriding is another process by which the surface or steel could be hardened by a nitride of iron. As the nitride of iron is not so stable, this method is more suitable for alloy steels of aluminium, cromium, molyldenum and vanadium, whose nitrides are stable.

Art. 360. Tempering — The strains set up during quenching due to austenite lattice not being given a full chance to transform, have to be relieved by a subsequent heat treatment called tempering. Moreover the contraction and the consequent dimensional change in the article is not uniform by sudden quenching. Thus the quenched steel is both hard and brittle, the hardness due to the formation of martensite and brittleness due to the quenching strains.

During tempering it is necessary that the martensite formation should not be lost. Steel should, therefore, be heated to a temperature sufficiently lower than the lower critical point. The subsequent slow cooling relieves the quenching strains by restoring equilibrium conditions in the material. The tempering temperatures are usually ranging from 300° F to 1000° F. The colour on the surface of steel during heating is a guide to temperature, viz., yellow brown, purple to blue. Tempering imparts ductility by removing brittleness. Thus tempered steel is both hard and ductile.

Art. 361. Normalising — For machine work steel has to be sufficiently soft and free from internal strains and cracks. The size and shape of the grains in steel also have to be of a specific type as required in different workshops and have, therefore, to be refined. The above two requirements are fulfilled by the normalising process.

Steel is heated to a temperature higher than the upper critical point by about 100 to 150° F and cooled gradually in air. The rate of cooling controls the grain size and softness is imparted to it with a homogeneous texture.

Art. 362. Annealing — During the processes of cold rolling, drawing and pressing, the material loses its ductile properties and becomes brittle. It has to be annealed by a heat treatment to restore this properly before it could be further handled. Annealing is not much different from normalising, except that the article to be annealed is cooled inside the furnace. The articles are heated above the upper critical point before cooling in both the cases.

Malleablo Cast Iron.

Art. 363. Principle — This is white cast iron which is annealed. The carbon in the combined form is converted into temper carbon and this imparts malleability to the castings. By the heat treatment the carbon which is in the form of cementite in the white cast iron is separated in the form of temper carbon and not in the form of flakes of graphite as in the case of gray cast iron. The sulphur combines with magnesium and forms magnesium sulphite. Silicon is present to the extent of 0.7 to 1.5 percent and plays a very important in separating carbon from cementite to form temper carbon in the process of annealing.

Art. 364. Annealing the Casting — The castings are put into boxes or annealing pots very carefully and are packed well with iron scales, iron ore, scrap, slag and sand. The pots are kept in a furnace for about 2 to 4 days and the heating is generally carried sufficiently high so as to cause the softening of the meterial and to effect the necessary decarburization. The furnace is then allowed to cool down gradually according to the predetermined cooling schedule as required to develop the necessary malleability. The total process usually takes about 5 to 8 days.

Malleable castings are both strong and ductile. The tensile strength is about 20 tons per sq. in. and the compressive strength 40 to 60 lbs. per sq. in. Malleable castings can be bent cold and can be forged and welded. They are tough and can withstand shocks and blows.

Alloy Steels.

Art. 365. Alloy Steel — Hitherto the preparation and properties of plain carbon steels were discussed. They also contained a very small proportions of the elements like silicon, manganese, etc. But these were not added for any specific purpose of forming an alloy. Plain carbon steel has its own limitations of use. For special purpose to develod specific properties alloy steels are used. The common alloying metals are chromium, aluminium, tungsten, manganese, nickel, molybdenum and vanadium. It may be noted that ordinary steel to which no other alloy is added is called " Straight-Carbon Steel". When alloying elements are added to iron, they form solid solutions in varying proportions in Gama-iron. With the addition of an alloying element, the straight carbon steels are generally improved. They gain in strength and behave satisfactorily under heat treatment. Depending on the number of alloying elements used, there are " ternary " or " quarternary " alloy steels. The examples of alloy steels are, nickel steel, chrome-nickel steel, chrome - nickel - vanadium steel, etc.

Some of the common types of alloy steels are given in the folloging articles.

Art. 366. Nickel Steel — This cantains usually 2.5 to 3.5 percent of nickel and the amount of carbon is 0.2 to 0.4 per cent. Nickel improves the tensile strength and reduces the brittleness. It also imparts hardness and ductiity. An additian of 1.5 percent of chromium to nicked steel improves these quality greatly. It stands wear and fatigue quite well and is largely used for armour plates, boiler plates, machine parts, shafts, etc. The addition of 30 percent af nickel yields a type of steel known as "Invar" which has a very low coefficient of expansion.

Art. 367. Chromium Steel — If 1.0 to 2.5 percent of chromium is added to steel, it becomes very hard and tough. The percentage of carbon also varies from 1.0 to 2.0. Chromium increases the elastic limit and the ultimate strength of steel. Chromium steel is not used for structural work. It is quite suited for cutlery. Its abrasive resistance has given it a wide application in the making of ball bearings. If the percentage of chromium is increased to about 12, the steel acquires rust—proof and acid—proof qualities. The steel is then termed as " Stainless steel ", which is so widely used in the making of sinks, surgical instruments, grills and ornamental fittings, etc. An addition of 8 percent of nickel and 18 per-cent of chromium gives the best type of stainless steel, which will be very strong and tough. Stainless steel also contains very small quantities of manganese, phosphorus, silicon and sulphur. Stainless steel could be rolled and pressed very satisfactorily. It possesses an important property of resisting corrosion which the ordinary straight-carbon mild steel does not possess. Permanent magnets are made of chromium and manganese steel. Sometimes tungsten is also added to chrome steels.

Art. 368. Manganese steel — We have seen that manganese plays an important part in removing sulphur from iron by forming a sulphide. In commercial steels manganese is present upto 2.0 percent as an alloying constituent. Manganese steel is equally hard, tough and wear resisting. Manganese helps the formation of stable carbides, so that its hardness is not affected by cooling.

Art. 369. Tungsten Steel — Best type of tool steel could be made with the addition of 5 to 7 percent of tungsten to steel. The carbon percentage should be round about 0.8 to form a eutectoid composition. It gives the best type of high speed steel. For lathe tools, drills and for chisels tungsten steel is best suited. Steel for hot work and for very high speeds could be prepared by adding about 18 percent tungsten, 4 percent chromium, 1 percent vanadium to high carbon steel containing round about 0.8 percent of carbon. By a suitable heat treatment consisting of heating, quenching, and tempering the formation of martensite is successfully effected. In modern practice steel for hot work is prepared by adding certain quantities of molybdenum and reducing the percentage of tungsten proportionately.

Art. 370. Vanadium Steel — This element also increases the strength of steel and helps the formation of a very small grain size in steel. It is therefore, used for grain refinement. It has the same properties as chromium and *manganese, but to a greater extent. It resists softening at high temperatures, a property which is essential for use in making high speed tools.*

Art. 371. Molybdenum Steel *— This is used in very small quantities of 0.2 to 0.3 percent. It is generally used in* combination with chromium and manganese. It enables steel to maintain a good tensile strength at high temperatures.

Tool Steels should be hard in general, and should not be brittle. Before the alloy steels were made, tool steels were prepared from plain high carbon steels by the crucible process. Tool steel for high speed work should maintain its hardness even at high temperatures.

Art. 372. Silicon Steel - Silicon imparts hardness and strength to ferrite in general. Silicon to form an alloy should be present to the extent of 1 to 2 percent in steel. The other effects of silicon have been already explained. A very good variety of spring steel could be manufactured with the following percentages,–1.5 of silicon, 0.6 of carbon, 0.7 of manganese and 0.6 to 08 of chromium.

Non–Ferrous Metals

Art. 373. General — The manner in which ferrous metals or those that are formed of iron as the principal constituent, are derived and used has been described in the previous articles. A brief description of the non-ferrous metals is given in the following articles. The principal ones are : Copper, zinc, Lead, Nickel, Tin, Aluminium, and Chromium. Other non–ferrous metals are, tungstan, manganese, cobalt, molybdenum, titanium, vanadium, etc. which are principally used as alloying metals,

Art. 374. Copper — Next in importance to steel is copper. It weighs 550 lbs. per cu. ft. and has a reddish colour. It is malleable and ductile and could be rolled and drawn. It melts at about 1950° F. Copper does not corrode in dry air. It has a high thermal and electrical conductivity. It is very widely used for making electrical wire, cables, etc.

Copper occurs in the native form, as well as, in ores as an oxide and a sulphide. Copper pyrites, $CuFeS_2$ is the important ore of copper. The ore is crushed powdered and washed to eleminate the impurities. The smelting of the native copper is then carried out in a reverberatory furnace where the sulphur is removed in the form of a slag and the molten metal is collected separately for purpos of casting. The ores are first treated in a blast furnace and then blown through in a convertor. The metal thus obtained is termed as " Matte " and "Blister Copper " respectively. It has to be subsequently refiined.

Refiining of copper could be done successfully in a reverberatory furnace where about 95 percent of the pure metal could be obtained. But the electrolytic process of depositing copper yields almost 99.8 percent of pure metal

Art. 375. Alloys of Copper — *Brass* — This is an alloy of copper and zinc in proportion varying from 70 percent of copper and 30 percent zinc, to 85 percent of copper to 15 percent zinc. Brass resists corrosion quite well. It can be rolled into sheets, turned into tubes, drawn into wires, and cast into molds.

Bronze — This is an alloy of copper, zinc and tin. All bronzes contain about 80 percent copper. The addition of tin upto 20 percent imparts hardness and strength to copper. Phosphur-bronze contains about 1 percent of phosphorus.

Art. 376. Zinc — Zinc is obtained from sulphide ores known as Zinc Blende. The ore is roasted and crushed. Zinc is then extracted by distillation and then refined. Zinc volotalises at high temperatures and could then be condensed into a liquid to obtain metallic zinc.

Zinc is very soft. It has a resistive power for oxidation on exposure to weather. Zinc is principally used for galvanizing and for alloying. Zinc oxide is extensively used for painting. Zinc weighs about 430 lbs. per cu. ft. and melts at 480° F.

Art. 377. Lead — Lead is another important metal in the non-ferrous group. It occurs usually as a sulphide known as galena, PbS. The ore is subjected to the usual procedure of crushing, roasting and washing, and finally smelting in a blast furnace to produce " matte ". As it is always associated with other metals, it is separated by the process known as " Liquidation ", where the difference in the fusion point temperatures of the various metals is taken advantage of. Lead mels at 625° F and has a weight of 700 lbs. per cu. ft.

Lead is a very soft and a non-corrodible metal having a very low strength. It is malleable and ductile and can be drawn into wires. Lead is widely used in making alloys, in plumbing work, paints, roof covering, etc. Lead is widely used in the making of type metals in printing.

Art. 378. Tin — This is a white lustrous metal occuring as an oxide ore. It is extracted by smelting and refined finally. It has a melting point of about 450° F and weighs about 450 lbs.per cu. ft. Tin is highly resistant to corrosion It is a very soft and a weak metal. It is extensively used for tin-plating and for making alloys.

Alloys of Tin and Lead : Solders—A very common process of joining lead pipes, tin plates, galvanized iron and copper is by soldering. A solder is an alloy whose melting point is lower than that of the metals to be jointed. A solder has an important property of wetting the two surfaces to be jointed. *A flux* is generally added to clean the surfaces to be jointed to develop this adhesion. zinc chloride, ammonium chloride, and rasin are the common fluxes used.The metals to be soldered should be heated to a temperature near about the melting point of the solder to enable it to adhere and flow. The common types of solders used are :—

Soft Solders contain — equal proportions of lead and tin. Fine solders contain 60—40 tin and lead. The *wiping Solder* used by the plumber contains 40 percent tin and 60 percent lead. 20-80 tin and lead alloy gives solder for jointing metals where strength is required. In all the above solders 2 to 3 percent of antimany is also used.

White Metal—In the case of metals required for bearings of moving parts, it is necessary that one of them should be of a softer metal. The white bearing metal is an alloy of tin, lead and antimony, with copper in it, in varying proportion. The bearing metals accommodate themselves for any defect in the alignment of bearings. After wearing away the bearings could be replaced by a suitable white metal.

Fubsible Alloy of lead and tin could be made to melt at a temperature of about 350° F. The addition of bismuth reduces this temperature to about 200° F, and that of bismuth and cadmium brings it down to even 150° F. Fusible alloys are largely used as safety measures in controlling the rise of temperatures.

Art. 379. Aluminium — Aluminium occurs very widely as an oxide, Al_2O_3 on the surface of the earth. Clays contain more than 25 to 30 percent of alumina. The oxide ore which yields aluminium on a commercial scale is Bauxite. After The ore is purified, the metal is extracted by an electrolytic process.

Aluminium weighs 165 lbs. per cu. ft. and melts at about 1150° F. It is very soft and ductile. Aluminium is largely used for electrical work. It can be powdered to a great fineness which helps it to act as a pigment in paints. Commercial aluminium is hard and tough and is used for making sheets, plates, bars, wires and various structural parts.

Aluminium Alloys — Aluminium forms alloys well with silica, zinc, copper, nickel, tin and chromium. Aluminium steel gives a very good type of a light structural material. Commercial aluminium contains silicon and manganese which impart them hardening properties. The most important alloy of aluminium is "*Duralumin*" or "*Dural*". It contains 4 percent copper; less than 1.0 Percent of manganese and magnesium; the balance is aluminium; generally iron and silicon are also present to the extent of about 0.5 percent. It is as strong a mild steel and can receive heat treatment quite well.

CHAPTER XIII

Miscellaneous Materials

Paints and Varnishes.

Protective coating. Paints. Constituents of paints :—their functions and manufacture.

Base; vehicle; pigment; drier and thinner. Water paints and distempers. Varnishes, - oil and spirit varnishes. Enamels of resin.

Metal Corrosion and protection.

Corrosion of iron. Prevention of corrosion. Alloying a gents. Metallic protective Coatings. Galvanizing. Tin-plating. Electroplating.

Glass and Glass Products.

Composition. Silica, lime, soda, potash, and red lead. Functions of constituents. Glass manufacutre.

Glass fabrication, — blowing, drawing, rolling.

Types of glases. Fibre glass. Laminated glass, etc. Annealing.

Paints And Varnishes.

Art. 380. Protective Coatings— Timber and steel and plastered surfaces are the principal ones that have to be protected from the weathering action. The usual protective coatings are all applied in a liquid form and subsequently harden by evaporation of their volatile constituent and also by chemical reactions. These reactions are mainly those of oxidation.

Paints : Paints essentially consist of :—

(i) A Base	(ii) A Vehicle
(iii) A Pigment	(iv) A Drier, and
(v) A Thinner	

The common materials used to act as these constituents and the functions played by them are given below :—

(i) *The Base*— The base of a paint is its principal constituent forming its body. It also possesses the binding properties. Zinc white, white lead, red lead are the common materials used as base. Sometimes iron - oxide and graphite are also used. The base forms an opaque layer to obscure the surface of the material to be painted. A lead paint is affected by the atmosphere action and is, therefore, not suited for final coats of paints. But it is quite suited for painting iron and steel work as it sticks quite well and acts as a good protective. White Zinc is unaffected by weathering, but is costly. It is an oxide of Zinc. For interior work *Lithophone* is largly used as a white paint.

(ii) *The Vehicle*— The function of a vehicle is to contain all the materials of a paint and to allow them to be applied on the surface to be painted. Linseed oil is the most widely used vehicle in the making of paints. It is obtained from flax-seed. Wood oil, cotton seed oil and soyabean oil are also used in some places. Linseed oil contains acids which react readily with oxygen and harden by forming a thin film. Raw linseed oil does not dry quickly and is not fit for external work. Pale boiled linseed oil is better than raw linseed oil. But to have best results and to dry the paint quickly and successfully in the form of a thin and a uniform homogenous film, refined and double boiled linseed oil is only used. It is quite suited for external work. Boiling makes the oil thicker and darker in colour. Raw oil is thin and if mixed with a suitable drier, it is used for making delicate thin paints for interior wood work.

(iii) *The Pigments* — These form the colouring matter used for giving the required tint or shade to the paints. They are solids in a very fine state of division and usually of the colloidal dimensions. These fine particles have a reinforcing effect on the thin film of the paint. The dried film of linseed oil cracks on hardening and the pigments lessen these cracks. It is therefore, necessary that the particles of the pigment should be in a completely wetted condition and fully dispersed in the vehicle. The best pigments are those that do not change their colour when exposed to heat, Sun's rays or acid laiden atmosphere. Most pigments fail to satisfy this requirement. The common pigments are lampblack, suit and charcoal black, for black colour; venetian red, red lead and Indian red, for red colour; burned umber, raw and burned sienna, for brown colour; chrome green for green colour; prussian blue and ultramarine, for blue colour; ochre and chrome yeellow for yellow colour. Powderoed metals like aluminium, copper, bronze, etc. are also used as metallic pigments.

(iv) *The Driers* — The function of a drier is to absorb oxygen from the air and to supply it to linseed oil, which hardens as explained before. Driers are usually compounds of metals like lead, manganese, cobalt, etc. dissolved in volatile liquid. Driers have a tendency to destroy the elasticity of the paint and therefore, should not be used in excess as this would cause the paint to peal off in scales. The driers are also termed as plasticizers.

(*v*) *The Thinner* — This acts as a solvant for the purpose of thinning the paints and thus impart them better covering power. The paint could thereby be spread uniformly on the surface. It also gives proper consistency to paints. The common thinning agents used are terpentine and nephtha. The thinner evaporates and dries the oil consequently.

Art. 381. Preparation of Paint — The surfaces to which paint has to be applied should be clean to develop proper adhesion. Old painting should be scraped well before a new coat is applied. To prepare a paint, the base is thoroughly ground in the vehicle and mixed with the thinning agent to impart the necessary workability to the paint. The pigment and drier are also separately ground and mixed with some oil to a thin consistency. The two are then thoroughly mixed to form the desired paint. Grinding in roller mills is an important operation in the mixing of paints.

Art. 382. Water Paints — These are similar to the paints described above except for the base which is a casein and the thinning agent is the water. Casein is mixed with and hydrated lime to form a paint in combination with the desired pigment. Casein requires a preservative to be mixed with. Water emulsions in oil and synthetic resins are also used in making these paints. Water paints are suited only for interior decorative work. Distemper is another name given to these water paints.

Art. 383. Varnishes - Oil Varnishes—These consist of melted resin dissolved in hot linseed oil. On cooling it can be mixed with terpentine for the purpose of thinning.

Spirit Varnishes — Shellac varnish and French polish are made by dissolving gums, and resins in a volatile solvant which is generally methylated spirit or alcohol. The hardening of the spirit varnish is due to the evaporation of the volatile solvant.

Art. 384. Resin Enamels — Enamels are prepared by grinding a paint such as the best quality of zinc oxide, in varnish or a viscous bodied oil. These give a harder and a more glossy film than an ordinary paint. Steel plates give a suitable surface for enamels. The pigments to be used should not contain any acid component as this would corrode the steel. Recently aluminium paint is largly used for protecting iron and steel members. It is prepared by mixing aluminium powder with a suitable varnish or resin.

Art. 385. Distempers — This is another name given to water paints as explained in ar. 392. All distempers contain :—

(i) A base, which is a casein, glue or starch;

(ii) A thinning agent which is water or water and oil emulsion; and

(iii) A pigment given under paint constituents. The oil bound water paint or distemper is available in the form of a soft mass or paste and to be thinned down by water. Oil free distempers are available generally in the form of powder which has to be thoroughly mixed with water to form a colouring liquid. These two varieties are washable, i.e. once they are applied and hardened, the surfaces could be washed by gentle rubbing. An inferior type of distemper could be made by mixing a pigment in glue or a mixture of starch and glue. It is not washable.

Metal Corrosion and Protection.

Art. 386. Corrosion of Iron and Steel — In damp atmosphere iron and steel are gradually eaten away by the formation of rust of iron changing into iron oxide. This is more so in the case of waters with some acidity coming in contact with iron. Rain water carries CO_2 gas dissolved in it. In industrial towns it is also charged with acid particles. In such cases, the corrosion of iron and steel takes place more rapidly. Iron forms iron carbonate with carbon-di-oxide. Under the influence of oxygen from the air the iron carbonate separates from iron to form iron oxide and carbon-di-oxide, which again helps to supply fresh carbon-di-oxide to form iron carbonate and to continue the process of corrosion. Dampness and air are quite essential to set up corrosion and acidity promotes it. Rusting also takes place due to the electrolytic action set up on the surface of iron and steel. The ionic reactions cause the formation of iron oxide.

Art. 387. Prevention of Corrosion — The corrosion of iron could be prevented in one of the following ways :—

(i) *Alloying Agents* — We have seen that the products of corrosion are carbonates and oxides. Alloying elements are added to steel and by forming a resistant oxide, they protect steel under this coating. For this purpose, to render steel stain-proof or rustless, a suffieient quantity of the alloying element should be added. Copper, chromium, nickel and phosphorus offer this protection to steel by forming their resistant oxides under atmosqherie conditions. It was pointed out that an addition of 10 to 14 percent of chromium yields stainless steel. A sufficient amount of chromium oxide film is formed on the surface to prevent the corrosion of steel.

(ii) *Metallic Protective Coatings* — This takes advantage of the principles of electro-chemical corrosion when two metals are in contact in aciduated water. The two metals form, one an *Anode* and the other a *Cathode* and it is the anode end that is eaten away. Magnesium, aluminium and zinc are used as protective metallic coatings for iron and they form an anode while iron forms the cathode. Thus in the process of corrosion, the protective coatings undergo a preferential rusting and save the iron from being rusted.

Galvanizing — In this process a thin coating of zinc is deposited on the surface of iron or steel. It is very cheap but is most readily corroded. The sheets and the articles are passed through a bath of molten zinc. Zinc also dissolves partly in iron and forms an alloy. The articles are first cleaned and dipped into a hydrochloric acid solution. Sheradising consists in heating the articles with powdered zinc in a closed air-tight vessel. Sheradising is also known as the cementation coating process. An alloy of zinc and nickel offers a better protection if used as a galvanizing material.

Tin Plating — The process is similar to galvanizing and the medium used is tin instead of zinc. The stages such as washing the plates in a flux or an acid, passing through a bath of molten tin and finally brushing off the excess coating of the metal, are all arranged in a continuous operation. Lead is also used to provide a coating for iron and the process is known as Terne plating. Aluminium coating is specially suited as a protective in marine atmosphere.

Electro Plating — Metallic coatings can also be giving on the principle of electrolysis. The article to be electroplated is made to form a cathode; on which are deposited the liberated ions from the solution of the matel for coating. Chromium, nickel, aluminium, copper and zinc are used as before. This method is quite suited where bright surfaces of costly metals like chromium, nickel or copper are desired.

(iii) *Painting* — This has been a very common practice used for providing a protective coating for metals. Brush painting or spray painting are usually the methods adopted for giving this coat.

Glass

Art. 388. Composition — The principal constituent of glass is silica; but if silica alone is used, it could be melted only at a very high temperature. On cooling it would give a good glass. At the same time, the molten mass of silica is very thin and therefore, could not be worked with. For satisfactory fabrication or handling of the molten mass, such as for blowing, drawing, rolling, pressing or spinning, it must be sufficiently viscous. It is, therefore, necessary that an alkaline material, such as sodium or potassium carbonate has to be added to reduce the melting point of silica and also to impart viscosity to the molten mass.

Pure silica and soda glass has its own disadvantage. It is soluble in water and is easily acted upon by acids. It does not possess any weather resisting properties. Again to overcome these defects and to impart durability to glass, lime is added as a third constituent. But the addition of too much lime makes the glass too fluid to be handled for fabrication. Lead oxide is also sometimes added to serve the same purpose as lime. It makes the glass bright and shiny. The glass thus prepared loses its original transparency due to silica but become crystalline and brittle.

The presence of iron is not at all desirable in glass constituents. But it is very difficult to have the raw materials quite free from iron. It forms into a silicate and gives green colour known as "bottle green." Manganese dioxide, MnO_2 is added to correct this colour. It virtually washes the glass liquid and removes the green colour. Manganese-di-oxide is therefore, called "Glass makers soap". Other colours could be given to glass by the addition of suitable metallic oxides.

A small quantity of "Cullet" is also added to the above constituents. Cullet is the old broken glass of the same type as that which is intended to be prepared.

Glass can now be described as an amosphous mixture of silicates of metals possessing the properties such as, hardness, brittleness, and transparency. But modern glass can be made so soft as could be bent easily and nailed through very conveniently. Glass has roughly the following composition:—

Table No. 18. *Composition of Glass.*

Constituents; percentages.	Type of glass.	
	Soda lime glass, Window glass, Plate glass, or ordinary glass.	Lead glass, High class glass Ware, Cut glass, and special glass.
Silica	70 to 76	50
Lime	10 to 13	——
Soda	10 to 13	——
Potash	——	17
Red Lead	——	33
Alumina	2 to 4	——

Boro Silicate Glass is made by mixing small quantities of borax and felspar. This glass has special heat resistant qualities. Cullet to the extent of about 50 percent is added to the above constituents.

Art. 389. Manufacture of Glass — The raw materials described above are ground and sieved. They are then mixed in specified proportions for being melted in a furnace. The glass melting furnace is termed as a *"Tank Furnace"*, at the one end of which are put the raw materials and at the other end the molten glass liquid is drawn out. The glass furnace belongs to the reverberatory type and is about 100 ft. long, 25 to 30 ft. wide and 4 to 5 ft. deep. The process of melting glass is continuous. Glass can also be melted in a *pot furnace*

Art. 390. Glass Fabrication — The art of preparing glass materials from the hot and viscous glass fluid is included in its fabrication. The different processes include :—

Blowing — A blow pipe is dipped in the liquid glass to take out a small quantity of the molten mass. It is then blown through to form a bulb and then a hollow cylinder which is subsequently cut and spread out to form a thin plate. The process of blowing could be done by a single individual blowing through the pipe or automatically by a compressed air cylinder on a large scale, blowing through a series of blow pipes.

Flat Drawing and Rolling — The viscous fluid could be drawn in the form of a plate by making an iron bar move sidewise through it. It brings with it a thin film of glass. Sheet glass could also be prepared by the process of rolling. A continuous sheet is formed and the required sizes could be cut out from it. Rolled glass is more plain and has a more even surface than the drawn glass.

Pressed Glass — The glass liquid is pressed into molds to prepare rectangular blocks of a superior quality from which cut glass ware is made.

Fiber Glass — Glass can be made, so soft as could be drawn into threads or fibers in the form of thin filaments. These can be even finer than cotton thread or silk. They have a great tensile strength and could be woven into mats, which could be used for air filters to remove dust from the air.

Laminated glass — Two or more sheets of glass could be made into a sandwich with a layer of resin plastic between them. Such a glass is splinter proof and shock absorbant and provides a good acoustical medium. If a layer of wire mesh or woven wire is introduced between the two laminae of glass sheets, wired glass is formed. The woven wire mesh is inserted as the glass plates are rolled.

Foam glass — This is prepared from powdered glass to which is added the desired quantity of carbon or any gas forming substance. The mixture is heated into a mold. The glass softens to react with carbon to give out a gas which makes the mass porous and light in weight.

Structural glass —Glass building blocks or glass bricks are now being prepared for use in walling or facing of buildings. They are used where diffused lighting is in demand in a building. They also possess good fire resisting property.

Art. 391. Tempered and Annealed Glass — The sudden cooling of glass introduces strains in the material and makes it brittle. The shrinkage strains could be removed by allowing it to cool slowly under controlled conditions in an annealing furnace. Such a glass would resist heat changes without cracking. The slow cooling can also be effected by allowing the articles to pass through a long tunnel in which the temperature is gradually diminishing from one end to the other,

Fused Silicate

Art. 392. Fused Silicate Enamel Ware — Ordinary steel articles are very often provided with a coat of vitreous enamel glass. This prevents rusting and makes the material acid proof. An enamel is a glass product with its coefficient of expansion almost the same as that of steel. The enamel can be of any desired colour.

The powdered enamel is blown against the hot surface of the steel articles to which it sticks on by fusion. The articles are reheated for the enamel to melt uniformly and form a thin layer. This process is repeated two or three times to obtain the required thickness and smoothness of the surface of the enamel.

CHAPTER XIV

Miscellaneous Materials *(Contd.)*

Asphalt and Bitumen.

Natural and artificial products. Forms of asphalt,— Cut–back; emulsion; cement; mastic; and straight–run.

Uses of asphalt. Bituminous felt.

Rubber.

Natural rubber. Latex. Coaggulation. Crude rubber. Vulcanizing. Synthetic rubber.

Plastics.

General. Types of plastics. Thermosetting and thermoplastic.

Materials for plastics. Resins. Common types of molding powders used. Fabrication of plastics. Fillers, plasticizers, solvants and pigments. Polymarization and condensation.

Molding,— pressure, injection, extrusion, blow and cast processess.

Properties of plastics. Plastic laminates. Plastic coatings.

Asphalt and Bitumen

Art. 393. General — Asphalt is the name given to the combination of a *Mineral Matter* which is either calcareous or silicious, and an organic matter which is a hydro-carbon, known as *Bitumen*. Asphalt can be obtained naturally or it can be prepared artificially.

Natural Asphalts, also known as Rock Asphalts, occur as deposits, from where the material is dug out. They contain bitumen, anything varying from 5 to 12 percent, upto 30 to 40 percent. In the case of the latter variety with high bitumen content, it is possible to extract bitumen from them. Bitumen forms the carbonecious cementing material in asphalts. Chemically it is a hydro-carbon as explained above. It is insoluble in water but dissolves completely in carbon-bisulphide, CS_2. It is black or brownish-black in colour. At ordinary temperatures, it becomes hard but at higher temperatures it softens and catches fire at about 450° F. It can be converted into a liquid by heating.

Rock Ashpalts with low bitumen contents are used directly for road making, etc. near about the places where they are available. The asphalt rock is crushed, heated and spread on the road surface. It is consolidated by rolling with the aid of a road roller and becomes hard as it cools down. Bitumen thereby binds the mineral matter such as limestones or sandstones just as cement binds the aggregate in concrete.

Rock Asphalt with high bitumen content yields bitumen. The extraction is done by heating the crushed material with the aid of steam coils passing through it. The rock asphalt liquifies and the bitumen separates due to the mineral matter settling down and the impurities floating to the surface as scum. The bitumen is refined and filled in drums for dispatch to use where required.

Art. 394. Residual Asphalt — Certain crude oils yield asphalt as a residue after their fractional distillation. After all the volatile oils are removed from them, such as naphtha, petroleum, kerosene, fuel and iubricating oils, ranging from temperature 750° F to 1650°F, the residue left in the distillation kettle contains asphalt. It has the property of solidifying on cooling. The residue is taken out and the bitumen is extracted from it for being filled in the drums.

Art. 395. Forms of Asphalt — (i) *Cut — back Asphalt* —For cold applications as in the case of repairing cracks in roofs, floors, reservoirs, etc., asphalt has to be in a liquid state as could be used by a brush. For this purpose it is thoroughly mixed with a volatile solvant such as petroleum, nephtha, or benzol. On application and after exposure, the volatile solvant evaporates, leaving behind asphalt in a solid condition, filling up the cracks.

(ii) *Asphalt Emulsion* — Asphalt and water are thoroughly mixed by vigerous shaking to form a composition in which asphalt particles are in a state of suspension. To stabilise this mixture an emulsifier is added. This prevents the separation of asphalt from water and forms an emulsion. Asphalt emulsions are widely used as paints where water-proof qualities are required and black colour is no objection. The paint dries after the water evaporates.

(iii) *Asphaltic Cement, or Blown Bitumen* — If air is blown through asphalt at high temperatures, the bitumen is partly oxidised and the liquid becomes thick and plastic and can be used as a cement paste. It becomes highly resistant to atmospheric variations. Owing to its elastic nature combined with adhesive and binding properties of a cementicious material, it is admirably suited for water-proofing, terrace roofing, expansion joints in concrete, etc

(iv) *Mastic Asphalt* — A combination of powdered natrual rock asphalt and the bitumen from the residual asphalt, with a mixture of a suitable proportion of fine sand, gives a good material which is used for damp-proof courses, kitchen and lavatory floors, road work, etc.

(v) *Straight-run Road Oils* — Instead of removing all the volatile matter from the asphaltic-base crude oils, if the fractional distillation is stopped at about 1300° F, the residual asphalt will be somewhat thin and will form a good oil which could be sprayed by pumps, or forced through road surfaces under pressure. It is quite suitable for reconditioning existing roads.

Art. 396. Uses of Asphalt and Bitumen — asphalt is widely used as a water-proofing material both as a membrane and as a binder. It forms good expansion joints and fills up the cracks of leaky roofs. It possesses sanitary properties and is therefore used in lavateries and floors of bath rooms, kitchens and of railwag coaches. It is used for providing a damp-proof course in buildings.

In the making of modern roads for rubber tyred vehicles, asphalt concrete is largly used. It is necessary that traffic must be continuous to keep the asphalt alive.

Asphalt is used for making paints and plastics.

Art. 397. Bituminous Felts — Felt is a product prepared by weaving in a zig-zag manner, vegetable fibres or animal hair, into a close-textured, flexible sheet. Felts could be used as water-proofing sheets by treating them with bituminous materials. In one form "Bitumen Impregnated Felts," are made. The surfaces of such felts could be finished either with fine sand, mica or talc powder, or crushed stone may be used in the case of exposed surfaces. Bituminous felts provide a good material for sound insulation and also act as a medium for absorbing shocks.

Rubber

Art. 398. Natural Rubber — This is derived from the juice of rubber trees, which are tapped by forming vertical and inclined grooves round the trunk. The depth of the grooves does not extend beyond the cambium layer. The fluid or the milky juice is called " Latex ". It is collected in pails or earthenware pots at the close of each day for making rubber.

The latex is then *Coaggulated* by heating with the addition of a weak solution of acetic acid. The mixture is continuously stirred. As a result or this the mixture is curdled and water is liberated. The mass is then rolled into sheets and gives what is known as *Crude Rubber*. Crude rubber can also be formed by spraying the latex in a hot chamber. The water evaporates and rubber falls into drops for being collected.

Art. 399. Vulcanizing. — Pure rubber softens and becomes sticky in hot weather and brittle in cold weather. It can be made to acquire useful properties for making into various articles, by mixing about 1 to 4 percent of sulphur. Other filler materials of mineral matter are also mixed with rubber, such as, carbon black, zink oxide, oxide of iron, china clay, etc. Such rubber becomes hard and tough. It is resistant to water and is unaffected by ordinary changes in temperature. The process of mixing rubber with sulphur to make it hard and resistant is called *Vulcanizing*. Hard rubber could be made by increasing the percentage of sulphur to about 30 and also by raising the vulcanizing temperature to about 300° F. At this temperature hard rubber could be moulded under a pressure of about 1500 lbs. per sq. in. to make moulded articles. Tyres are usually moulded hard rubber products, with the sulphur percent varying from 15 to 30.

Art. 400. Synthetic Rubber — Rubber is also made synthetically by polymerization of hydrocarbon. Neoprene is one variety of synthetic rubbers and is made from acetylene. In many respects it is superior to natural rubber. It possesses excellant weather resistant properties and has a good resistance to acids, oils and greese. It exhebits better mechanical properties than natural rubber. Thiokol is another synthetic rubber which is of a harder quality with a better resistive power.

Plastics

Art. 401. General — Plastic is an organic material prepared out of *Resins*, with or without the incorporation of fillers, plasticizers, solvents or pigments. Resins can be either of natural origin or of synthetic make. A plastic material could be shaped permanently for use either by moulding or by casting under pressure and increased temperature. There are non-rigid plastics also which permit of a slight change in shape of the finished articles under pressure. Other varieties of plastics even permit of cold moulding. Plastics also include the products of cellulose derivatives.

Natural resins like shellac, and bitumen have been used in plywood industry for a very long period, as has been already point out. They became soft and melted when heated and hardened when cooled. The manufacture of synthetic resin is of very recent origin. Backeland was the first person to prepare in 1907, synthetic resin on a commercial scale, from the reaction of phenol and formaldehyde, with the addition of small quantities of acids and alkalies. The synthetic resins prepared therefrom could be hardened under pressure and heat. *Bakelite* is the general name given to these products. During the reaction a great amount of heat is given out and liquid resin is produced. It could be subsequently crystallised and powdered by crushing and grinding. It is called molding powder and is used in the making of plastics. The properties of synthetic resins could be developed and controlled, which is not possible with natural resins.

Art. 402. Types of Plastics — There are principally two types of plastics :—

(i) Thermo-setting; and
(ii) Thermo-plastic.

The characteristic properties of these are already mentioned under adhesives on page 814. They generally require heat and pressure for shaping and hardening them.

The *Themo-setting Variety* requires great pressure and a momentary heated condition during shaping for subsequent hardening. Heat sets up cross-linkages between the molecules, the result of which is an infusible mass which is very hard and resistant to heat. During this process chemical reaction takes place, which is not reversible. The scrap of a thermo-setting plastic article is not reusable. Bakelite is a good example of this type of plastic.

The Thermo-Plastic Variety hardens due to a physical change occurring in the material. They could be softened by heat repeatedly, and the linkage between the moleculers is rather loose. The material becomes more hard as it cools down. The process of softening by heat and hardening when cooled down could be repeated indefinitely. This property allows the scrap from the broken and rejected articles, and the trimmings from molding machines to be reused. Thermo-plastic articles require to be kept for sometime in the mold until they cool down and harden. Thermoplastics are soluble in many solvents. Bibumen, cellulose and shellac are the principal varieties of this type.

Materials for Plastics

Art. 403. Common Thermo-Setting Resins — (i) *Phenol Formaldehyde* — These resins are prepared by condensation of phenol and formaldehyde in a steam jacketed kettle, Much heat is liberated during the process. Phenol is carbolic acid and is obtained from coal tar or synthetically from benzene and air. Formaldehyde is a gas, liberated when wood alcohol and air are passed over heated platinum or copper, or synthetically from carbon-monoxide and hydrogen. It is dissolved in water to form a 40 percent solution known as formalin. To hasten the process of condensation of phenol and formaldehyde, an acide or an alkali is added. During the process, resin and water are formed. The water is carefully seperated from the resin and the latter is subsequently drawn out. It is then dried and powdered for use in making plastics. Phenol resins are dissolved in alcohol for making paints and varnishes.

(ii) *Phenol Furfural - dehyde* — This is prepared out of the waste agricultural products such as husks of rice, shells of oats, ground-nut, crushed refuse of sugarcane. These are digested with sulphuric acid by the process of acid hydrolysis, and finally distilled. Furfuraldehyde comes out as vapour, and is dissolved in water to form a solution like formaldehyde. It reacts with phenol to form resin and water. The resin formed is slightly of a darker colour and is used for making plastics.

(iii) *Urea Formaldehyde* — Urea resins are also prepared as condensation products of urea and formaldehyde in the presence of an acid or an alkali. Urea is prepared from farm waste and manure. It can also be prepared from ammonia and carbon-di-oxide, under a pressure of over 1000 lbs. per sq. in. Ammonia is derived from the nitrogen in the air. Urea resins are also termed as amino resins. They are harder and more brittle than phenolic resins. They have good weather resisting power and are widely used for making plastics for electrical equipment.

(iv) *Casein Plastics* — We have seen how casein is used as an adhesive. It is a protein organic adhesive obtained from sour and curdled milk. Casein reacts with formaldehyde to yield a plastic material and takes up the dyes readily. The hardening of casein plastics is a delayed process. Industriaily they have a wide application in the making of buttons, buckles, etc., as they could be machined satisfactorily.

Art. 403. Common Thermo - Plastic Resins — (i) *Cellulose Derivatives* — Cotton linters or short fibres left on the seeds ofter ginning, and purified paper pulp, are the chief sources of cellulose. The cellulose is modified chemically to form :—

(a) Cellulose easters; and

(b) Cellulose ethers.

Cellulose Easter — Nitrate This is the plastic material which yields celluloid. It is prepared by reacting cellulose with hot sulphuric acid and nitric acid. The cellulose used is in the form of cotton waste fibre. Celluloid admits of excellent fabrication either by compression or by injection. It can be cut and drilled, plained and sawn. Knife handles, set-squares, fountain pens, dolls, etc. are made out of celluloid. Similarly cellulose Acetate is prepared by using acetic acid instead of nitric acid. The plastics produced from this material have a very high softening temperature.

Cellulose Ethers — Ethyl. The purified cellulose from cotton linters is treated with caustic soda to form alkali cellulose. It is then reacted with ethyl sulphate. Ethyl cellulose is white and yields plastics of hard rubber-like, transparent sheetings. It possesses electrical insulating properties. Methyl cellulose is prepared by reacting alkali cellulose with chloride, and methyl sulphate. The plastics prepared from methyl cellulose are soluble in water and therefore are not moisture resistant. Methyl cellulose is best suited for making emulsion paints, adhesives, etc.

✓(ii) *Acrylic* — These resins form the next variety of thermo-plastics. Methyl Methacrylate resin is made from acetone, prepared by fermentation of carbohydrates. Acetone forms acetone cyano–hydrin with hydrocyanic acid, which by a complex series of chemical reactions is converted into methyl methacrylate or acrylic resin. These plastics possess best optical properties such as clarity and transparency. They have good weather resisting qualities and are both flexible and rigid. They are very light in weight.

✓(iii) *Vinyl Resins* — Vinyl acetate and Vinyl chloride are the two principal varieties. Acetytene gas is the source of these resins. If it is passed into acetic acid, vinyl acetate is formed; while, vinyl chloride is formed, if it is reacted with dry hydrogen chloride gas. The products have to be polymerised to convert them into useful plastics. Polyvenyl resins of soft and semi–soft varieties are good substitutes for leather and are used for making tubes and electric insulating materials.

(iv) *Styrene Plastics* — Polystyrene. This is prepared by catalytic polymerisation from styrene. Styrene is prepared in two ways :— By forcing ethylene through benzene in the presence of aluminium chloride; or by dehydrogenation of ethyl benzene. Polystyrene is resistant to inorganic acids, alkalies and moisture. It is a very cheap transparent plastic.

The various synthetic materials mentioned above are available as " *Molding Powder* " in the form of granules which are used for making plastics, as described below.

Fabrication of Plastics

Hitherto the discussion about the various synthetic materials for making plastics was made. These materials themselves do not possess all the properties generally required in the finished plastic articles and have only a limited range of applications. For the purpose of importing these properties and for their fabrication or molding and shaping, molding compounds such as : —

(i) Fillers;
(ii) Plasticizers; and
(iii) Solvants;

are added as required. There is a wide range of these molding compounds. Their selection and their mixing in different proportions, is determined by the manufacturers of plastic articles which have to exhibit the desired properties and usability.

Fillers — These are added to molding powder, to increase the bulk and lower the cost and also to reduce the shrinkage during molding and to impart moldability. Fillers are also added to impart the desired property in the plastic article. The common fillers used are :— *Wood Powder* is a general type of filler used. It is absorptive and light in weight. *Mineral Fillers* are used where heat resistance is desired. *Fibrous materials* like cotton fabric, and asbestos are added where shock resistance and resitance to high temperature are important. Mica is also used as a filler for developing electric insulation properties.

Plasticizers — These are added to impart softness combined with strength, flexibility, toughness and elasticity to the moulded article. By the addition of a plasticizer and with the incoration of a *Volatile meterial,* the desired properties could be imparted to plastics, the volatile materials acting as solvants

Art. 404. Molecular Size — *Polymerisation and Condensation* — Carbon combines with hydrogen to form a hydrocarbon. It can combine with four atoms, e. g. methane CH_4, where one atom of carbon combines with four atoms of hydrogen to form one molecule of methane. A Molecule of hydrocarbon can also contain two or more than two atoms of carbon, e. g. ethane, C_2H_6 with a single linkage or bond between the two carbon atoms to form a saturated molecule. Ethylene also contains two atoms of carbon but with only four atoms of hydrogen so that the two atoms of carbon in it are attached by a double linkage. This is a weaker bond and the molecule is called unsaturated molecule and is more active.

An unsaturated molecule has a great importance for building up the bigger or larger size molecules of a plastic. When these molecules combine and a larger molecule is formed, the process is known as " polymerization " and the product is known as a " *Polymer* ". When in the process of bulding up larger molecules, one of the molecules formed is a large molecule and the other a small molecule like water, the process is known as " *Condensation* ". In the formation of a synthetic product by building up large or multi-molecules, polymerization and condensation processes are very important.

Art. 405. Molding — This is a very simple method of making plastic articles. The molding compound in the form of a granular powder, is mixed with the necessary quantities of fillers, plasticizers, solvants and pigments, and kneaded well in rolling mechines to prepare a thorough and a homogeneous mixture. The mixture is then rolled into rough sheets and crushed to a particular particle size to facilitate molding, casting or extension.

(i) *Pressure Molding* — For molding, the powder is pressed into a mold with the necessary pressure. The mold is also heated to the required temperature. The pressure and temperature are both maintained for a very short period of one to five minutes. The article is then taken out of the mold and given a finishing such as triming the edges, brushing and polish grinding, etc. In the case of thermo-plastic marerial the article is allowed to cool down in the mold before being taken out.

(ii) *Injection Molding* — The plastic powder is injected by a piston into a cold mold. For this purpose, the powder has to be heated slightly for softening.

(iii) *Extrusion Molding* — The piston of the injection molding is replaced by a screw – operating behind a die of the desired shape. Plastic tubings are first extruded and then cold drawn. The extrusion is effected through a cold die with an annular opening of the size of the tube. Plastic sheets are also made by the extrusion process effected through a horizontal slit.

(iv) *Blow Molding* — In this process, air pressure or vacuum are employed to force the softened plastic powder into the mold and to take up its shape.

(v) *Cast Molding* — Architectural features and ornamental figures could be obtained in plastics by the process of cast molding. The plastic compound has to be liquified instead of the powder being softened. The cast blocks could be turned and drilled very conveniently.

Art. 406. Properties of Plastics — Plastics possess a very wide range of machanical properties, from soft, highly tensile and extensibe products to hard, brittle and rigid materials. These properties are usually associated with temperature. They have comperatively a lower density than metals and hence they are light. But they have a higher coefficient of expansion under heat. They have also a low thermal conductivity. Plastics are, in general, good electrical insulators.

Art. 407. Plastic Laminates—The method of forming laminated wood and plywood construction by employing synthetic resins, is already explained in Chapter IX. Such materials have a wide application in modern construction field where strength, durability and lightness are the essential requirements. The wood laminates can be also given a metal surface for the adhesion of which plastic cements of rubber and synthetic resin compounds are used. On the other hand, the plastic can be also given a metal coating either by the method of electroplating or by metal spraying .

Paper, cotton fabric, canvas, asbestos, mats, etc. could be saturated and impregnated with a synthetic resin to prepare hard and strong.sheets or boards. Resin soaked laminated canvas sheets are specially suited for work under high pressure and shock, as required in automobile parts.

Art. 408. Synthetic Coatings or Plastic Coatings—Specially prepared phenolic resins are soluble in alcohol and oils; and therefore they could be used to make the best types of varnishes. On the drying of the solvant, the phenolic film hardens. These varnishes and resin coatings are quite hard, durable and non-absorbant.

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