

15.5 GYPSUM PLASTER

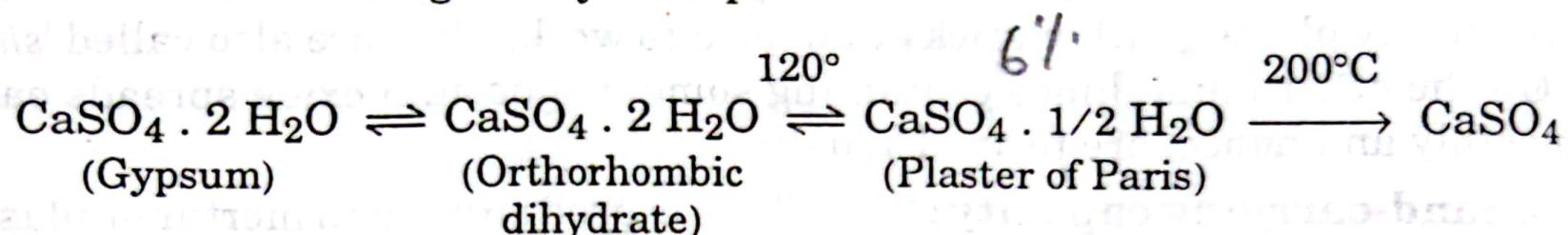
✓ Notes

1911

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The mineral gypsum [which consists essentially of hydrated calcium sulphate, $\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$] is extensively used as raw material for the manufacture of plasters, which are almost universally used for coating the inner walls of dwellings. As mined, however, it usually contains a considerable percentage of impurities, the chief of which are clay, calcium and magnesium carbonates, and iron oxide.

Plaster of Paris [$\text{CaSO}_4 \cdot \frac{1}{2} \text{H}_2\text{O}$] is produced by heating fairly pure gypsum to a temperature of about $120\text{--}160^\circ\text{C}$. If the gypsum is heated above 200°C , the anhydrous sulphate is produced, which loses the power of readily combining with water. The various changes may be depicted as follows :



The operation of manufacturing plaster of Paris from gypsum consists in first crushing and grinding of gypsum, and then calcining the ground product in kilns (heated to about 150°C) and finally, pulverizing the calcined product.

Setting and hardening : When plaster of Paris is mixed with water, the powder forms a plastic mass, which quickly hardens or sets, expanding slightly in the process and regains the closely-packed crystalline structure of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Setting of plaster of Paris can be accelerated by admixing it with alkali sulphates like K_2SO_4 , Na_2SO_4 (or alums), which initiate as well as hasten the crystallization process.

Uses : (1) Its slight expansion on setting, renders plaster of Paris suitable for making moulds, since details are thereby accurately reproduced. (2) It is used in making castings structural tiles and in surgical bandages. (3) Its chief uses are as plaster for walls and in plaster-board, which is made up of alternate layers of a fibrous material such as felt or paper and gypsum plaster.

15.6 CEMENT ✓

Cement may be broadly be described as "a material possessing adhesive and cohesive properties, and capable of bonding materials like stones, bricks, building blocks, etc." The principal constituents of cement used for constructional purposes are compounds of Ca (calcareous) and Al + Si (argillaceous). The cements have property of setting and hardening under water, by virtue of certain chemical reactions with it and are, therefore, called 'hydraulic cements'.

SiO₂ *Al₂O₃* *500-700°C* CLASSIFICATION : (1) Natural cement is made by calcining a naturally occurring argillaceous limestone (i.e., 20-40% clay-containing limestone) at a high temperature and subsequently, pulverizing the calcined mass. During calcination, silica and alumina, present in sufficient quantities, combine with the calcium oxide to form the corresponding calcium silicates and aluminates.

Restoration/Green Properties : Natural cement possesses hydraulic qualities, but is quick-setting and of relatively low strength. Mortar made from natural cement and sand is satisfactorily used in laying bricks and setting stones. It is also used in large masses of concretes such as dams and foundations. After the discovery of Portland cement, the use and production of natural cement has been nearly dropped.

(2) **Puzzolana cement** is among the oldest cementing materials known. It was invented by Romans and used by them in making concrete for the construction of walls and domes. By definition, **puzzolana cements** "are materials which when mixes with lime, without the use of heat, form hydraulic cementing materials". Such cements consist, essentially, of silicates of aluminum, iron and calcium. Puzzolana cements are made by simply mixing and griding : (i) natural puzzolana (which are deposits of volcanic ash) consisting of a glassy material, produced by rapid cooling of lava (a molten mixture of silicates of calcium, iron and aluminium), and (ii) slaked-lime.

Properties : Puzzolana cements possess hydraulic properties. They are seldom used as such at present time, but are mixed with Portland cement.

(3) **Slag cement** is made from blast furnace slag and hydrated lime. The blast furnace slag (consisting largely of a mixture of calcium and aluminium silicates) is granulated by pouring it into a stream of cold water. It is then dried and mixed with hydrated lime, and then the mixture is finely pulverized. Slag cements are slow to harden, so an accelerator like clay, salt or caustic soda is sometimes added.

Properties : Slag cements set more slowly than Portland cement. They have lower strength and are poor in abrasion-resistance. Slag cements are used, to a limited extent, for making concrete in bulk construction, where strength is relatively unimportant.

Slag a byproduct of processing iron ore to iron and steel.

(4) **Portland cement** is defined as "an extremely finely ground product obtained by calcining together, at about 1500°C , an intimate and properly proportioned mixture of argillaceous (clay-containing) and calcareous (lime-containing) raw materials, without the addition of anything subsequent to calcination, excepting the retarder gypsum".

Properties : Portland cement is the most important and reliable cementing material, used for constructional works. It was discovered in 1824 by Joseph Aspidin, a brick layer of Leeds. It was so-named, because a paste of cement with water on setting and hardening resembled in colour and hardness to Portland stone, a limestone quarried in Dorset.

15.7 MANUFACTURE OF PORTLAND CEMENT

Raw materials for the manufacture of cement are : (1) *Calcaerous materials*, CaO [such as limestone, chalk, marl, etc.] ; (2) *Argillaceous materials*, Al_2O_3 and SiO_2 [such as clay, shale, slate, etc.] ; (3) *Powdered coal or fuel oil*, and (4) *Gypsum* ($\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$)

Functions of the ingredients of cement : (1) *Lime* is the principal constituent of cement. Its proportion must be properly regulated. However, excess of lime reduces the strength of cement, because it makes the cement to expand and disintegrate. On the other hand, presence of lesser amount of lime than required also reduces the strength of cement and makes it quick-setting.

(2) *Silica* imparts strength to cement.

(3) *Alumina* makes the cement quick-setting. Excess of alumina, however, weakens the cement.

(4) *Calcium sulphate* (gypsum) helps to retard the setting action of cement. It actually enhances the initial setting time of cement.

(5) *Iron oxide* provides : (a) colour, (b) strength, and (c) hardness to the cement.

(6) *Sulphur trioxide*, in small proportion, is desirable. When present in small amount, it imparts soundness to cement. However, its excess reduces the soundness of cement.

(7) *Alkalies*, if present in excess, cause the cement efflorescent.

Manufacture of Portland cement involves the following steps :

(1) **Mixing of raw materials** can be done either by : (a) dry process or (b) wet process.

(a) **Dry process** : The raw materials [limestone (or chalk) and clay (or shale)] are crushed (in gyratory crushers) into roughly 2-5 cm size pieces. Then, these are ground to fine powder (in ball mills/tube mills). Each separate powdered ingredient is stored in a separate hopper. Then, the powdered materials are mixed in the required proportions to get dry 'raw mix', which is stored in storage bins (called silos) and kept ready to be fed in a rotary kiln. Raw materials are mixed in calculated proportions so that the average composition of the final product is as follows :

| Component | Percentage range by mass |
|--|--------------------------|
| Lime (CaO) | 60-69 |
| Silica (SiO_2) | 17-25 |
| Alumina (Al_2O_3) | 3-8 |
| Iron oxide (Fe_2O_3) | 2-4 |
| Magnesium oxide (MgO) | 1-5 |
| Sulphur trioxide (SO_3) | 1-3 |
| Alkali oxides ($\text{Na}_2\text{O} + \text{K}_2\text{O}$) | 0.3-1.5 |

(b) **Wet process** : The calcareous raw materials are crushed, powdered and stored in big storage tanks (called *silos*). The argilaceous material (say clay) is thoroughly mixed with water in wash mills, to remove any adhering organic matter, etc. The basin-washed clay is also stored. Powdered limestone (from silos) and washed wet-clay (from basins) are allowed to flow in a channel, in the right proportions. From the channel, the two raw materials are led to '*grinding mills*', where they are mixed intimately to form a paste, called *slurry* [Grinding operation is carried out in either tube mill or ball mill or both]. The slurry is led to a '*correcting basin*', where its chemical composition may be adjusted, if necessary. *This slurry contains about 38 to 40 per cent water.* The slurry is finally stored in storage tanks and kept ready for feeding to a rotary kiln.

Table 2 : Merits and demerits of dry and wet processes.

| 74% cement Dry process | Wet process 26% cement prod. |
|---|--|
| 1. It is adopted when the raw materials are quite hard. | It can be used for any type of raw materials. |
| 2. Fuel consumption is low. | Fuel consumption is higher. |
| 3. Process is slow. X | Process is comparatively faster. |
| 4. Cement produced is of inferior quality. | Cement produced is of superior quality. |
| 5. Cost of production of cement is less. Dehydration zone less | Cost of production of cement is somewhat higher. |
| 6. On the whole, the process is costly. | On the whole, the process is cheaper. |

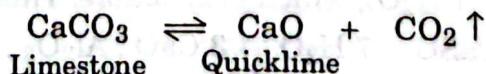
(2) Burning is usually done in *rotary kiln*, which is a steel tube, about 2.5 to 3.0 m in diameter and 90 to 120 m in length, lined inside with *refractory bricks*. The kiln is laid in *slightly inclined* position at a gradient of 1 in 25 to 1 in 30. This rests on *roller bearings*, which are supported on column of masonry or concrete. The kiln is capable of rotating at 1 r.p.m. (revolution per minute) about its longitudinal axis. *Burning fuel* (usually powdered coal or oil) and *air* are injected at the lower end. A long hot flame is produced, which heats the interior of the kiln upto a maximum temperature of about 1,750°C.

25°
v 2.86

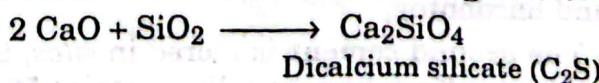
Process : The '*raw-mix*' or '*corrected-slurry*' is injected into the kiln at its upper end; while *hot flames* is forced into the kiln from the lower end. Due to slope and slow rotation of the kiln, the materials fed in move continuously towards the hottest-end at a speed of about 15 m per hour. As the mixture or slurry gradually descends, the temperature rises.

Chemistry : (i) In the upper part of kiln, where the temperature is around 400°C, most of the water in the slurry gets evaporated (*drying zone*).

(ii) In the central part of kiln, where the temperature is around 1,000°C, limestone of dry mix or slurry undergoes *decomposition* to form quick-lime and carbon dioxide ; and the latter escapes out. The material forms small lumps, called *nodules* [*calcination zone*].



(iii) In the lower part of the kiln, the temperature is between 1,500 to 1,700°C. Here lime and clay (of nodules) undergo chemical interaction or fusion, yielding *calcium aluminates and silicates* (*clinkering zone*).



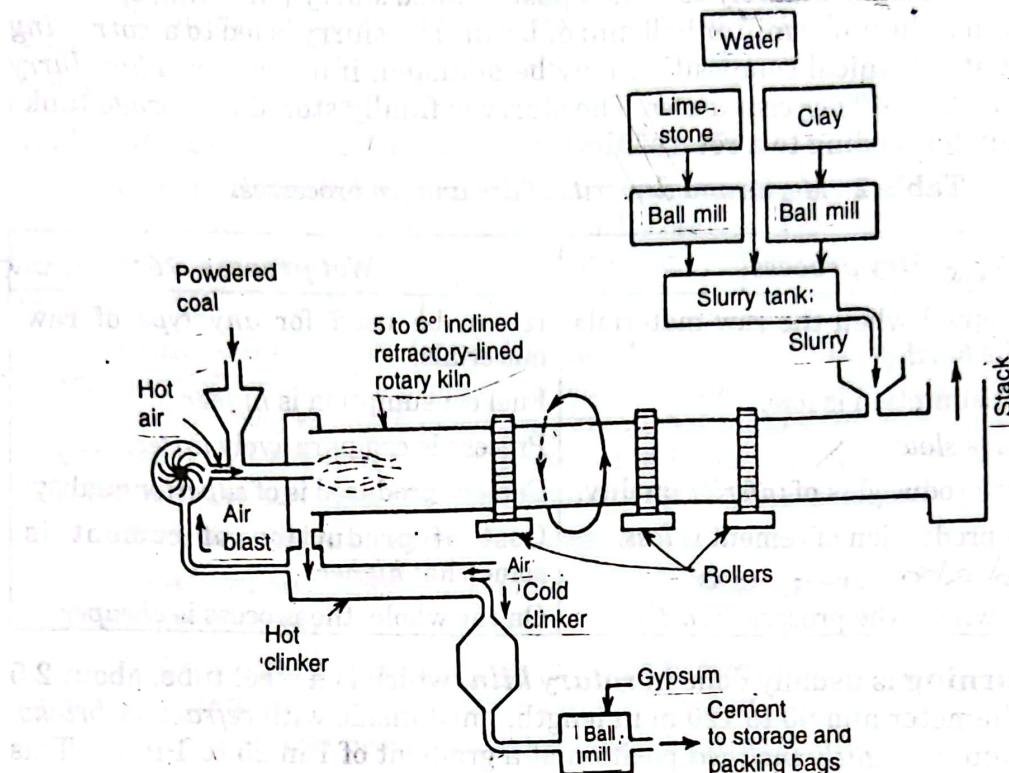
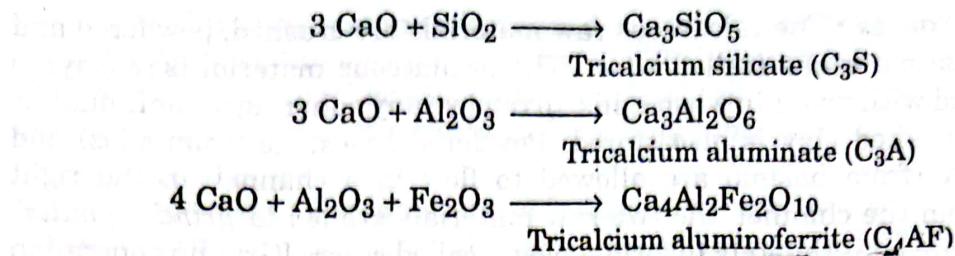
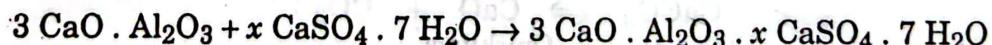


Fig. 2. Rotary cement kiln.

The aluminates and silicates of calcium then fuse together to form small (of about 0.5 to 1 cm diameter) hard, greyish stones, called *clinkers*. These clinkers are very hot (at about 1,000°C). The rotary kiln at the base is provided with another *small rotary kiln*. In this, hot clinkers fall and cool air is admitted from opposite direction. Air counter-blast cools the clinkers. *Hot air so-produced is used for burning powdered coal/oil*. The cooled clinkers are collected in small trolleys.

(3) Grinding : The cooled clinkers are ground to a fine powder in ball mills or tube mills. During final grindings, a small quantity (2-3%) of powdered gypsum is added, so that the resulting cement *does not set very quickly*, when it comes in contact with water. *Gypsum, thus, acts as a retarding agent for early setting of cement.*

After the initial set, the cement-water paste becomes stiff, but *gypsum retards the dissolution of C₃A* by forming tricalcium sulphoaluminate ($3 \text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot x \text{CaSO}_4 \cdot 7 \text{H}_2\text{O}$), which is *insoluble*. Thus :



After initial set

Gypsum

Tricalcium sulphoaluminate
(Insoluble)

Formation of insoluble tricalcium sulphoaluminate prevents too early further reactions of setting and hardening.

(4) Packing : The ground cement is stored in *silos*, from which it is fed to automatic packing machines. Each bag, usually, contains 50 kg of cement.

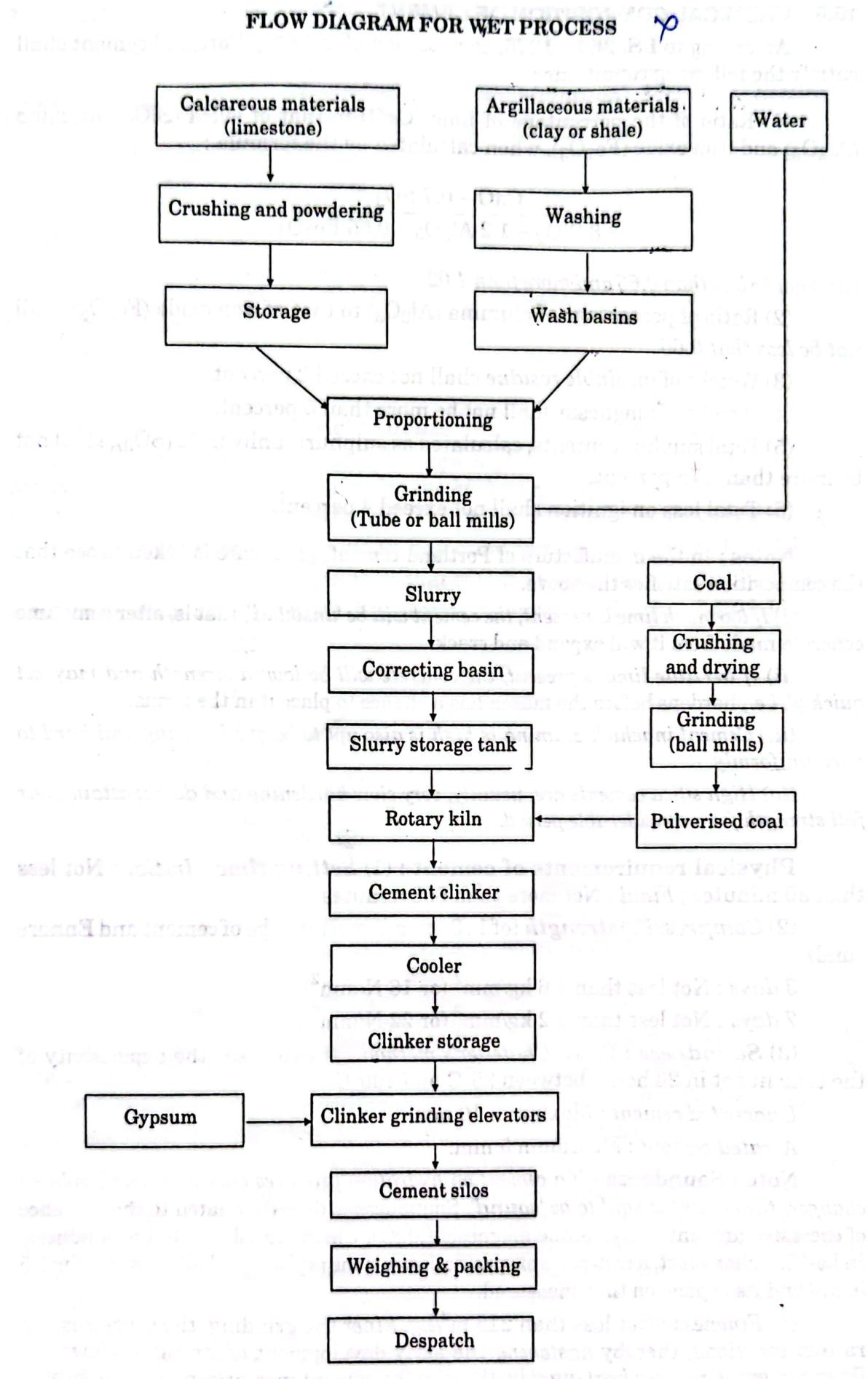


Fig. 3. Flow diagram of cement manufacture.

15.9 CHEMICAL CONSTITUTION OF PORTLAND CEMENT ✓

Average compound composition of Portland cement is :

| Name of compound | Chemical formula | Abbreviation used | Average % | Setting time |
|-----------------------------|---|-------------------|-----------|--------------|
| Tricalcium silicate | $3\text{CaO} \cdot \text{SiO}_2$ | C ₃ S | 45 | 7 days |
| Dicalcium silicate | $2\text{CaO} \cdot \text{SiO}_2$ | C ₂ S | 25 | 28 days |
| Tricalcium aluminate | $3\text{CaO} \cdot \text{Al}_2\text{O}_3$ | C ₃ A | 1 | 1 day |
| Tetracalcium aluminoferrite | $4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3$ | C ₄ AF | 9 | 1 day |
| Calcium sulphate | CaSO_4 | - | 5 | - |
| Calcium oxide (free) | CaO | - | 2 | - |
| Magnesium oxide | MgO | - | 4 | - |

Characteristics of constituents : (i) **Tricalcium silicate (C₃S)** has "medium" rate of hydration ; and develops high ultimate strength quite rapidly. Moreover, its ultimate-strength is also the highest amongst all the constituents. So it is responsible for ultimate-strength. The heat of hydration is about 880 kJ/kg.

(ii) **Dicalcium silicate (C₂S)** has quite low early-strength, but develops ultimate-strength of slightly less than that of C₃S. It hydrates very slowly. It is also responsible for ultimate-strength. It possesses the heat of hydration of 420 kJ/kg.

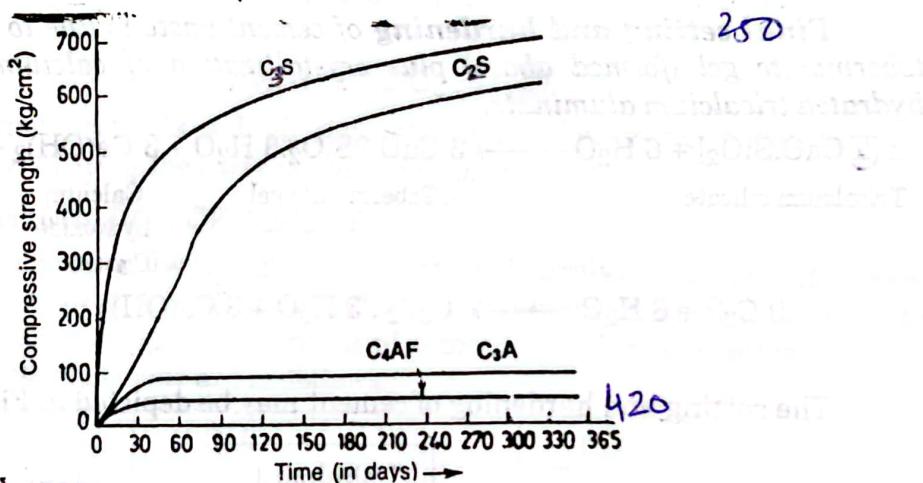


Fig. 4. Development of strength by major constituents in cement.

(iii) **Tricalcium aluminate (C₃A)** hydrates slowly and does not contribute much to the strength of cement, since its early-strength and ultimate-strength are poorest amongst all the constituents. Its heat of hydration is about 250 kJ/kg.

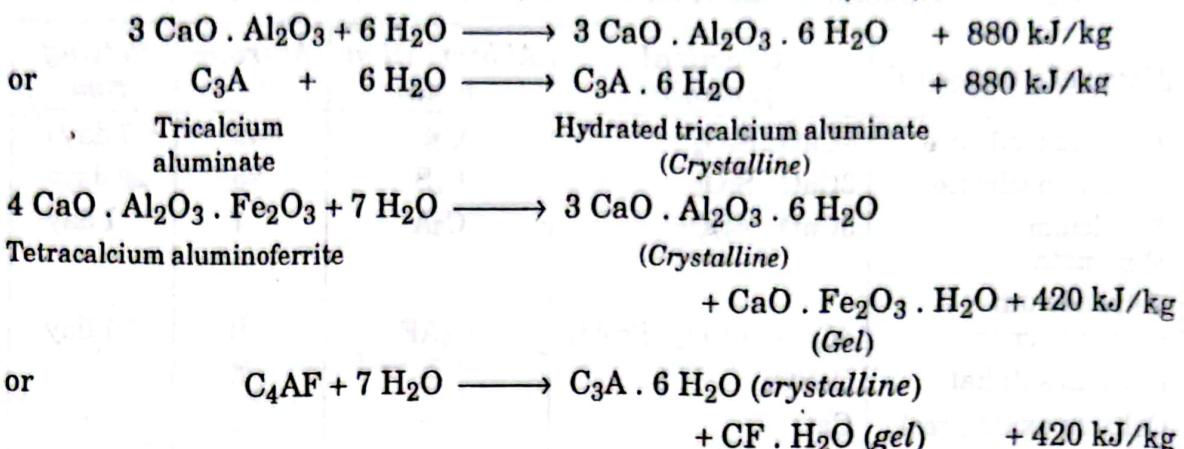
15.10 SETTING AND HARDENING OF PORTLAND CEMENT ✓ 880

When cement is mixed with water to a plastic mass, called "cement paste", hydration reaction begins, resulting in the formation of gel and crystalline products. The interlocking of the crystals, finally bind the inert particles of the aggregates into a compact rock-like material. The process of solidification-comprises of : (i) setting, and then (ii) hardening. 'Setting' is defined as stiffening of the original plastic mass, due to initial gel formation. "Hardening" is development of strength, due to crystallization.

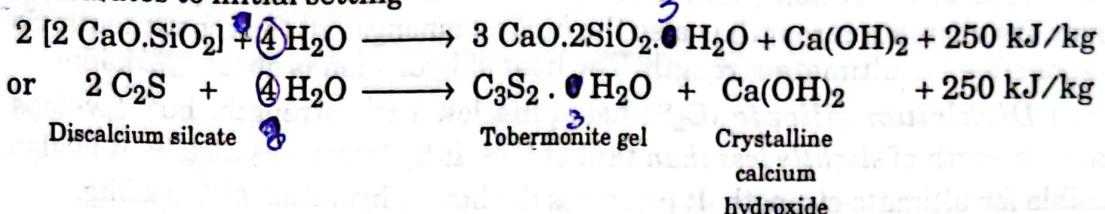
After setting, hardening starts, due to the gradual progress of crystallization in the interior of the mass. The strength developed by cement paste at any time, depends upon the amount of gel formed and the extent of crystallization.

initial set early strength ultimate

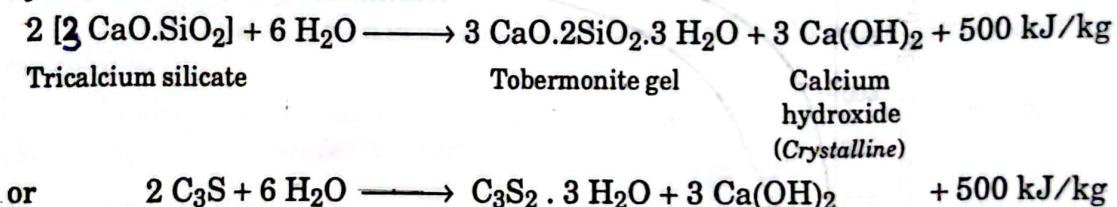
Initial setting of cement-paste is mainly due to the hydration of tricalcium aluminate (C_3A) and gel formation of tetracalcium aluminoferrite.



Also dicalcium silicate starts hydrolysing to tobermorite gel (which possesses a very high surface area* and thus, very high adhesive property), which also contributes to initial setting



Final setting and hardening of cement-paste is due to the formation of tobermorite gel (formed above) plus crystallization of calcium hydroxide and hydrated tricalcium aluminate.



The setting and hardening of cement may be depicted in Fig. 5.

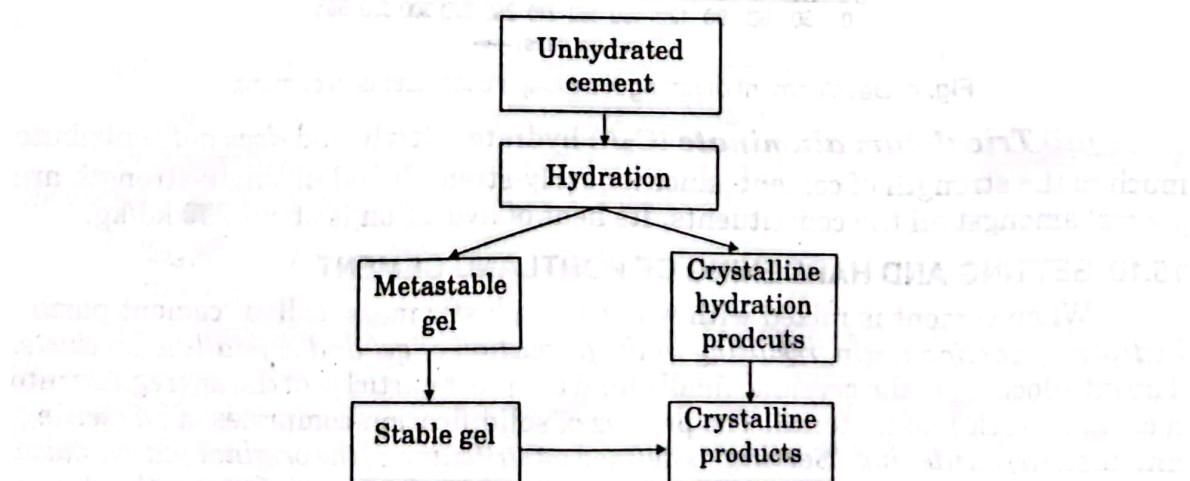


Fig. 5. Setting and hardening of cement.

* 1 g of cement has a surface area of above 10^3 cm³; whereas 1 g of tobermorite gel has a surface area of 10^6 cm³.

Sequence of chemical reactions during setting and hardening of cement : When water is added to cement, its various constituents undergo hydration and crystallization at different rates. (i) At first, hydration of tricalcium aluminate (C_3A) and tetracalcium aluminoferrite (C_4AF) takes place. (ii) Next, the hydration of tricalcium silicate (C_3S) begins within 24 hours and gets completed in 7 days. (iii) The gel of aluminate begins to crystallize and at the same time, dicalcium silicate (C_2S) begins to hydrate in 7 to 28 days. Thus, the *initial set* of cement is due to the *hydration of aluminate*. The development of *early-strength*, between 1 to 7 days, is due to the *hydration of tricalcium silicate* and the further hydration of aluminate. The *increase of strength*, between 7 to 28 days, is due to *hydration of dicalcium silicate and continued hydration of tricalcium silicate*.

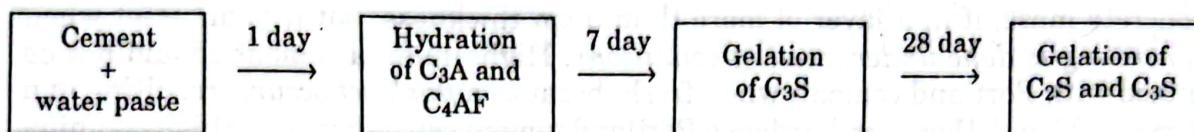
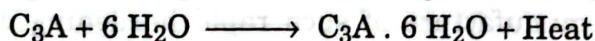
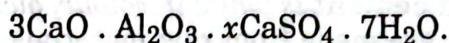


Fig. 6. Sequence of changes during setting and hardening of cement.

Function of gypsum in cement : Tricalcium aluminate (C_3A) combines with water very rapidly with the evolution of a large amount of heat.



After the initial-set, the paste becomes somewhat stiff. However, the added gypsum retards the dissolution of C_3A by forming *insoluble calcium sulpho-aluminate*:



This reaction prevents a high concentrations of alumina in the cement solution, thereby *retarding the early initial-set of the cement*.

15.11 HEAT OF HYDRATION OF CEMENT

When water is mixed with cement, hydration, hydrolysis and gelation reactions start and some heat is liberate simultaneously. On an average, 500 kJ/kg of heat is evolved during complete hydration of cement. The heats of hydrations of various constituents of cement are as follows :

| Constituent of cement | C_3A | C_3S | C_4AF | C_2S |
|---------------------------|--------|--------|---------|--------|
| Heat of hydration (kJ/kg) | 880 | 500 | 420 | 250 |

Consequently, in order to avoid the shrinkage cracks on setting and hardening, it is quite necessary to pour concrete in position in such amounts that the *heat liberated during hydration is dissipated as quickly as possible*.

15.12 SPECIAL CEMENTS

(1) **Aluminous or high-alumina cements** are made by fusing a mixture of bauxite and limestone at 1,500 to 1,600°C in rotary kiln and then grinding the resulting mass to the same fineness as that of Portland cement.

Typical composition of such a cement is : 35 to 40% CaO : 35 to 55% Al_2O_3 ; 5 to 15% $FeO + Fe_2O_3$, and 5 to 10% SiO_2 . The most important constituents of such cements are *monocalcium aluminate* (CA) and *tricalcium pentaluminate* (C_3A_5), besides some dicalcium silicate (C_2S) and tetracalcium aluminoferrite (C_4AF). Both CA and C_3A_5 hydrate initially to a gel, $CaAl(OH)_5 \cdot 3H_2O$, which gradually changes to a very stable crystalline complex, $Ca_3Al_2(OH)_{12} \cdot 3H_2O$ and a gel of aluminium hydroxide, $Al(OH)_3$. The setting time of high-alumina cement is similar to that of

Portland cement, but its *rate of hardening is very rapid and full-strength is attained in 24 hours*. Since the crystalline complexes formed from high-alumina cements are stable, even on heating, so the *aluminous cement retains its strength at high temperatures*. Another advantage of high-alumina cement, as compared to Portland cement, is its *superior chemical-resistance to sea-water and sulphate-bearing ground water*. Moreover, such a cement is *resistant to very dilute acid solutions* (frequently occurring in industrial wastes), *dilute sulphurous acid solutions* (resulting from the combustion of sulphur-containing fuels) and to hydrogen sulphide solutions.

The advantages of *rapid-hardening* of aluminous cement is, however, offset to some extent by a *rapid evolution of heat of hydration*, which cannot be easily dissipated in a short time. This causes a considerable rise in the temperature of the concrete mass, if in a layer of more than 5 cm thickness, but it is an asset when *concreting is done under freezing conditions*. High-alumina cement should not be mixed with Portland cement, when fresh, because a *flash set occurs*, resulting in a *very weak bond*. However, hardened Portland cement can be bonded to high-alumina cement to get a strong bond.

(2) **High early-strength (H.E.S.) cements** are made from materials with a high lime to silica ratio. They contain a higher proportion of tricalcium silicate than regular Portland cements and hence, harden more quickly and with greater evolution of heat. During the manufacture of such rapid hardening cements, addition of gypsum, during the final grinding, is usually avoided and also such cements are grinded much finer than ordinary cements. Such cements have only 5 minutes and 30 minutes initial and final setting times respectively.

(3) **White Portland cement** is white in colour, owing to the absence of iron compounds. Such cements are made from raw materials which are free from iron oxide. It is very expensive and finds useful applications, e.g., repairing and joining marble pillars and blocks, manufacture of tiles and for mosaic works. For the latter purpose, the cements may be coloured by means of colouring matters like yellow ochre, venetian red, etc.

(4) **Sorel cement** is made by the addition of a strong solution of magnesium chloride to finely ground calcined magnesia. The material, sometimes known as magnesium oxychloride cement [$3\text{MgO} \cdot \text{MgCl}_2 \cdot 11\text{H}_2\text{O}$], sets hard in three to four hours. This material is principally used in composite flooring. Such floorings have the advantage of being non-slip, fire-proof, not easily scratchable, durable and capable of taking a good wax or oil polish.

The rate of hardening of cement is still increased by addition of calcium chloride or formate. The accelerated rate of setting is especially useful during cold weather. It is believed that CaCl_2 accelerates the hydration of C_2S and C_3S , the strength-contributing components of the cement. On the other hand, the hydration of C_3A is retarded. The optimum quantity of CaCl_2 to be used for such purposes is 1.5% by weight of the total weight of cement. However, if this is exceeded, the corrosion of the steel embedded in the concrete is promoted, especially if the concrete is less compact or porous.

(5) **Barium and strontium cements** are obtained by replacing calcium by barium or strontium. So, such a cement contains tribarium and dibarium silicates, instead of calcium silicates. Such cements show increased resistance to penetrations by radioactive radiations. Hence, they find extensive applications in *concrete shields for atomic piles*.

(6) **Silicate cements or acid-resistant cements** are produced by mixing an inert acid-resisting aggregate (such as finely ground quartzite) with sodium or potassium or silicon ester, in suitable proportions. Their cementing property is due to the precipitation of the silica gel, caused by adding suitable setting agents such

as sodium silicon fluoride or ethyl acetate or by evaporation of water. The bond developed by silicate cement is hard, but also brittle. On drying, this cement becomes very porous and permeable to liquids. For this reason, it should always be kept wet or immersed in a liquid to prevent shrinking of the gel.

(7) **Water-proof cement** : Such a cement is obtained by adding *water-proofing substances* (like calcium stearate, aluminium stearate and gypsum with tannic acid) to ordinary Portland cement, during grinding. The characteristics of such cements depend on the type and quantity of admixture added. A water-proof cement has to do two distinct functions, viz., (i) to make concrete impervious to water under pressure, and (ii) to resist the absorption of water. Chemically inactive substances added are like calcium soaps, aluminium soaps, resins, vegetable oils, waxes, coal-tar residues and bitumen, which acts as *pore-blocking agents*. These act as *water-repelling agents*. Moreover, they increase appreciably the *resistance to the penetration of moisture*.

15.13 CONCRETE AND RCC

Concrete is a building and structural material, obtained by mixing a binding material (cement or lime), inert mineral aggregates (sand, crushed stone, gravel, broken brick, slag, etc.) and water in a suitable proportion and which can be readily worked or moulded into almost any desired shape and when set, it is compact, rigid, strong and durable.

When *lime* is the binding material, the concrete is known as *lime concrete* and when *cement* forms the binding material, the concrete is called as *cement concrete*. The proportions of cement and aggregates in concrete vary with the use to which it is to be put. For *water-tight works*, concrete is made up of 1 part cement, 1 part sand and 2 parts gravels. If not required to be water-tight, the mixture can be changed to 1 part cement, 3 parts sand, and 5 parts gravels. *The more the cement, within limits, the more water-proof the concrete will be.*

Uses of concrete : Concrete is by far the most important of all non-metallic materials of construction. It ranks second only to steel in its wide and varied constructional importance. Its typical uses are in roads, buildings, floors, roofs, columns, arches, tanks, sewers, foundations, abutments, piers, reinforce-works, water-proof structures and other purposes where compressive strength is required.

Curing of concrete : *The hardening of concrete is due to hydration reaction of the constituent cement compounds.* These processes continue indefinitely, but the greatest amount of strength and hardness is developed during the first few days, immediately following placement, *So it is essential to keep the concrete damp for at least a week, to enable the hydration reactions to occur completely.* Moreover, the chemical reactions of the cement and water progresses only under favorable temperature conditions. *Reactions are slowed down in concrete at low temperature and completely stops, when the water in the concrete is frozen.* *Curing is the process of maintaining a satisfactory moisture content and favorable temperature in concrete during the period immediately following placement, so that hydration of the cement may continue, until the desired properties are developed to a sufficient degree to meet the requirement of service.* During hydration of cement, lot of heat is evolved. So special care has to be taken to dissipate this heat ; otherwise cement work is likely to develop cracks. *Thus, curing also helps in dissipation of heat.*

Reinforced concrete construction (R.C.C.) : *Plain concrete has a great compressive strength, but little ability to withstand tension.* Consequently, structures which are required to bear tensile stresses are *reinforced* (or strengthened) by embedding steel bars or rods and metal meshes in such a way that the tension is

taken up by the steel ; while the concrete carries the compression. *This combination of steel and concrete produces structure, called reinforced concrete construction (R.C.C.), which can bear all types of loads.* Reinforced concrete work is mostly used in floor-beams, piers, lintels, girders, arches, slabs, bridges, etc.

Advantage of R.C.C. over plain concrete : (1) R.C.C. is easier to make and cast into any desired shapes, which can bear *all types of loads*. (2) It possesses greater rigidity, moisture and fire-resistances. (3) Steel reinforcement also tends to *distribute the shrinkage cracks*, thus preventing the formation of large cracks. (4) Its maintenance cost is *practically negligible*.

15.14 DECAY OF CONCRETE

Although cement concrete is mechanically quite strong, yet it highly susceptible to chemical attack, because concrete contains some free lime (CaO). In acidic water (*viz.*, pH < 7), lime of concrete dissolves, thereby making it *weak*, pH of most natural waters is slightly greater than 7 (*i.e.* they are slightly alkaline), consequently, such waters do not have any marked effect on the strength of concrete. However, as the acidity increases (or pH decreases), the deterioration of concrete enhances. It may be pointed here that *lime is more soluble in soft water than hard water*. Consequently, deterioration of concrete is more quick, when in contact with soft water. Lime of concrete is also removed by sulphates and chlorides, present in water. If concrete is soaked in mineral oil for sometime, its resistance to abrasion decreases. Sugar also causes concrete failure. If even as low as 0.1% sugar is added to cement, the setting time is delayed and its strength is greatly reduced, during the first four weeks. The cause of concrete failure, due to presence of sugar has been traced in the use of old sugar sacks for carrying sand or for covering the freshly concrete used during curing.

The most serious type of damage to concrete takes place in the presence of *sulphates*. The sulphates combine with tricalcium aluminate to form sulpho-aluminates, which occupies *more volume*. This causes expansion, thereby the life of concrete is greatly reduced. Such a danger can be avoided by eliminating tricalcium aluminate from the cement composition and manufacturing cement containing tetracalcium aluminoferrite, instead of aluminate.

Protection of concrete : (1) *By giving a coating of bituminous material.* This prevents direct contact between concrete and water. This is a very cheap method.

(2) *By coating the surface with silicon fluoride* in a soluble form together with oxides of Zn, Mg or Al. The precipitate of calcium fluoride so-formed in the capillaries prevents dissolution of lime.