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2.1 Lime:

2.1.1 Lime:

It is produced by heating limestone which is more or less pure calcium carbonate and it is used as a material for construction from ancient times.

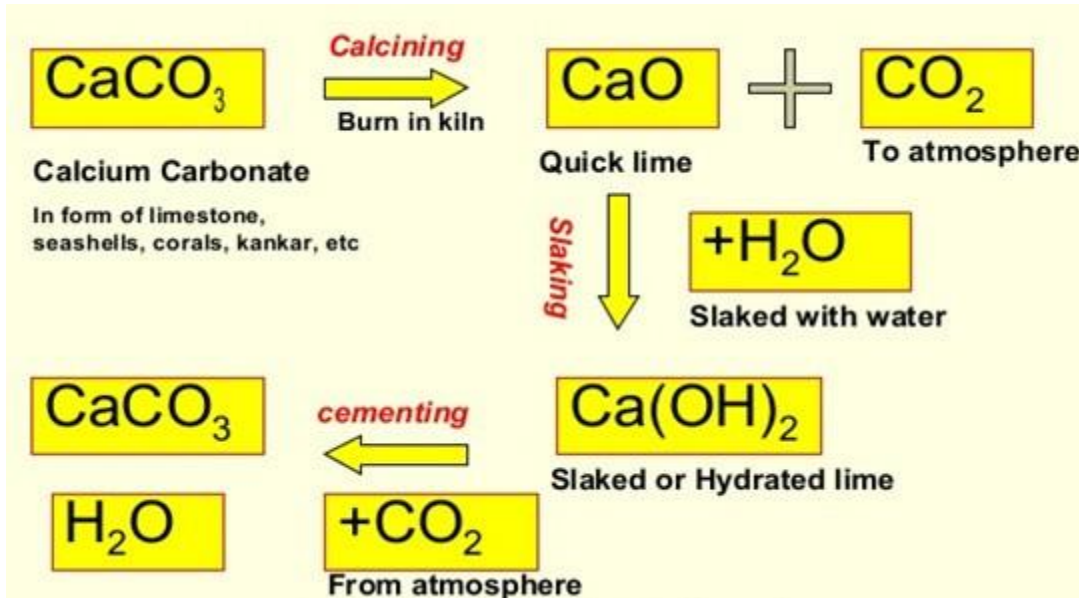


Fig 1 Process of lime

2.1.2 Properties of lime:

1. Easily workable
2. Provide strength
3. Good plasticity
4. Good resistance to moisture
5. Stiffness
6. Excellent binding
7. Fire resisting

2.1.3 Uses of lime:

1. Used as a binding material in concrete
2. Used as a binding material in brick and masonry stone
3. Used for white washing
4. Production of artificial stone, limestone brick etc
5. Used in manufacturing of paint
6. Used in soil stablization

2.1.4 Classification of lime:

1. Fat lime
2. Hydraulic lime
3. Poor lime

1. Fat lime:(rich lime/high calcium lime/pure lime)

- It contain above 95% calcium oxide.

Properties:

- ✓ High degree of plasticity
- ✓ Perfectly white colour
- ✓ Set slowly in presence of air

Uses:

- ✓ Whitewashing
- ✓ Plastering of walls
- ✓ Mortar in stone and brick masonry

2. Hydraulic lime(water lime):

- It contain clay and some amount of ferrous oxide

Properties:

- ✓ Set under water
- ✓ Not Perfectly white color
- ✓ It contain 30% of clay so it is called as natural cement

. Poor lime:(lean lime)

- Contain more than 30 % of clay
- Muddy colour
- Set very slowly
- Poor binding property

Uses:

- Unimportant work like floor levelling, floor concrete

2.1.5 Lime mortar:

Lime mortar is made by mixing lime, sand and water. Lime used for mortar may be fat lime (quick or hydrated lime) or hydraulic lime. Fat lime has high calcium oxide content. Its hardening depends on loss of water and absorption of carbon dioxide from the atmosphere and possible recrystallisation in due course. Hydraulic lime contains

silica, alumina and iron oxide in small quantities. When mixed with water it forms putty or mortar having the property of setting and hardening under water.

Slaked fat lime is used to prepare mortar for plastering, while hydraulic lime is used for masonry construction and are most suitable for construction of chimneys and lightly loaded superstructure of buildings. The mix proportions of lime mortar for various types of works are given in Table 1.

Table 1 Mix Proportions

S.No	Type of Lime	Fineness modulus	Type of work
1	Sand lime	2.5	Plastering
2	Hydraulic Lime	2.5	Pointing Masonry

Notes: 1. Sand in lime mortar is an adulterant, and reduces its shrinkage. Lime mortar becomes porous allowing air to penetrate and helps the mortar in hardening.

2. Lime mortar is not suitable for water-logged areas and damp situations.

Lime mortars have plasticity, good cohesion with other surfacing and little shrinkage. They harden and develop strength very slowly continuously gaining strength over long period. Fat lime mortars do not set but stiffen only as water is lost by absorption (by masonry units) and evaporation. The gain in strength is a very slow reaction of lime with carbon dioxide absorbed from air.

Preparation of lime mortar

- Pounding-small quantities
- Grinding –large quantities of mortar
 1. Bullock driven grinding mill
 2. Power driven grinding mill

Pounding:

- Pit are formed on ground with lining of brick or stone at their sides and bottom.
- Pit are about 1.8m long, 40 cm wide at bottom, 50cm wide at top and 50cm deep.
- Lime and sand are mixed in dry state and placed in pit
- Small quantity of water added
- 4 Or 5 person used to mix the mortar

- Heavy wooden pounder used to mix the mortar
- Required amount of water added frequently
- This method is not efficient

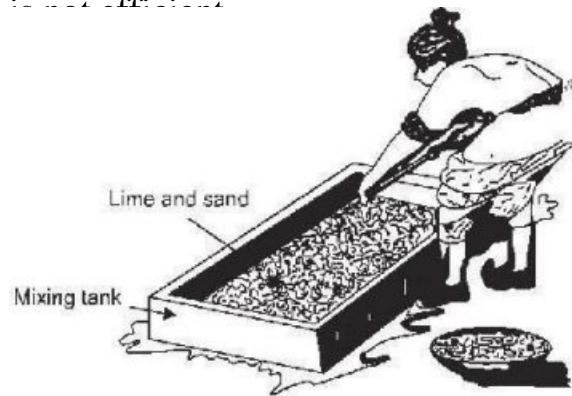


Fig. 2 Manual Mixing

Grinding:

1. Bullock driven grinding mill:

- A circular trench of dia about 6 to 9m and depth 40 mm is prepared
- Width 300mm
- A horizontal wooden shaft passes through stone wheel
- One end of shaft is attached to pivot and other end the bullock
- Lime and sand are placed in trench and required quantity of water added
- Bullock is turn around the mill.

Fig. 3 Bullock Driven Mortar Mill (Ghanni)

2. Power driven grinding mill:

- Power is required to mix the mortar
- It contain revolving pan of dia 1.8 to 2.4 m
- 2 roller are provided with in pan
- Pan are revolved with help of oil engine, steam engine or electric power

- Lime, sand and required amount of water added pan are revolved
- This method gives better quality

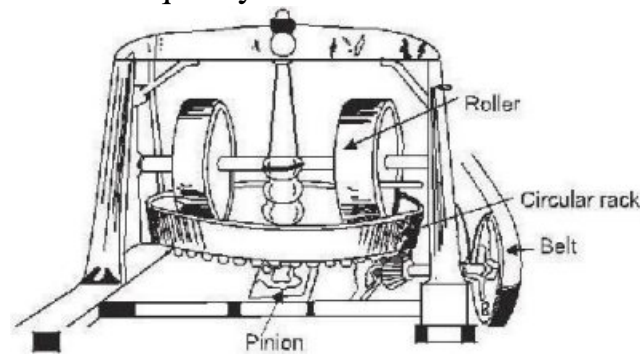


Fig. 4 Power Driven Mortar Mill (Pan Mill)

Precautions : Lime mortar or putty should be kept moist till use and in no case its drying is allowed. The mortar made of hydraulic lime should be consumed within one day and that with fat lime within 2-3 days.

2.1.6 Classification of lime mortar

1. Non hydraulic lime mortar
2. hydraulic lime mortar
3. Black mortar

1. Non hydraulic lime mortar:

- ✓ Set by carbonation so exposed to CO_2 of air
- ✓ Proportion of lime and sand are 1:2, 1:3
- ✓ Light in color, do not cause efflorescence
- ✓ Unsuitable for damp situation, foundation, thick wall
- ✓ Its setting action depends upon CO_2
- ✓ Only used for thin joint in brick work

2. hydraulic lime mortar:

- ✓ Set by hydration
- ✓ These mortar are made from class A & class B
- ✓ Ratio of mortar 1:2
- ✓ Used for heavy engineering works

3. Black mortar

- ✓ So called because of their colour
- ✓ Lime mortar in 1:3

✓ They become hard after set

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2.2 Cement:

2.2.1 Cement

Cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement is seldom used on its own, but rather to bind sand and gravel (aggregate) together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. Concrete is the most widely used material in existence and is behind only water as the planet's most-consumed resource.

Cements used in construction are usually inorganic, often lime or calcium silicate based, which can be characterized as non-hydraulic or hydraulic respectively, depending on the ability of the cement to set in the presence of water (see hydraulic and non-hydraulic lime plaster).

Non-hydraulic cement does not set in wet conditions or under water. Rather, it sets as it dries and reacts with carbon dioxide in the air. It is resistant to attack by chemicals after setting.

Hydraulic cements (e.g., Portland cement) set and become adhesive due to a chemical reaction between the dry ingredients and water.

2.2.2 Composition of cement:

There are eight major components/ingredients of cement. The following image shows the ingredients of cement:

Table 2 Composition of cement

2.2.2.2 Functions of cement components/ingredients:

The main features of these cement components are given below along with their functions and usefulness or harmfulness:

1.Lime:

- Lime is calcium hydroxide or calcium oxide.
- The presence of sufficient amount of lime requires silicates and aluminates of calcium.
- Reduction in lime reduces the strength of cement property.
- Reduction in lime causes cement to set quickly.
- Excessive lime makes the cement unsound.
- Excessive presence of lime causes cement to disintegrate and expand.

2.Silica:

- Silicon dioxide is known as silica, the chemical formula SiO_2 .
- Sufficient amount of silica should be present in the cement to di-calcium and tri-calcium silicate.
- Silica reinforces cement.
- Silica typically represents a limit of about 30 percent cement.

3.Alumina:

- Alumina is aluminum oxide. The chemical formula is Al_2O_3 .
- Alumina provides quick setting properties to cement.
- The presence of the expected amount of alumina leads to a lower clinkering temperature.
- Excess alumina weakens cement.

4.Magnesia:

- Magnesium oxide. The chemical formula is MgO .

- In terms of percentage, Magnesia should not be present more than 2% in cement.
- Additional magnesia will reduce the strength of cement.

5. Iron oxide:

- The chemical formula is Fe_2O_3 .
- Iron oxide gives color to cement.
- Acting as a flux.
- At very high temperatures, it chemically reacts with calcium and aluminum to form tri-calcium alumino-ferrite.
- Tricalcium alumino-ferrite provides hardness and strength to the cement.

6. Calcium Sulfate:

- The chemical formula is CaSO_4
- It is present in cement in the form of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)
- It slows down quickly which in turn reduces the setting action of cement.

7. Alkaline:

- It should not be more than 1%.
- Highly alkaline substances cause efflorescence.

8. Sulfur trioxide:

- The chemical formula is SO_3
- In terms of percentage, it should not be present for more than 2%.
- Cement becomes unsound due to excess sulfur trioxide.

2.2.3 Manufacture Of Cement

Calcareous and argillaceous raw materials are used in the manufacture of Portland cement. The calcareous materials used are cement rock, limestone, marl, chalk and marine shell. The argillaceous materials consist of silicates of alumina in the form of

clay, shale, slate and blast furnace slag.

From the above materials, others like lime, silica, alumina, iron oxide and small quantities of other chemicals are obtained. Cement can be manufactured either by dry process or wet process.

2.2.3.1 Dry Process

The dry process is adopted when the raw materials are quite hard. The process is slow and the product is costly. Limestone and clay are ground to fine powder separately and are mixed. Water is added to make a thick paste. The cakes of this paste, which contain about 14 per cent of moisture, are dried and are charged into rotary kiln (Fig. 23). The product obtained after calcination in rotary kiln is called clinker. The clinker is obtained as a result of incipient fusion and sintering at a temperature of about 1400°-1500°C. Because ferric oxide has lower melting point than the other oxides, it acts as a flux. Aeration of cement clinker, which is commonly practised to slake free lime, also causes an absorption of some moisture and carbon dioxide. Absorption of moisture tends to decrease the setting whereas that of carbon dioxide accelerates setting. The clinker is cooled rapidly to preserve the metastable compounds and their solid solutions — dispersion of one solid in another — which are made as the clinker is heated. Clinker is then cooled and ground in tube mills where 2-3% of gypsum is added. Generally, cement is stored in bags of 50 kg. A flow diagram of dry process is shown in Fig 5. The purpose of adding gypsum is to coat the cement particles by interfering with the process of hydration of the cement particles. This retards the setting of cement.

Fig5 Rotary kiln

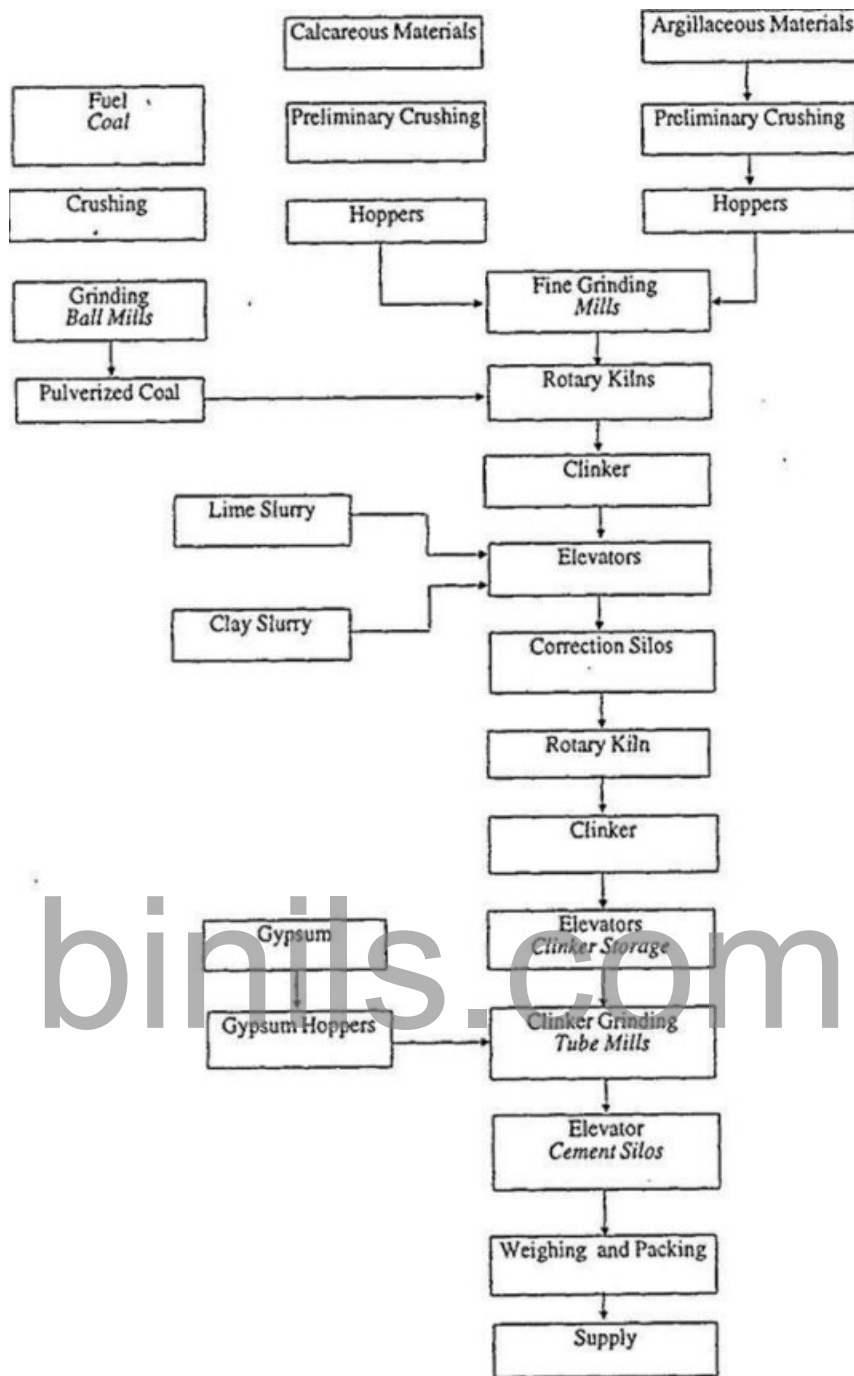


Fig. 6 Flow Diagram of Cement Manufacture—Dry Process

2.2.3.2 Wet Process:

Operations in the wet process of cement manufacture mixing, burning and grinding. The crushed raw materials are fed into ball mill and a little water added. On operating the ball mill, the steel balls in it vertical the raw materials which form a slurry with.

This slurry is passed to silos (storage tanks), where proportioning of the compounds is adjusted to ensure red chemical composition. The corrected slurry adding about 40 per cent moisture content is then fed rotary kiln (Fig. 24) where it loses moisture and ms into lumps or nodules. These are finally burned at 0-1600°C. The nodules change to clinker at this temperature. Clinker is cooled and then ground in tubes. While grinding the clinker, about 3 per cent gypsum added. The cement is then stored in silos from where supplied. A flow diagram of manufacturing cement wet process is shown in Fig. 27

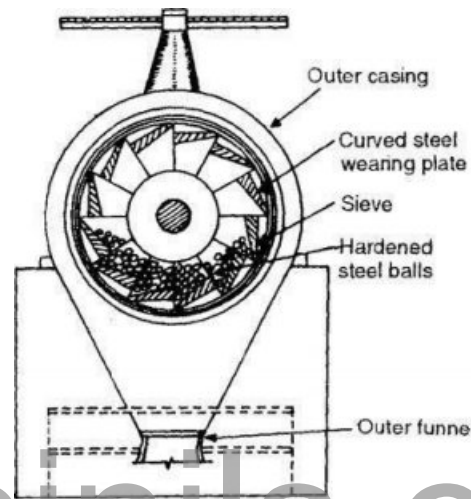


Fig 7 Ball mill

Comparison of Wet and Dry Process: The chief advantages of the wet process are the low cost of excavating and grinding raw materials, the accurate control of composition and homogeneity of the slurry, and the economical utilization of fuel through the elimination of separated drying operations. On the other hand the longer kilns, essential in the wet process, cost more and are less responsive to a variable clinker demand than the short kilns which can be used in the dry process.

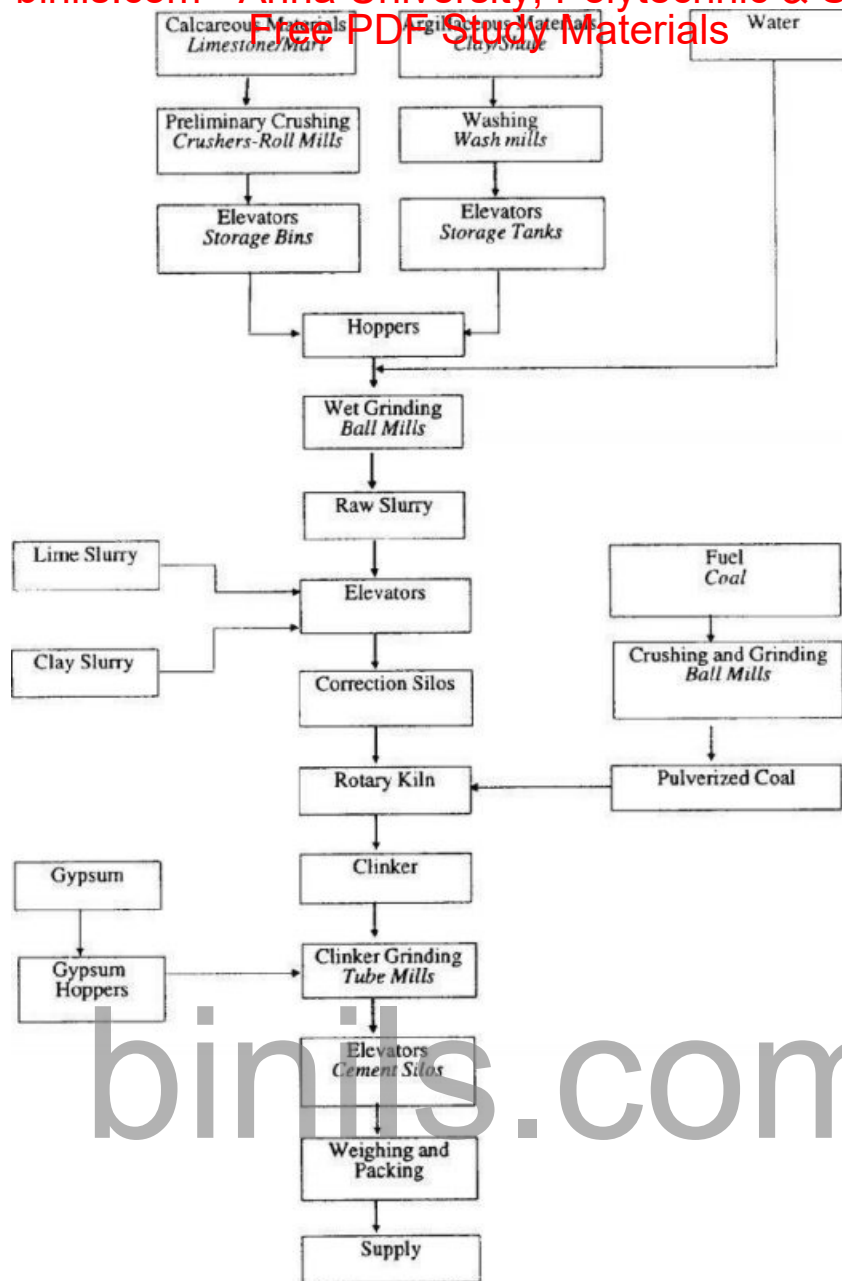


Fig. 8 Flow Diagram of Cement Manufacture—Wet Process

2.2.4 Properties of Cement Mortar:

Properties of mortar which are sought for use in masonry are: workability, water retentivity, rate of stiffening, strength, resistance to rain penetration and durability. These properties have been discussed below explaining their effect on masonry. Choice of masonry mortar is governed by several considerations such as

1. WORKABILITY

Workability is the property of mortar which enables it to be spread and applied to

masonry unit with ease. It also facilitates proper filling of joints in masonry. A good mortar would hang from the trowel and will flow down readily when lightly jerked. This property of mortar depends on properties of various ingredients used for making mortar and on the method of mixing adopted.

As a general rule, a mud mortar prepared from fine clay soil has better workability than one prepared from sandy soil and a lime mortar has a better workability than cement mortar.

Lime when used in the form of putty, gives better workability than when used in dry hydrated form. Also grinding of lime mortar in a mortar mill, results in improved workability.

When using dry hydrated lime in mortar, it is desirable to soak lime in water before mixing with sand in order to improve its workability. When mortar is made by mixing dry hydrated lime and sand without pre-soaking of lime, workability can be improved somewhat, by keeping the mixed mortar in a covered heap for about 12 hours before use. This process, known as maturing, allows particles to swell up time to time.

A mortar made from well graded sand has better workability than one made from ungraded sand.

Cement mortar made with ungraded coarse sand has poor workability, particularly when mix is lean and sand used is angular. Workability of such a mortar can be improved by either adding lime or chemicals known as plasticizers.

To some extent workability depends upon consistency of mortar which is measured by recording depth of penetration of a standard cone as detailed in IS 2250 : 1981. That Standard recommends following values of depth of penetration for different purposes:

depth

For laying walls with solid bricks --	90-130 mm
For laying perforated bricks —	70-80 mm
For filling cavities —	130-150 mm

As a general principle, when joints are thin or units have high suction, consistency should be more and when units are heavy and have low suction, consistency should be less.

A good craftsman adjusts the consistency of mortar by varying the quantity of water through his experience.

Composite cement-lime mortars are well known for their good workability and have some other desirable properties.

2. WATER RETENTIVITY

Most of the masonry units have normally appreciable suction, depending on their porosity and moisture content and they begin to suck moisture from mortar as soon as these come in contact with mortar. If units draw out too much moisture from the mortar rapidly, the latter is unable to gain adequate strength, when gain of strength is dependent on the process of hydration in mortar. Thus, when binder used is Portland cement or hydraulic lime, it is necessary that mortar should not part with its moisture readily by suction-that is mortar should have good water retentivity.

As a general rule, lime mortar and cement-lime mortar have good water retentivity while plain cement mortar made with coarse ungraded sand has low water retentivity.

Water retentivity of cement mortar is improved by the addition of hydrated lime or finely ground limestone or chemical compounds known as plasticizers. Generally speaking, mortars having good workability have also good water retentivity.

A standard test for determination of water retentivity in masonry mortars is given in IS 2250 : 1981. In accordance with that standard, water retentivity of masonry mortar should not be less than 70 percent. It may be clarified that property of water retentivity in masonry mortars is important mainly when masonry units have high rate of suction-as for example, common burnt clay brick and concrete block. In case of engineering brick and hard stone, which have low suction, high water retentivity of mortar does not have much advantage. In case of common brick which has water absorption of about 20

percent, suction rate of units is reduced by pre-soaking or pre-wetting of the units.

In case of concrete blocks and such other units, which have very high shrinkage rate, pre-soaking or prolonged pre-wetting is likely to result in extensive cracking of masonry due to drying shrinkage and therefore pre-wetting has to be done on a restricted scale and a mortar with high water retentivity (85 percent or more) should be chosen for such masonry.

3. RATE OF STIFFENING

Stiffening of mortar in masonry is caused either by loss of moisture or by the setting action of binder used in the mortar or by both. Most of the moisture lost is absorbed into the masonry unit but some evaporates into the atmosphere. A mud mortar stiffens only by loss of moisture and there is no setting action of its clay. A lime-sand mortar made from non-hydraulic lime (limes of grade C and D) also stiffens in early stages by loss of moisture but it has also very mild and slow setting action due to carbonation. A cement mortar stiffens mainly through setting action of cement.

Behaviour of a cement-lime mortar is in-between that of lime mortar and cement mortar. It is necessary that mortar should have sufficiently high rate of initial stiffening so that construction work could proceed at a reasonable pace.

If rate of stiffening is too low, mortar, due to its plasticity will get compressed and squeezed out, as the work proceeds, due to self-load of masonry, thus resulting in variation in thickness of joints and distortion of masonry.

On the other hand, if rate of stiffening is too rapid, it will result in cracking masonry as the unavoidable shrinkage in units due to drying and slight settlements in foundation due to loads, cannot then be accommodated within the mortar joints.

In cold regions, when nights are frosty, it is important that mortar should stiffen rapidly enough so that it is not damaged by frost by formation of ice crystals within the body of mortar. For this reason, as a general rule, cement mortar should not be leaner than 1:5 and cement lime mortar leaner than 1: 1/2 : 4.5.

In addition, some further precautions like preventing masonry units, sand and water from getting too cold, use of warm water for mixing of mortar, use of calcium chloride as an accelerator in cement mortar, covering the freshly laid masonry with tarpaulins at the close of the day's work, etc. should be taken.

4. STRENGTH

A mortar gains strength, to a small extent by loss of moisture that is by drying action as in mud mortar and non-hydraulic lime mortar, but mainly by setting action of its cementitious content, namely lime and cement. In case of lime mortar made from non-hydraulic lime, which sets through carbonation, gain of strength is very slow.

In case of cement mortar or lime mortar made from hydraulic lime, gain of strength is due to hydration and is comparatively rapid.

From structural considerations it is necessary that masonry should attain the requisite strength by the time loads are imposed on it. With that in view, 28-day strength of a mortar is taken into consideration.

As stated earlier, mud mortar stiffens only by loss of moisture and its constituents, namely soil has no setting action. It softens again on absorbing moisture and is easily eroded by rain. It has, therefore, very low strength and poor durability. For this reason, mud mortar is considered suitable only for use in superstructure of temporary or semi-permanent buildings with very light loadings. When mud mortar is used in brick or stone masonry, basic stress in masonry should be limited to 0.2 N/mm^2 and to prevent erosion due to rain, external face of walls should be protected either by lime/cement pointing or some form of non-erodible plaster. Mud mortar should not be used in moist or wet situations for example foundations of a wall. This mortar is also not suitable for use in areas infested with white ants.

Strength of masonry depends on strength of mortar. It is however, to be kept in mind that undue importance should not be attached to strength of mortar at the cost of other properties of mortar.

Mortar need not, therefore, be stronger than what is necessary from consideration of strength of masonry, and it should possess other desirable properties. High strength mortar has an advantage only in case of high strength units, and heavy loads.

Ordinarily in buildings designed as per provisions of Design Standard Codes, slenderness ratio of load bearing elements is restricted so that due to over-loading, failure of masonry would take place by tensile splitting of masonry and not by buckling. Therefore, bond between mortar and masonry is more important than compressive strength of mortar. Use of composite cement-lime mortar, because of its better bond strength, gives a stronger masonry than that with plain cement mortar, even though plain cement mortar may have higher compressive -strength.

5. RESISTANCE TO RAIN PENETRATION

Rain water penetrates a masonry wall by three different modes, namely:

- Through pores of masonry units,
- Through pores of mortar, and
- Through cracks between units and mortar.

It has been found that rain penetration through units and mortar is not very significant and main source of rain penetration is through cracks in masonry.

Moreover, rain penetration is much more through wide cracks, even if few in number, than through thin cracks which may be more in number.

These cracks are mostly caused by shrinkage of units and mortar on drying, thermal movement of units and mortar and inevitable slight settlement to which every building is subject. Thus, from the view point of rain penetration, bonding property of mortar is of great importance. It has been observed that if mortar is not very strong, if it gains strength slowly, and if it has good bond with units, movement of units due to shrinkage, temperature variations and settlement of foundation get accommodated to a great extent within the mortar and cracks are, therefore, thin and evenly distributed. As a result, masonry has much better resistance to rain penetration.

A composite cement-lime mortar possesses practically all the above mentioned

desirable qualities. In this mortar relative proportion of cement and lime is varied to suit the strength requirement of masonry and shrinkage coefficient of units.

For units having high shrinkage for example, concrete block, lime content should be ample. Mixes of composite mortars in common use are 1 : 1/2 : 4.5, 1 : 1 : 6, 1 : 2 : 9 and 1 : 3 : 12. Of these 4 mixes 1 : 1 : 6 mix is in more common use since it has reasonably good strength and also, imparts to masonry, adequate resistance to rain penetration.

6. DURABILITY

Deterioration in mortar takes place due to:

Frost action before the mortar has gained sufficient strength, and repeated cycles of freezing and thawing,

Prolonged chemical action between soluble sulphates present either in burnt clay bricks or in soil in contact with masonry in foundation, and

Ingress of moisture through cracks into the body of the masonry and consequent repeated cycles of wetting and drying over a number of years and crystallization of salts.

For protection against frost damage, and repeated cycles of freezing and thawing, it is necessary that mortar should gain strength rapidly, it should be dense and should have good ultimate strength. It should therefore, contain adequate proportion of portland cement, and sand should be well graded.

Since lime mortar is slow in setting, and does not have much ultimate strength, its use is not suited when there is early frost hazard or when masonry is likely to be subjected to repeated cycles of freezing and thawing.

Use of an air-entraining admixture in cement mortar 1 : 5 or 1 : 6 considerably improves its resistance to frost action and repeated cycles of freezing and thawing.

For protection against sulphate attack, a rich cement mortar (1 : 4 mix or better) or composite cement-lime mortar 1 : 1/2 : 4.5 using ordinary portland cement should be used when only moderate protection is needed and rich cement mortar (1 : 4 or better)

with sulphate resisting cement should be provided when sulphate attack is expected to be severe.

It should be borne in mind that if masonry in any situation remains generally dry, sulphates, even if present in brick or sand in excessive quantity, cannot cause much damage.

To ensure durability of mortar against weathering action due to repeated cycles of wetting and drying of masonry (for example, parapets) in exposed situations, mortar should be dense and moderately strong. For this mortar should be either 1 cement: 5 sand or 1 cement: 1 lime: 6 sand using well graded sand.

Further, properties of mortar should match the type of unit used in masonry, so that there are no wide cracks in masonry. For example, when using units having high shrinkage, such as concrete blocks, cement-lime mortar should be used since this mortar, being slow in gaining strength, permits volumetric changes in units within the mortar joints without occurrence of wide cracks and has good resistance to rain penetration. Use of some air-entraining admixture in cement mortar also improves its durability quite appreciably.

2.2.4 Types of Cement Grades

There are different grades of cement, which are specified by IS 1489: 1991 as below of cement grade list.

OPC 33 Grade Cement

OPC 43 Grade Cement

OPC 53 Grade cement

OPC 53

- OPC (Ordinary Portland Cement) 33 Grade Cement
- The Cement, which has Compressive strength of 33 N/ mm² after the 28 days when tested, is known as 33-Grade Cement.

- Fineness (specific area) of 33 Grade Cement = 300 m²/kg
- 3 days compressive strength = 16 N/mm²
- 7 days compressive strength = 22 N/mm²
- 28 days compressive strength = 33 N/mm²

Properties of 33-Grade Cement

- This grade of cement has high workability and is mainly used for masonry work and for plastering work.
- The initial strength of 33 Grade Cement continues to gain even after 28 days.
- The heat of hydration of 33 Grade Cement is lower as compared to the 43 grade and 53-grade cement.
- Uses of 33-Grade Cement
 - It is widely used in plastering work.
 - It is also used for the brickwork of walls.
 - In the tiling work.
 - It is generally used for work, which required low compressive strength of below M20.
 - The Code of reference for 33-grade cement is IS Code – IS 269: 1989.

43 Grade Cement

- OPC (Ordinary Portland Cement) 43 Grade Cement
- The Cement, which has Compressive strength of 43 N/ mm² after the 28 days when tested, is known as 43-Grade Cement. Fineness (specific area) of 43 Grade Cement = 225 m²/kg
- 3 days compressive strength = 23 N/mm²
- 7 days compressive strength = 33 N/mm²

- 28 days compressive strength = 43 N/mm²

Properties of 43-Grade Cement

- It has low chloride content, so it doesn't cause corrosion of steel reinforcement.
- It gives good workability of concrete.
- The initial strength of 43 Grade Cement continues to gain even after 28 days.
- The heat of hydration of 43 Grade Cement is medium.
- This will give a better surface finish to the structures.
- It is moderately sulfate resisting.
- Uses of 43 Grade Cement
 - It is used in the preparation of Ready Mix Concrete (RMC).
 - It is used for PCC and RCC work.
 - It is used in the construction of RCC bridges.
 - For Construction of Silos and Chimneys.
 - It is used for finishing of all types of structures like buildings, bridges, roads, and water retaining structures.
 - It is used in precast and prestressed concrete.
 - It is also used in Ship form Construction.
 - It is used in the construction where a grade of concrete up to M30.
 - The Code of reference for 43-Grade Cement is IS Code – IS 8112: 1989.

OPC 53

- OPC (Ordinary Portland Cement) 53 Grade Cement
 - The Cement, which has Compressive strength of 53 N/ mm² after the 28 days when tested, is known as 53-Grade Cement. Fineness (specific area)

of 53 Grade Cement = 225 m²/kg

- 3 days compressive strength = 27 N/mm²
- 7 days compressive strength = 37 N/mm²
- 28 days compressive strength = 53 N/mm²

Properties of 53 Grade Cement

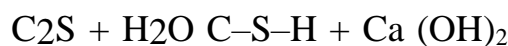
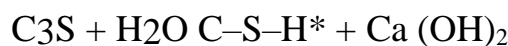
- It is a Sulphate resisting cement.
- It has low chloride content.
- It can be used in speedy Construction.
- It saves shuttering cost due to early removal.
- The initial strength of 53 Grade Cement continues to gain even after 28 days.
- Uses of 53 Grade Cement
 - It is used in the construction of concrete sleepers for Railways.
 - It is used in pre-stressed girders.
 - The 53-Grade Cement achieves early strength.
 - It is used in industrial buildings roads and runways.
 - It is used in the construction of RCC bridges and precast concrete.
 - Generally used for M25 and above concretes.
 - It is used in the construction of all RCC components like a beam, columns, footings, and slabs.

2.2.5 Hydration Of Cement

The chemical reaction between cement and water is known as hydration of cement. The reaction takes place between the active components of cement (C₄AF, C₃A, C₃S and C₂S) and water. The factors responsible for the physical properties of concrete are the extent of hydration of cement and the resultant microstructure of the hydrated

cement. When the cement comes in contact with water, the hydration products start depositing on the outer periphery of the nucleus of hydrated cement. This reaction proceeds slowly for 2-5 hours and is called induction or dormant period. As the hydration proceeds, the deposit of hydration products on the original cement grain makes the diffusion of water to unhydrated nucleus more and more difficult, consequently reducing the rate of hydration with time. At any stage of hydration, the cement paste consists of gel (a fine-grained product of hydration having large surface area collectively), the unreacted cement, calcium hydroxide, water and some minor compounds.

The crystals of the various resulting compounds gradually fill the space originally occupied by water, resulting in the stiffening of the mass and subsequent development of the strength. The reactions of the compounds and their products are as follows:



Calcium sulpho-aluminate



The product C-S-H gel represents the calcium silicate hydrate also known as tobermorite gel which is the gel structure. The hydrated crystals are extremely small, fibrous, platey or tubular in shape varying from less than 2 nm to 10 nm or more. The C-S-H phase makes up 50-60% of the volume of solids in a completely hydrated Portland cement paste and is, therefore, the most important in determining the properties of the paste. The proposed surface area for C-S-H is of the order of 100-700 m²/g and the solid to solid distance being about 18 Å. The Ca(OH)₂ liberated during the silicate phase crystallizes in the available free space. The calcium hydroxide

crystals also known as portlandite consists of 20-25% volume of the solids in the hydrated paste. These have lower surface area and their strength contributing potential is limited. The gel must be saturated with water if hydration is to continue. The calcium hydroxide crystals formed in the process dissolve in water providing hydroxyl (OH^-) ions, which are important for the protection of reinforcement in concrete. As hydration proceeds, the two crystal types become more heavily interlocked increasing the strength, though the main cementing action is provided by the gel which occupies two-thirds of the total mass of hydrate.

Notes:

1. It has been found that hydration of C 3S produces lesser calcium silicate hydrate and more $\text{Ca}(\text{OH})_2$ as compared to the hydration of C2S. Since $\text{Ca}(\text{OH})_2$ is soluble in water and leaches out making the concrete porous, particularly in hydraulic structures, a cement with small percentage of C3S and more C2S is recommended for use in hydraulic structures.

2. It is particularly important to note that the setting (the change of cement paste from plastic to stiff solid state) and hardening (gain of strength with hydration is a chemical reaction, wherein water plays an important role, and is not just a matter of drying out. Infact, setting and hardening stop as soon as the concrete becomes dry.

2.2.6 Rate Of Hydration:

The reaction of compound C3A with water is very fast and is responsible for flash setting of cement (stiffening without strength development) and thus it will prevent the hydration of C3S and C2S. However, calcium sulphate (CaSO_4) present in the clinker dissolves immediately in water and forms insoluble calcium sulphoaluminate. It deposits on the surface of C3A forming a colloidal membrane and consequently retards the hydration of C3A. The amount of CaSO_4 is adjusted to leave a little excess of C3A to hydrate directly. This membrane in the process breaks because of the pressure of the compounds formed during hydration and then again C3A becomes active in the

reaction.

The hardening of C₃S can be said to be catalyzed by C₃A and C₃S becomes solely responsible for gain of strength up to 28 days by growth and interlocking of C-S-H gel. The increase in strength at later ages is due to hydration of C₂S.

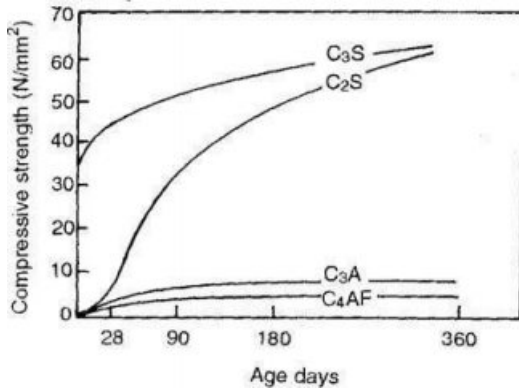


Fig.9 Contribution of Cement Compounds to Strength of Cement

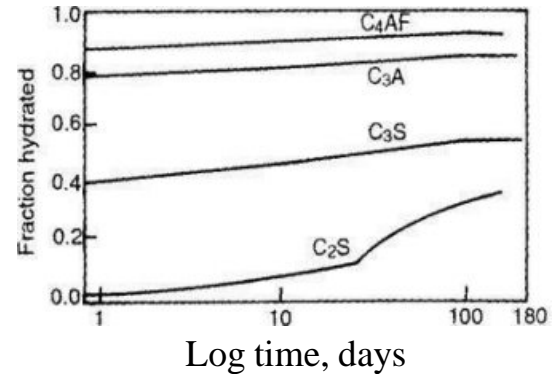


Fig. 10 Rate of Hydration of Pure Cement Compound

Notes:

1. The development of strength of the four principal compounds of cement with age is shown in Fig. 9

2. The rate of heat evolution of the compounds if equal amount of each is considered will be in the following descending order:

C₃A, C₃S, C₄AF, C₂S

3. The rate of hydration is increased by an increase in fineness of cement. However, total heat evolved is the same. The rate of hydration of the principal compounds is shown in Fig. 10 and will be in the following descending order:

C₄AF, C₃A, C₃S, C₂S

2.3 Test on cement:

2.3.1 Physical Tests (IS: 4031)

1. Fineness Test
 - Sieve Method:
 - Air Permeability Method
 - Wagner Turbidimeter Method
2. Consistency Test
3. Initial and Final Setting Times:
4. Soundness Test
5. Autoclave Test
6. Strength
 - Compressive Strength
 - Tensile strength
7. Heat of hydration
8. Specific Gravity Test

1. Fineness Test

The degree of fineness of cement is the measure of the mean size of the grains in it. There are three methods for testing fineness: the sieve method—using 90 micron (9 No.) sieve, the air permeability method— Nurse and Blains method and the sedimentation method— Wagner turbidimeter method. The last two methods measure the surface area, whereas the first measures grain size. Since cement grains are finer than 90 micron, the sieve analysis method does not represent true mean size of cement grains. Also, the tiny cement grains tend to conglomerate into lumps resulting in distortion in the final grain size distribution curves. Considering these demerits, fineness is generally expressed in terms of specific area, which is the total surface area of the particles in unit weight of material.

Conditions affecting Fineness: The chemical composition and the degree of calcination influence the hardness of the clinker and consequently the fineness to which

the cement is ground. Clinker, high in iron or silica, is apt to be hard and difficult to grind. The same is true with a hard-burned clinker. Fineness is also influenced by the time of grinding and the character of the pulverizing machinery. It has been found that cement becomes finer with age provided it does not absorb too much moisture. This is probably due to the decrepitation of the coarser grains resulting from the hydration of the embedded lime particles.

Importance: Finer the cement more is the strength since surface area for hydration will be large. With increase in fineness, the early development of strength is enhanced but the ultimate strength is not affected. An increase in the fineness of the cement increases the cohesiveness of the concrete mix and thus reduces the amount of water which separates to the top of a lift (bleeding), particularly while compacting with vibrators. However, if the cement is ground beyond a certain limit, its cementative properties are affected due to the prehydration by atmospheric moisture. Finer cement reacts more strongly in alkali reactive aggregate. Also, the water requirement and workability will be more leading to higher drying shrinkage and cracking.

i) Sieve Method: 100 g of cement sample is taken and air-set lumps, if any, in the sample are broken with fingers. The sample is placed on a 90 micron sieve and continuously sieved for 15 minutes. The residue should not exceed the limits specified below:

ii) Air Permeability Method: The fineness of cement is represented by specific surface, i.e. total surface area in cm^2 per gram or m^2 per kilogram of cement and is measured by Lea and Nurse apparatus or by wagner turbidimeter..

The Lea and Nurse apparatus shown in Fig. 28 essentially consists of a permeability test cell—where cement is placed and air pressure is applied, flowmeter—to determine the quantity of air passing per second through its capillary tube per unit difference of pressure, and manometer—to measure the air pressure.

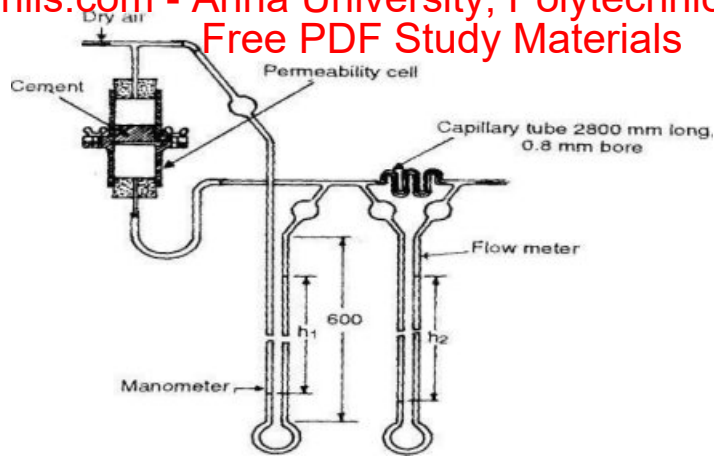


Fig. 9 Permeability Apparatus

To determine the fineness, a cement sample of 20 mm height is placed on a perforated plate (40 micron perforations) and air pressure is applied. The manometer is connected to the top of the permeability cell and the air is turned on. The lower end of the permeability cell is then slowly connected to the other end of the manometer. The rate of flow is so adjusted that the flow meter shows a pressure difference (h_2) of 30-50 cm. The reading (h_1) in the manometer is recorded. The process is repeated till the ratio h_1/h_2 is constant. The specific surface is given by the expression

where L = thickness of cement layer
 A = area of cement layer
 d = density of cement

Y = porosity of cement (0.475) h_2 = flowmeter reading

h_1 = manometer reading

K is the flow meter constant and is obtained by

$$Q = \frac{K h_2 d_1}{P}$$

P

where m = viscosity of air

d_1 = density of kerosene

Q = quantity of air passed per second

The minimum specific surface for various cements should be as specified in Table 3.

Table 3 Minimum Specific Surfaces of Cements

Type of cement		Specific surface not less than cm ² /g
Ordinary Portland Cement	(OPC)	2250
Rapid Hardening Cement	(RHC)	3250
Low Heat Cement	(LHC)	3250
Portland Pozzolana Cement	(PPC)	3000
High Alumina Cement	(HAC)	2250
Super Sulphate Cement	(SSC)	4000

iii) Wagner Turbidimeter Method: L.A. Wagner developed a turbidimeter to estimate the surface area of one gram of cement. The cement is dispersed uniformly in a rectangular glass tank filled with kerosene. Then, parallel light rays are passed through the solution which strikes the sensitivity plate of a photoelectric cell. The turbidity of the solution at a given instant is measured by taking readings of the current generated by the cell. By recording the readings at regular intervals while the particles are falling in the solution, it is possible to secure information regarding the grading in surface area and in size of particle. Readings are expressed in sq. cm per gram.

2) Consistency Test

This is a test to estimate the quantity of mixing water to form a paste of normal consistency defined as that percentage water requirement of the cement paste, the viscosity of which will be such that the Vicat's plunger penetrates up to a point 5 to 7 mm from the bottom of the Vicat's mould.

Importance: The water requirement for various tests of cement depends on the normal consistency of the cement, which itself depends upon the compound composition and fineness of the cement.

Test Procedure: 300 g of cement is mixed with 25 per cent water. The paste is filled in the mould of Vicat's apparatus (Fig. 29) and the surface of the filled paste is

smoothened and levelled. A square needle 10 mm x 10 mm attached to the plunger is then lowered gently over the cement paste surface and is released quickly. The plunger pierces the cement paste. The reading on the attached scale is recorded. When the reading is 5-7 mm from the bottom of the mould, the amount of water added is considered to be the correct percentage of water for normal consistency.

3) Initial and Final Setting Times:

When water is added to cement, the resulting paste starts to stiffen and gain strength and lose the consistency simultaneously. The term setting implies solidification of the plastic cement paste. Initial and final setting times may be regarded as the two stiffening states of the cement. The beginning of solidification, called the initial set, marks the point in time when the paste has become unworkable. The time taken to solidify completely marks the final set, which should not be too long in order to resume construction activity within a reasonable time after the placement of concrete. Vicat's apparatus used for the purpose is shown in Fig..

The initial setting time may be defined as the time taken by the paste to stiffen to such an extent that the Vicat's needle is not permitted to move down through the paste to within 5 ± 0.5 mm measured from the bottom of the mould. The final setting time is the time after which the paste becomes so hard that the angular attachment to the needle, under standard weight, fails to leave any mark on the hardened concrete. Initial and final setting times are the rheological properties of cement.

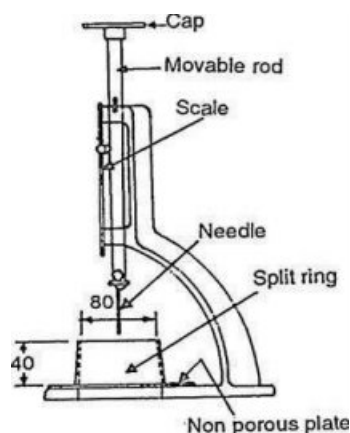


Fig 10 Vicat apparatus

Importance: It is important to know the initial setting time, because of loss of useful properties of cement if the cement mortar or concrete is placed in moulds after this time. The importance of final setting time lies in the fact that the moulds can be removed after this time. The former defines the limit of handling and the latter defines the beginning of development of mechanical strength.

Conditions Affecting Setting Time: The factors influencing the setting properties of cement are its composition, the percentage of retardant, degree of calcination, fineness of grinding, aeration subsequent to grinding clinker, percentage of water used to make cement paste, the temperature of the mixing water, cement and the atmosphere where the cement paste is placed, and the amount of manipulation the paste receives. The effect of lime, silica and alumina in controlling the set have been discussed in Sec. 5.3. The effect of gypsum is to increase the setting time of freshly ground cement. It is usually mixed with the clinker before final grinding, or just after the clinker has received preliminary grinding. The addition of gypsum before calcination causes it to decompose into lime and sulphur trioxide. Since the latter is liberated in the kiln, there is resulting effect on the setting time. Often, an underlined cement becomes quick setting after seasoning. This can be avoided by adding to the cement 1 or 2 per cent of hydrated lime or the fraction of a per cent of Plaster of Paris. Setting time of cement is rapid with the increase in the fineness of cement. When the mixing water used in testing cement paste is increased by 1 per cent above that required for normal consistency, an increase of about 30 minutes or more is observed in the initial or final set.

Cements stored in warm rooms will, in general, be quick setting than those stored in cold places. Cold mixing water retards set while warm water accelerates it. Cement exposed to thoroughly saturated atmosphere will set much more slowly than those exposed to a dry atmosphere. If, however, a considerable proportion of moist CO₂ is present in the air, the setting time is found to reduce greatly. By lengthening the time of mixing and by prolonged troweling of the surface mortars, it is also possible to

considerably delay the setting time.

Test Procedure:

A neat cement paste is prepared by gauging cement with 0.85 times the water required to give a paste of standard consistency. The stop watch is started at the instant water is added to the cement. The mould resting on a nonporous plate is filled completely with cement paste and the surface of filled paste is levelled smooth with the top of the mould. The test is conducted at room temperature of $27 \pm 2^\circ\text{C}$. The mould with the cement paste is placed in the Vicat's apparatus as shown in Fig. 5.9 and the needle is lowered gently in contact with the test block and is then quickly released. The needle thus penetrates the test block and the reading on the Vicat's apparatus graduated scale is recorded. The procedure is repeated until the needle fails to pierce the block by about 5 mm measured from the bottom of the mould. The stop watch is pushed off and the time is recorded which gives the initial setting time.

The cement is considered to be finally set when upon applying the needle gently to the surface of test block, the needle makes an impression, but the attachment fails to do so.

4) Soundness Test

It is essential that the cement concrete does not undergo large change in volume after setting. This is ensured by limiting the quantities of free lime and magnesia which slake slowly causing change in volume of cement (known as unsound). Soundness of cement may be tested by Le-Chatelier method or by autoclave method. For OPC, RHC, LHC and PPC it is limited to 10 mm, whereas for HAC and SSC it should not exceed 5 mm.

Importance: It is a very important test to assure the quality of cement since an unsound cement produces cracks, distortion and disintegration, ultimately leading to failure.

Conditions affecting Soundness: The main cause for unsoundness in Portland cement is the hydration of the uncombined lime encased within the cement particles. Exposed, finely ground, free lime in small percentages, hydrates before the cement sets and

produces no injurious effect. The uncombined lime in cement is a result of either underburning the clinker or of excess lime in the raw materials. Freshly ground cement is often unsound due to the presence of uncombined lime. Cement is thus allowed to aerate for two to three weeks, allowing the lime to hydrate, to overcome unsoundness.

Fine grinding of the raw material and clinker help to produce a sound cement. By grinding fine the raw materials, it is possible to produce a homogeneous mixture before burning where the lime is uniformly distributed. The coarse grains of cement may imprison minute particles of uncombined lime which do not hydrate. These lime particles on hydration produce disintegration.

Le-chatelier Method: The apparatus is shown in Fig. 11. The mould is placed on a glass sheet and is filled with neat cement paste formed by gauging 100 g cement with 0.78 times the water required to give a paste of standard consistency. The mould is covered with a glass sheet and a small weight is placed on the covering glass sheet. The mould is then submerged in the water at temperature of 27°-32°C. After 24 hours, the mould is taken out and the distance separating the indicator points is measured. The mould is again submerged in water. The water is now boiled for 3 hours. The mould is removed from water and is cooled down. The distance between the indicator points is measured again. The difference between the two measurements represents the unsoundness of cement.

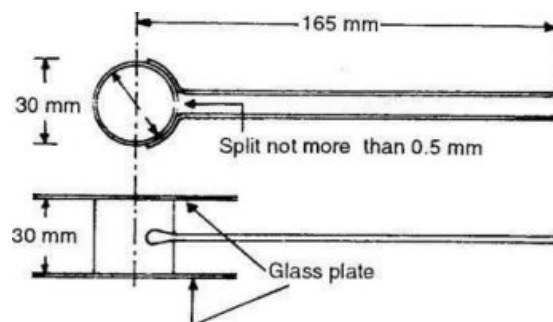


Fig. 11 Le-chatelier Apparatus

5) Autoclave Test: The 25 × 25 × 250 mm specimen is made with neat cement paste. After 24 hours the moulded specimen is removed from the moist atmosphere, measured for length, and so placed in an autoclave at room temperature that the four tides of each

specimen are at least exposed to saturated steam. The temperature of the autoclave is raised at such a rate that the gauge pressure of the steam rises to 2.1 N/mm^2 in 1 to $1 \frac{1}{4}$ hours from the time the heat is turned on. The pressure is maintained for 3 hours. Then the heat supply is shut off and the autoclave is cooled at such a rate that the pressure is less than 0.1 N/mm^2 at the end of the hour. The autoclave is then opened and the test specimens are placed in water at temperature of 90°C . The temperature is gradually brought down to $27 \pm 2^\circ\text{C}$ in 15 minutes. The specimens are maintained at this temperature for next 15 minutes and are then taken out. The length of the specimen is measured again. The difference in the two measurements gives the unsoundness of the cement.

6) Determination of Strength

Cement hydrates when water is added to it and cohesion and solidity is exhibited. It binds together the aggregates by adhesion. The strength of mortar and concrete depends upon the type and nature of cement. So, it should develop a minimum specified strength if it is to be used in structures. Cement is tested for compressive and tensile strengths.

Conditions affecting Strength: Cement is very strong at early ages if a high lime or high alumina content is there. Gypsum and Plaster of Paris in small percentages also tend to increase the strength slightly, but when present in quantities larger than 3 per cent, these substances provide variable effects. The effect of the clinker compounds on strength have already been discussed. In addition to the effect of composition, the strength of cement is greatly influenced by the degree of burning, the fineness of grinding, and the aeration it receives subsequent to final grinding. An underburnt cement is likely to be deficient in strength.

i) Compressive Strength: Compressive strength is the basic data required for mix design. By this test, the quality and the quantity of concrete can be controlled and the degree of adulteration can be checked.

The test specimens are 70.6 mm cubes having face area of about 5000 sq. mm. Large

size specimen cubes cannot be made since cement shrinks and cracks may develop. The temperature of water and test room should be $27^{\circ} \pm 2^{\circ}\text{C}$. A mixture of cement and standard sand in the proportion 1:3 by weight is mixed dry with a trowel for one minute and then with water until the mixture is of uniform colour. Three specimen cubes are prepared. The material for each cube is mixed separately. The quantities of cement, standard sand and water are 185 g, 555 g and $(P/4) + 3.5$, respectively where P = percentage of water required to produce a paste of standard consistency. The mould is filled completely with the cement paste and is placed on the vibration table. Vibrations are imparted for about 2 minutes at a speed of 12000 ± 400 per minute.

The cubes are then removed from the moulds and submerged in clean fresh water and are taken out just prior to testing in a compression testing machine. Compressive strength is taken to be the average of the results of the three cubes. The load is applied starting from zero at a rate of 35 N/sq mm/minute. The compressive strength is calculated from the crushing load divided by the average area over which the load is applied. The result is expressed in N/mm^2 .

ii) **Tensile Strength:** The tensile strength may be determined by Briquette test method or by split tensile strength test.

Importance: The tensile strength of cement affords quicker indications of defects in the cement than any other test. Also, the test is more conveniently made than the compressive strength test. Moreover, since the flexural strength, is directly related to the tensile strength this test is ideally fitted to give information both with regard to tensile and compressive strengths when the supply for material testing is small.

Briquette Method: A mixture of cement and sand is gauged in the proportion of 1:3 by weight. The percentage of water to be used is calculated from the formula $(P/5) + 2.5$, where P = percentage of water required to produce a paste of standard consistency. The temperature of the water and the test room should be $27^{\circ} \pm 2^{\circ}\text{C}$. The mix is filled in the moulds of the shape shown in Fig. 5.11.

After filling the mould, an additional heap of mix is placed on the mould and is

pushed down with the standard spatula, until the mixture is level with the top of the mould. This operation is repeated on the other side of the mould also. The briquettes in the mould are finished by smoothing the surface with the blade of a trowel. They are then kept for 24 hours at a temperature of $27^{\circ} \pm 2^{\circ}\text{C}$ and in an atmosphere having 90 per cent humidity. The briquettes are then kept in clean fresh water and are taken out before testing. Six briquettes are tested and the average tensile strength is calculated. Load is applied steadily and uniformly, starting from zero and increasing at the rate of 0.7 N/sq mm of section in 12 seconds.

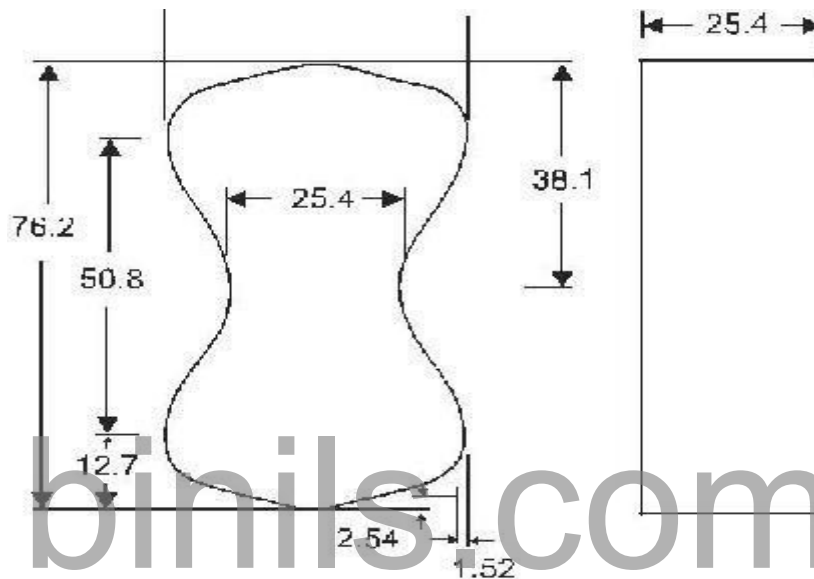


Fig. 12 Dimensions of Standard Briquette

Ordinary Portland cement should have a tensile strength of not less than 2.0 N/mm^2 after 3 days and not less than 2.5 N/mm^2 after 7 days.

Notes:

- (i) In the tension test of cement the load on the briquette should be applied centrally. Since briquettes become brittle with age, the effect of slight eccentricity or any torsional strain is pronounced in long-time tests.
- (ii) The strength increases when the loading rate is increased from that specified.

7) Heat of hydration

Heat is evolved during hydration of cement, the amount being dependent on the relative quantities of the clinker compounds.

Importance: The evolution of heat causes an increase in temperature of the concrete, being greatest in mass concreting. Since the cooling of a mass of concrete can only occur from surfaces exposed to atmosphere the temperature of the interior is higher than that at the surface and also there is a rapid increase in strength in the interior than at the surface. Shrinkage cracks may result from stresses, induced by cooling of the surface while the interior of concrete is still at higher temperature. However, in practice, the heat evolution may be taken to its advantage in cold weather provided the concrete is warm at the time of placing and excessive heat loss is prevented by suitable lagging.

Test Procedure: The apparatus used to determine the heat of hydration of cement is known as calorimeter and is shown in Fig. 13. 60 g of cement and 24 ml of distilled water are mixed for 4 minutes at temperature 15° – 25° C. Three specimen glass vials 100×20 mm are filled with this mixture, corked and sealed with wax. The vials are then stored with the mixture in a vertical position at $27^{\circ} \pm 2^{\circ}$ C. The heat of hydration is obtained by subtracting the respective heat of solution of unhydrated cement calculated nearest to 0.1 calorie.

For determining the heat of solution of unhydrated cement, weigh a sample of about 3 g. At the sametime, weigh out 7.0 g of cement for the loss on ignition.

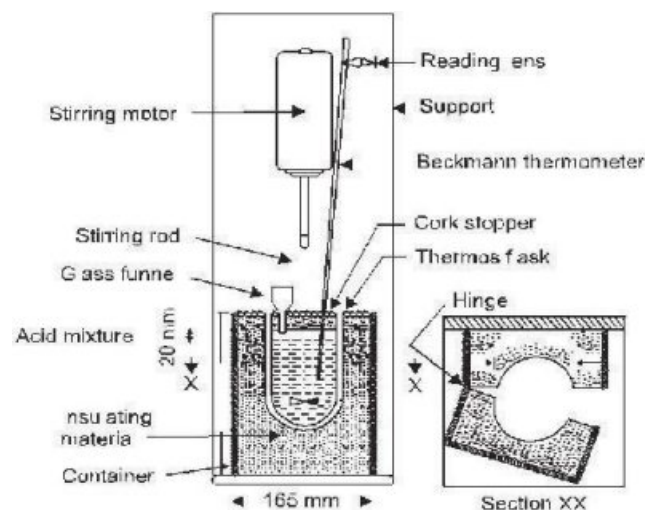


Fig.13 Calorimeter

Heat of solution (Cal/g) of unhydrated cement

where 0.2 is the specific heat of unhydrated cement.

For determining heat of solution of the hydrated cement, one of the glass vials is opened and the adherent wax is removed. The cement is ground rapidly, to avoid carbonation, to pass an 850 micron sieve. From this weigh out 4.2 g and 7.0 g of cement samples for heat of solution and loss on ignition.

The heat of solution of hydrated cement (Cal/g ignited weight)

$$\frac{\text{Heat capacity} \times \text{corrected temperature}}{\text{Weight of sample corrected for ignition}}$$

The ignition loss can be obtained by placing the sample in a cool furnace and raising the temperature of the furnace to 900°C over a period of 1 hour. The sample is kept at 900° ± 50°C for 3-4 hours and then cooled in a desiccator containing anhydrous calcium chloride. Weigh after half an hour. The difference in the two weighings give the loss on ignition.

To determine the heat capacity sufficient quantity of zinc oxide is ignited for one hour at 900° ± 50°C. It is cooled in a desiccator containing anhydrous calcium chloride and ground to pass 250 micron sieve. About 7 g of this ignited oxide is reheated to 900° ± 50°C for 5 minutes and then cooled for about 2½ hours (not more than 5 hours). The calorimeter is assembled and temperature reading correct to 0.001°C is recorded to determine the initial heating or cooling correction. The zinc oxide is then introduced. The temperature readings are recorded at one minute intervals until the solution is complete. The recording of readings is continued for next 5 minutes to determine the final heating or cooling correction. The initial and final heating or cooling rates against the corresponding calorimeter temperature are plotted. The two points thus obtained are joined by a straight line. From this graph the corrections are read off for each temperature reading during the solution period. Heat capacity is calculated from the expression.

$$\text{Heat capacity (} ^\circ\text{C)} = \frac{\text{Cal} \times \text{weight of ZnO}(256.1 \setminus 0.2 \setminus 0.1)}{\text{corrected temperature rise}}$$

where, 256.1 is the heat of solution of zinc oxide at 30°C and 0.2 the negative temperature coefficient of the heat of solution, is the final temperature of the

calorimeter, 0.1 is the specific heat of zinc oxide and is the room temperature in °C.

8) Specific Gravity Test

The specific gravity of hydraulic cement is obtained using Le-Chatelier flask shown in Fig. 14.

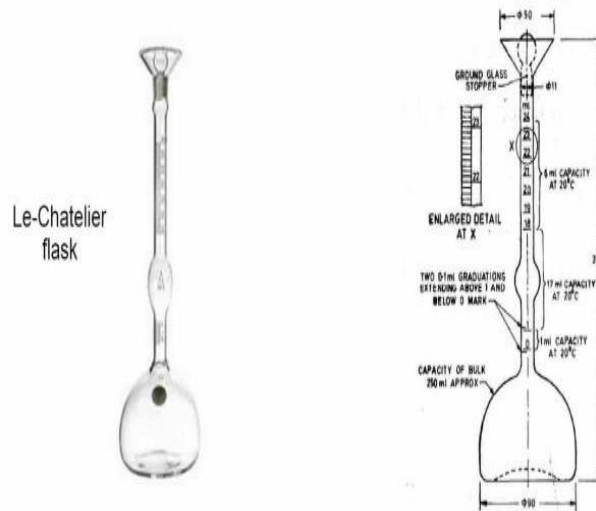


Fig.14 Le-Chatelier Flask for Specific Gravity Test

Conditions affecting Specific Gravity: Long seasoning is the chief cause of a low specific gravity in unadulterated cement. This is because the freshly ground cement when exposed to air rapidly absorbs moisture and carbon dioxide. Cements with high contents of iron oxide have a higher specific gravity. The effect of fineness of grinding upon specific gravity is slight. Very finely ground cements are likely to have lower specific gravities.

Test Procedure: The flask is filled with either kerosene free of water, or naphtha having a specific gravity not less than 0.7313 to a point on the stem between zero and 1-ml mark. The flask is immersed in a constant temperature water bath and the reading is recorded. A weighed quantity of cement (about 64 g of Portland cement) is then introduced in small amounts at the same temperature as that of the liquid. After introducing all the cement, the stopper is placed in the flask and the flask rolled in an inclined position, or gently whirled in a horizontal circle, so as to free the cement from air until no further air bubbles rise to the surface of the liquid. The flask is again immersed in the water-bath and the final reading is recorded. The difference between the first and the final reading represents the volume of liquid displaced by the weight of the cement used in the test.

2.3.2 Chemical Tests (IS: 4032)

1. Loss on ignition
2. Silica
3. Combined Ferric Oxide and Alumina
4. Ferric Oxide
5. Alumina
6. Calcium Oxide
7. Magnesia: The filtrate (W3) is acidified with hydrochloric acid and is concentrated to
8. Sulphuric Anhydride
9. Insoluble Residue

1) Loss on ignition: 1.00 g of the sample is heated for 15 minutes in a weighed and covered platinum crucible of 20 to 25 ml capacity by placing it in a muffle furnace at any temperature between 900° and 1000°C. It is then cooled and weighed. Thereafter, the loss in weight is checked by a second heating for 5 minutes and reweighing. The loss in the weight is recorded as the loss on ignition and the percentage of loss on ignition to the nearest 0.1 is calculated ($\text{loss in weight} \times 100$). The percentage loss on ignition should not exceed 4 per cent.

2) Silica: 0.5 g of the sample is kept in an evaporating dish, moistened with 10 ml of distilled water at room temperature to prevent lumping. To this 5 to 10 ml of hydrochloric acid is added, and digested with the aid of gentle heat and agitation until solution is complete. Dissolution may be aided by light pressure with the flattened end of a glass rod. The solution is evaporated to dryness on a steam bath. Without heating the residue any further, it is treated with 5 to 10 ml of hydrochloric acid and then with an equal amount of water. The dish is covered and digested for 10 minutes on a water bath. The solution with an equal volume of hot water is diluted and is immediately filtered through an ashless filter paper, and the separated silica (SiO_2) is washed thoroughly with hot water and the residue is reserved.

The filtrate is again evaporated to dryness, baking the residue in an oven for one hour at 105°C to 110°C. Then the residue is added with 10 to 15 ml of hydrochloric acid (1:1) and is heated on a water bath. This solution is then diluted with an equal volume of hot water and the small amount of silica it contains is filtered and washed on another filter paper. The filtrate and washings are reserved for the determination of combined alumina and the ferric oxide.

The papers containing the residues are transferred to a weighed platinum crucible. The papers are dried and ignited, first at a low heat until the carbon of the filter papers is completely consumed without inflaming, and finally at 1100°C to 1200°C until the weight remains constant (say W1).

The ignited residue thus obtained, which will contain small amounts of impurities is treated in the crucible with a few drops of distilled water, about 10 ml of hydrofluoric acid and one drop of sulphuric acid and evaporated cautiously to dryness. Finally, the small residue is heated at 1050°C to 1100°C for a minute or two: cooled and weighed (say W2). The difference between this weight and the weight of the ignited residue represents the amount of silica (W).

$$\text{Silica (\%)} = 200 (W1 - W2)$$

3) Combined Ferric Oxide and Alumina: 200 ml of the sample from the filtrate reserved in silica test is heated to a boil. A few drops of bromine water or concentrated nitric acid is added during boiling in order to oxidize any ferrous ion to the ferric condition. It is then treated with ammonium hydroxide (1:1), drop by drop, until the solution smells of ammonia. The solution containing the precipitates of aluminium and ferric hydroxides is boiled for one minute. The precipitate is allowed to settle, filtered through an ashless filter paper and washed with two per cent hot ammonium nitrate solution. The filtrate and washings are set aside.

The precipitate and the filter paper is transferred to the same beaker in which the first precipitation was effected. The precipitate is then dissolved in hydrochloric acid (1:3). The solution is diluted to about 100 ml and the hydroxides are reprecipitated. The

solution is filtered and precipitated with two 10 ml portions of hot ammonium nitrate solution. The filtrate and washings are then combined with the filtrate set aside and is reserved for the determination of calcium oxide.

The precipitate is placed in a weighed platinum crucible, heated slowly until the papers are charred, and finally ignited to constant weight at 1050°C to 1100°C with care to prevent reduction, and weighed (W1) as combined alumina and ferric oxide.

If silica is suspected to be carried into the filtrate used for this estimation, the residue in the crucible is treated with a drop of water, about 5 ml of hydrofluoric acid and a drop of sulphuric acid and is evaporated cautiously to dryness. Finally, the crucible is heated at 1050°C to 1100°C for one or two minutes; cooled and weighed (W2). The difference between this weight and the weight (W1), represents the amount of residue silica. This amount is subtracted from the weight of ferric oxide and alumina found as W1 and the same amount is added to the amount of silica (W). The ratio of percentages of alumina to iron oxide should not exceed 0.66.

Combined ferric oxide and alumina (%) = $\frac{\text{weight of residue}}{\text{weight of sample}} \times 200$

4) Ferric Oxide: 40 ml of cold water is added to 1 g of the sample and while the mixture is stirred vigorously, 50 ml of hydrochloric acid is added. If necessary, the solution is heated and cement is ground with flattened end of a glass rod until it is evident that cement is completely decomposed. The solution is heated to a boil and is treated with stannous chloride solution added drop by drop while stirring, until the solution is discoloured. A few drops of stannous chloride solution is added in excess and the solution is cooled to room temperature. Then, 15 ml of a saturated solution of mercuric chloride and 25 ml of manganese sulphate solution are added and titrated with standard solution of potassium permanganate until the permanent pink colour is obtained. Iron as ferric oxide is calculated.

5) Alumina: The calculated weight of ferric oxide and the small amount of silica is subtracted from the total weight of oxides (W1). The remainder is the weight of alumina and of small amounts of other oxides reported as alumina.

6) Calcium Oxide: The combined filtrate reserved in the combined ferric oxide and alumina test is acidified with hydrochloric acid and evaporated to a volume of about 100 ml. 40 ml of saturated bromine water is added to the hot solution and ammonium hydroxide is added until the solution is distinctly alkaline. The solution is boiled for 5 minutes or more, making certain that the solution is at all times distinctly alkaline. Then the precipitate is allowed to settle, filtered and washed with hot water.

The beaker and filter is washed once with nitric acid (1:33) and finally with hot water. Any precipitate (of manganese dioxide) that may be left on the funnel is discarded. The filtrate is mixed with hydrochloric acid and boiled until all the bromine is expelled. 25 ml of boiling ammonium oxalate solution is added to the boiling solution. The solution is made alkaline with ammonium hydroxide and brought to boiling, the boiling being continued until the precipitated calcium oxalate assumes a well-defined, granular form. The precipitate is allowed to stand for about 20 minutes or until it has settled, filtered and washed moderately with ammonium oxalate solution (one gram per litre). The filtrate and washings (W3) are set aside for estimating magnesia.

The precipitated lime after ignition and heating at 1100°C-1200°C is weighed. The percentage of CaO = weight of residue \times 200. Also CaO 0.7, SO₃ 2.8, SiO₂ 1.2, Al₂O₃ 0.65, Fe₂O₃ in percent should not be less than 0.66.

7) Magnesia: The filtrate (W3) is acidified with hydrochloric acid and is concentrated to about 150 ml. To this solution, about 10 ml of ammonium hydrogen phosphate solution (250 g per litre) is added and the solution is cooled by placing in a beaker of ice water. After cooling, ammonium hydroxide is added drop by drop, while stirring constantly, until the crystalline magnesium ammonium phosphate begins to form, and then the reagent is added in moderate excess (5 to 10 per cent of the volume of the solution), the stirring being continued for several minutes. The solution is set aside for at least 16 hours in a cool atmosphere and then filtered. The precipitate is washed with ammonium nitrate wash solution (100 g of ammonium nitrate dissolved in water, 200 ml of ammonium hydroxide added and diluted to one litre). It is then charred slowly

and the resulting carbon is burnt carefully. The precipitate is ignited at 1100°C to 1200°C to constant weight, taking care to avoid bringing the pyrophosphate to melting.

From the weight of the magnesium pyrophosphate obtained, the magnesia content of the material taken for the test is calculated.

The percentage of MgO = weight of residue \times 72.4. Free magnesia in cement should be less than 4 per cent.

8) Sulphuric Anhydride: To one gram of the sample, 25 ml of cold water is added and while the mixture is stirred vigorously 5 ml of hydrochloric acid is added. If necessary, the solution is heated and the material is ground with the flattened end of a glass rod until it is evident that the decomposition of cement is complete. The solution is diluted to 50 ml and digested for 15 minutes. The residue is filtered and washed thoroughly with hot water. The filter paper with the residue (W4) is set aside. The filtrate is diluted to 250 ml and heated to boiling. 10 ml of hot barium chloride (100 g per litre) solution is added drop by drop and the boiling is continued until the precipitate is well formed. The solution is digested on steam bath for 4 hours or preferably overnight. The precipitate is filtered and the precipitate is washed thoroughly. The filter paper and the contents are placed in a weighed platinum or porcelain crucible and slowly the paper is incinerated without inflaming. Then it is ignited at 800°C to 900°C, cooled in a desiccator and the barium sulphate is weighed. From the weight of the barium sulphate obtained, the sulphuric anhydride content of the material taken for the test is calculated. The percentage of SO₃ = weight of residue \times 34.3. Sulphur in cement should be less than 2.5 per cent.

9) Insoluble Residue: The filter paper containing the residue (W4) is digested in 30 ml of hot water and 30 ml of 2 N sodium carbonate solution maintaining constant volume, the solution being held for 10 minutes at a temperature just short of boiling. It is then filtered and washed with dilute hydrochloric acid (1:99) and finally with hot water till free from chlorides. The residue is ignited in a crucible at 900°C to 1000°C, cooled in a desiccator and weighed. The insoluble residues should not exceed 1.5 per cent.

2.4 Types Of Cement

Cements of unique characteristics for desired performance in a given environment are being manufactured by changing the chemical composition of OPC or by using additives, or by using different raw materials. Some of the cements available in the market are as follows.

1. Rapid Hardening Portland Cement
2. High Alumina Cement
3. Supersulphated Portland Cement
4. Sulphate Resisting Portland Cement
5. Portland slag Cement
6. Low Heat Portland Cement
7. Portland Pozzolana Cement
8. Quick Setting Portland Cement
9. Masonry Cement
10. White and Coloured Portland Cement
11. Air Entraining Cement
12. Calcium Chloride Cement

1) Rapid Hardening Portland Cement (IS: 8041) has high lime content and can be obtained by increasing the C₃S content but is normally obtained from OPC clinker by finer grinding (450 m²/kg). The basis of application of rapid hardening cement (RHC) is hardening properties and heat emission rather than setting rate. This permits addition of a little more gypsum during manufacture to control the rate of setting. RHC attains same strength in one day which an ordinary cement may attain in 3 days. However, it is subjected to large shrinkage and water requirement for workability is more. The cost of rapid hardening cement is about 10 per cent more than the ordinary cement. Concrete made with RHC can be safely exposed to frost, since it matures more quickly.

Properties:

Initial setting time 30 minutes (minimum)

Final setting time 10 hours (maximum)

Compressive strength

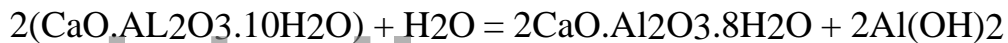
1 day	16.0 N/mm ²
3 day	27.5 N/mm ²

Uses:

It is suitable for repair of roads and bridges and when load is applied in a short period of time.

2) High Alumina Cement (IS: 6452):

This is not a type of Portland cement and is manufactured by fusing 40 per cent bauxite, 40 per cent lime, 15 per iron oxide with a little of ferric oxide and silica, magnesia, etc. (Table 5.5) at a very high temperature. The alumina content should not be less than 32%. The resultant product is ground finely. The main cement ingredient is monocalcium aluminate CA which interacts with water and forms dicalcium octahydrate hydroaluminate and aluminium oxide hydrate.



The dicalcium hydroaluminate gel consolidates and the hydration products crystallize. The rate of consolidation and crystallization is high leading to a rapid gain of strength. Since C3A is not present, the cement has good sulphate resistance.

Table 4 Composition of a Typical High Alumina Cement

Composition	Percentage
Al ₂ O ₃ , TiO ₂	43.5
Fe ₂ O ₃ , FeO, Fe ₃ O ₄	13.1
CaO	37.5
SiO ₂	3.8
MgO	0.3
SO ₃	0.4
Insoluble material	1.2

Loss on ignition	0.2
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Properties:

It is not quick setting: initial setting time (minimum) is 30 minutes, even up to 2 hours. The final setting time should not exceed 600 minutes. It attains strength in 24 hours, high early strength, high heat of hydration and resistance to chemical attack. Compressive strength after one day is 30.0 N/mm² and after 3 days it is 35.0 N/mm². After setting and hardening, there is no free hydrated lime as in the case of ordinary Portland cement. The fineness of the cement should not be less than 225 m²/kg. The cement should not have expansion more than 5 mm.

Uses:

It is resistant to the action of fire, sea water, acidic water and sulphates and is used as refractory concrete, in industries and is used widely for precasting. It should not be used in places where temperature exceeds 18°C.

3) Supersulphated Portland Cement (IS: 6909)

It is manufactured by intergrinding or intimately blending a mixture of granulated blast furnace slag not less than 70 per cent, calcium sulphate and small quantity of 33 grade Portland cement. In this cement tricalcium aluminate which is susceptible to sulphates is limited to less than 3.5 per cent. Sulphate resisting cement may also be produced by the addition of extra iron oxide before firing; this combines with alumina which would otherwise form C₃A, instead forming C₄AF which is not affected by sulphates. It is used only in places with temperature below 40°C.

Water resistance of concretes from supersulphate Portland cements is higher than that of common Portland cements because of the absence of free calcium oxide hydrate. In supersulphate Portland cements the latter is bound by slag into calcium hydroaluminates of low solubility and calcium hydrosilicates of low basicity, whereas concretes from Portland cement carry a large amount of free calcium oxide hydrate which may wash out and thus weaken them. Supersulphate Portland cement has satisfactory frost and air resistances, but it is less resistant than concrete from Portland cement due to the fact that hydrosilicates of low basicity show greater tendency to deformation from humidity fluctuations and resist the combined action of water and

frost less effectively.

Properties:

It has low heat of hydration and is resistant to chemical attacks and in particular to sulphates. Compressive strength should be as follows:

72 ± 1 hour	15 N/mm ²
168 ± 2 hours	22 N/mm ²
672 ± 4 hours	30 N/mm ²

It should have a fineness of 400 m²/kg. The expansion of cement is limited to 5 mm. The initial setting time of the cement should not be less than 30 minutes, and the final setting time should not be more than 600 minutes.

Uses:

Supersulphated Portland cement is used for similar purpose as common Portland cement. But owing to its higher water-resisting property, it should be preferred in hydraulic engineering installations and also in constructions intended for service in moist media. RCC pipes in ground water, concrete structures in sulphate bearing soils, sewers carrying industrial effluents, concrete exposed to concentrated sulphates of weak mineral acids are some of the examples of this cement. This cement should not be used in constructions exposed to frequent freezing-and-thawing or moistening-and-drying conditions.

4) Sulphate Resisting Portland Cement (IS: 12330):

In this cement the amount of tricalcium aluminate is restricted to an acceptably low value (< 5). It should not be mistaken for super-sulphated cement. It is manufactured by grinding and intimately mixing together calcareous and argillaceous and/ or other silica, alumina and iron oxide bearing materials. The Materials are burnt to clinkering temperature. The resultant clinker is ground to produce the cement. No material is added after burning except gypsum and not more than one per cent of air-entraining agents are added.

Properties:

The specific surface of the cement should not be less than 225 m²/kg. The expansion of cement is limited to 10 mm and 0.8 per cent, when tested by Le-chatelier method and autoclave test, respectively. The setting times are same as that for ordinary Portland

cement. The compressive strength of the cubes should be as follows.

72 ± 1 hour	10 N/mm ²
168 ± 2 hours	16 N/mm ²
672 ± 4 hours	33 N/mm ²

It should have a fineness of 400 m²/kg. The expansion of cement is limited to 5 mm. The initial setting time of the cement should not be less than 30 mm and the final setting time should not be more than 600 mm.

This cement can be used as an alternative to ordinary Portland cement or Portland pozzolana cement or Portland slag cement under normal conditions. Its use however is restricted where the prevailing temperature is below 40°C. Use of sulphate resisting cement is particularly beneficial in conditions where the concrete is exposed to the risk of deterioration due to sulphate attack; concrete in contact with soils or ground waters containing excessive sulphate as well as concrete in sea water or exposed directly to sea coast.

5) Portland slag Cement (IS: 455):

It is manufactured either by intimately intergrinding a mixture of Portland cement clinker and granulated slag with addition of gypsum or calcium sulphate, or by an intimate and uniform blending of Portland cement and finely ground granulated slag. Slag is a non-metallic product consisting essentially of glass containing silicates and alumino-silicates of lime and other bases, as in the case of blast-furnace slag, which is developed simultaneously with iron in blast furnace or electric pig iron furnace. Granulated slag is obtained by further processing the molten slag by rapid chilling or quenching it with water or steam and air. The slag constituent in the cement varies between 25 to 65 per cent.

Properties:

The chemical requirements of Portland slag cement are same as that of 33 grade Portland cement. The specific surface of slag cement should not be less than 225 m²/kg. The expansion of the cement should not be more than 10 mm and 0.8 per cent when tested by Le Chatelier method and autoclave test, respectively. The initial and final setting times and compressive strength requirements are same as that for 33 grade ordinary Portland cement.

Uses:

This cement can be used in all places where OPC is used. However, because of its low heat of hydration it can also be used for mass concreting, e.g., dams, foundations, etc.

6) Low Heat Portland Cement (IS:12600)

To limit the heat of hydration of low heat Portland cement (LHC), the tricalcium aluminate component in cement is minimised and a high percentage of dicalcium silicate and tetracalcium alumino ferrite is added. The heat of hydration should not be more than 272 and 314 J/g at the end of 7 and 28 days respectively. The rate of development of strength is slow but the ultimate strength is same as that of OPC. To meet this requirement, specific surface of cement is increased to about 3200 cm²/g.

Properties:

Less heat is evolved during setting low heat Portland cement. When tested by Le Chatelier method and autoclave test the expansion should not be more than 10 mm and 0.8%, respectively. The minimum initial setting time should not be less than 60 minutes, and the final setting should not be more than 600 minutes.

The compressive strength should be as follows.

72 ± 1 hour	10 N/mm ²
168 ± 2 hours	16 N/mm ²
672 ± 4 hours	35 N/mm ²

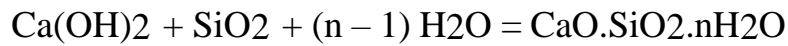
Uses:

It is most suitable for large mass concrete works such as dams, large raft foundations, etc.

7) Portland Pozzolana Cement (IS: 1489 (Part I):

It is manufactured by grinding Portland cement clinker and pozzolana (usually fly ash 10-25% by mass of PPC) or by intimately and uniformly blending Portland cement and fine pozzolana. Pozzolana (burnt clay, shale, or fly ash) has no cementing value itself but has the property of combining with lime to produce a stable lime-pozzolana compound which has definite cementitious properties. Free lime present in the cement is thus removed. Consequently, the resistance to chemical attack increases making it suitable for marine works. The hardening of Portland pozzolana cement consists in

hydration of Portland cement clinker compounds and then in interaction of the pozzolana with calcium hydroxide released during the hardening of clinker. At the same time, calcium hydroxide is bound into a water-soluble calcium hydrosilicate according to the reaction with the effect that pozzolana Portland cement acquires greater water-resisting property than ordinary Portland cement.



Properties:

These have lower rate of development of strength but ultimate strength is comparable with ordinary Portland cement.

Compressive Strength

72 ± 1 hour	16 N/mm ²
168 ± 2 hours	22 N/mm ²
672 ± 4 hours	33 N/mm ²

The initial and the final setting times are 30 minutes (minimum) and 600 minutes (maximum), respectively. The drying shrinkage should not be more than 0.15% and the fineness should not be less than 300 m²/kg.

Uses:

It has low heat evolution and is used in the places of mass concrete such as dams and in places of high temperature.

8) Quick Setting Portland Cement:

The quantity of gypsum is reduced and small percentage of aluminium sulphate is added. It is ground much finer than ordinary Portland cement.

Properties:

Initial setting time = 5 minutes

Final setting time = 30 minutes

Uses:

It is used when concrete is to be laid under water or in running water.

9) Masonry Cement (IS 3466):

The Portland cement clinker is ground and mixed intimately with pozzolanic

material (flyash or calcined clay), or non-pozzolanic (inert) materials (lime-stone, conglomerates, dolomite, granulated slag) and waste materials (carbonated sludge, mine tailings) and gypsum and air entraining plasticizer in suitable proportions.

The physical requirements of masonry cement are as follows.

1. Fineness: Residue on 45-micron IS Sieve, Max, Percent (by wet sieving) 15
2. Setting Time (by Vicat Apparatus):
 - (a) Initial, Min 90 min
 - (b) Final, Max 24 h
3. Soundness:
 - (a) Le-Chatelier expansion, Max 10 mm
 - (b) Autoclave expansion, Max 1 %
4. Compressive Strength: Average strength of not less than 3 mortar cubes of 50 mm size, composed of 1 part masonry cement and 3 parts standard sand by volume, Min
 - 7 days 2.5 MPa
 - 28 days 5 MPa
5. Air Content: Air content of mortar composed of 1 part masonry cement 6 per cent and 3 parts standard sand by volume, Min
6. Water Retention: Flow after suction of mortar composed of 1 part 60 % of masonry cement and 3 parts standard sand by volume, Min original flow

10) White and Coloured Portland Cement (IS: 8042):

It is manufactured from pure white chalk and clay free from iron oxide. Greyish colour of cement is due to iron oxide. So, the iron oxide is reduced and limited below 1 per cent. Coloured cements are made by adding 5 to 10 per cent colouring pigments before grinding. These cements have same properties as that of ordinary Portland cement and are non-staining because of low amount of soluble alkalis. Sodium aluminofluoride is added during burning which acts as a catalyst in place of iron.

Properties:

Loss on ignition of white cement is nil. The compressive and transverse strength of this cement is 90 per cent of that of 33 grade ordinary Portland cement.

Uses:

These cements are used for making terrazzo flooring, face plaster of walls (stucco), ornamental works, and casting stones.

11) Air Entraining Cement:

Vinsol resin or vegetable fats and oils and fatty acids are ground with ordinary cement. These materials have the property to entrain air in the form of fine tiny air bubbles in concrete.

Properties:

Minute voids are formed while setting of cement which increases resistance against freezing and scaling action of salts. Air entrainment improves workability and water/cement ratio can be reduced which in turn reduces shrinkage, etc.

Uses:

Air entraining cements are used for the same purposes as that of OPC.

12) Calcium Chloride Cement: It is also known as extra rapid hardening cement and is made by adding 2 per cent of calcium chloride. Since it is deliquescent, it is stored under dry conditions and should be consumed within a month of its dispatch from the factory.

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2.5 INDUSTRIAL BY PRODUCT:

2.5.1 Fly ash:

Fly ash is a fine powder that is a by product of burning pulverized coal in electric generation power plants. Fly ash is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, fly ash forms a compound similar to Portland cement. This makes fly ash suitable as a prime material in blended cement, mosaic tiles, and hollow blocks, among other building materials. When used in concrete mixes, fly ash improves the strength and segregation of the concrete and makes it easier to pump.

2.5.2 Applications for Fly Ash

Fly ash can be used as prime material in many cement-based products, such as poured concrete, concrete block, and brick. One of the most common uses of fly ash is in Portland cement concrete pavement or PCC pavement. Road construction projects using PCC can use a great deal of concrete, and substituting fly ash provides significant economic benefits. Fly ash has also been used as embankment and mine fill, and it has increasingly gained acceptance by the Federal Highway Administration.

The rate of substitution—of fly ash for Portland cement—typically specified is 1 to 1 1/2 pounds of fly ash for 1 pound of cement.¹ Accordingly, the amount of fine aggregate in the concrete mix must be reduced to accommodate the additional volume of the fly ash.

There are two common types of fly ash:

- Class F
- Class C.

1) Class F: Class F fly ash contain particles covered in a kind of melted glass. This greatly reduces the risk of expansion due to sulfate attack, which may occur in fertilized soils or near coastal areas. Class F is generally low-calcium and has a carbon content less than 5 percent but sometimes as high as 10 percent.

2) Class C:

Class C fly ash is also resistant to expansion from chemical attack. It has a higher percentage of calcium oxide than Class F and is more commonly used for structural

concrete. Class C fly ash is typically composed of high-calcium fly ashes with a carbon content of less than 2 percent.

Currently, more than 50 percent of the concrete placed in the U.S. contains fly ash.² Dosage rates vary depending on the type of fly ash and its reactivity level. Typically, Class F fly ash is used at dosages of 15 to 25 percent by mass of cementitious material, while Class C fly ash is used at dosages of 15 to 40 percent.³

2.5.3 Benefits:

Fly ash can be a cost-effective substitute for Portland cement in many markets. Fly ash is also recognized as an environmentally friendly material because it is a byproduct and has low embodied energy, the measure of how much energy is consumed in producing and shipping a building material. By contrast, Portland cement has a very high embodied energy because its production requires a great deal of heat. Fly ash requires less water than Portland cement and is easier to use in cold weather.

Other benefits include:

- Produces various set times
- Cold weather resistance
- High strength gains, depending on use
- Can be used as an admixture
- Considered a non-shrink material
- Produces dense concrete with a smooth surface and sharp detail
- Great workability
- Reduces crack problems, permeability, and bleeding
- Reduces heat of hydration
- Allows for a lower water-cement ratio for similar slumps when compared to no-fly-ash mixes
- Reduces CO₂ emissions

2.5.4 Disadvantages

Smaller builders and housing contractors may not be familiar with fly ash products, which can have different properties depending on where and how it was obtained. Additionally, fly ash applications may face resistance from traditional builders due to

its tendency to effloresce along with concerns about freeze/thaw performance. Other concerns about using fly ash in concrete include:

- Slower strength gain
- Seasonal limitation
- Increased need for air-entraining admixtures
- Increase of salt scaling produced by higher proportions of fly ash

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2.6 Aggregate

- Aggregate are generally cheaper than cement and impart greater volume stability and durability to concrete.
- The aggregate is used primarily for the purpose of providing bulk to the concrete.
- To increase the density of the resulting mix, the aggregate is frequently used in two or more sizes.
- The most important function of the fine aggregate is to assist in producing the workability and uniformity in mixture.
- The aggregates provide about 75% of the body of the concrete and hence its influence is extremely important. They must be of proper shape (either rounded or approximately cubical), clean hard strong and well graded.
- The materials used for manufacture of mortar and concrete such as sand, gravel etc. are called as aggregate.

2.6.1 Natural Aggregates:

These are obtained by crushing from quarries of igneous, sedimentary or metamorphic rocks. Gravels and sand reduced to their present size by the natural agencies also fall in this category. The most widely used aggregate are from igneous origin. Aggregates obtained from pits or dredged from river, creek or sea are most often not clean enough or well graded to suit the quality requirement. They therefore require sieving and washing before they can be used in concrete.

2.6.2 REQUIREMENT OF GOOD AGGREGATE :

- It must be clean i.e. it should be free from lumps, organic materials etc.
- It should be strong.
- It should be durable.
- It should not react with cement after mixing.
- It should have rough surface.
- It should not absorb water more than 5%.
- It should not be soft and porous.
- It should be chemically inert.
- It should be of limiting porosity.

- It should preferably be cubical or spherical in shape.

2.6.3 CLASSIFICATION OF AGGREGATE

- Classification According to Geological Origin
 1. Natural Aggregate
 2. Artificial Aggregate
- Classification According to Size
 1. Fine Aggregate
 2. Coarse Aggregate
- Classification According to Shape
 1. Rounded Shape
 2. Irregular Aggregate
 3. Angular Aggregate
 4. Flaky Aggregate
- Classification Based On Unit Weight
 1. Normal Weight Aggregate:
 2. Heavyweight Or High-density Aggregate
 3. Light Weight Aggregate

1) Classification according to geological origin

- **Natural Aggregate:**

- These aggregates are generally obtained from natural deposits of sand and gravels, or from quarries by cutting rocks.
- The cheapest among them are the natural sand and gravel. Which have been reduced to their present size by natural agents, such as water, wind and snow, etc.
- The river deposits are the most common and are good quality.

- **Artificial Aggregate:**

- The most widely used artificial aggregate are clean broken bricks and air cooled fresh blast- furnace- slag.
- The broken bricks of good quality provide a satisfactory aggregate for the mass concrete and are not suitable for reinforced concrete work if the crushing strength of brick is less than 30 to 35 Map.

- The bricks should be free from lime mortar and lime sulfate plaster.
- The bricks aggregate is not suitable for waterproof construction.
- It has poor resistance to wear and hence is not used in concrete for the road work

2) Classification according to size:

Fine aggregate: The aggregate which passes through 4.75 mm sieve and retained on 75 micron sieve are known as fine aggregate.

It is classified into

a) **Sand:** It consists of small angular or rounded grains of silica depending upon the source from which it is obtained. It is classified as:

- It is found as deposited in soil and is to be excavated out. Its grains are generally sharp or angular. It should be free from organic matter and clay. It is usually considered to be the best fine aggregate for use in mortar and concrete.

(i) **Pit or quarry sand:** Excavation of soil

(ii) **River Sand:** It is obtained from the banks and beds of rivers. It may be fine or coarse. Fine sand obtained from beds and banks of rivers is often found mixed with silt and clay so it should be washed before use. But coarse sand is generally clean and excellent for use especially for plastering.

(iii) **Sea Sand:** It consists of fine rounded grains of brown colour and it is collected from sea shores or sea beaches. Sea sand usually contains salts and while using that in mortar, etc, causes disintegration of the work in which it is used. In R.C.C work these salts will attack reinforcement if salt content is high. These salts may cause efflorescence. It should be used locally after thorough washing.

(iv) **Crushed stone:** It is obtained by crushing the waste stones of quarries to the particular size of sand. Sand obtained from by crushing a good quality stone is excellent fine aggregate.

b) **Coarse Aggregate:** The aggregate retained on 4.75 mm IS sieve are Known as coarse aggregate.

(i) **Crushed stone:**

Crushed stones are used for the construction of roads and railway tracks, etc

(ii) **Gravel:**

It is another very good coarse aggregate. It is obtained from river beds, quarries and seashores. The gravel obtained from sea shores should be well washed with fresh water before use in order to remove the impurities which may be clay, salts, silt etc. It is commonly used in the preparation of concrete.

(iii) Broken pieces of bricks:

It is also a good artificial source of coarse aggregates. It is obtained by breaking well burnt bricks. It is generally used in lime concrete at places where aggregates from natural sources are either not available or are expensive. It can be used at places where low strength is required. It should be watered well before using it in the preparation of concrete. It is commonly used for mass concrete in foundations and under floors.

3) Classification according to Shape:

1. **Rounded Shape:** The aggregate with rounded particles (river or seashore gravel) has minimum voids ranging 32 to 33 %. The only disadvantage is that interlocking between its particles is less and hence the development of bond is poor, making it unsuitable for high strength concrete and pavement.
2. **Irregular Aggregate:** The aggregate having partly rounded particles (pit sand and gravel) has higher voids ranging from 35 to 38%. It requires more cement paste for a given workability.
3. **Angular Aggregate:** The aggregate with sharp, angular and rough particles (crushed rocks) has a maximum of voids ranging from 38 to 40%. The interlocking between the particles is good.
4. **Flaky Aggregate:** An aggregate is termed flaky when its least dimension (thickness) is less than three-fifths of its mean dimension. The presence of these particles should be restricted to 10 to 15%.

4) Classification based on Unit Weight

1. **Normal Weight Aggregate:** The commonly used aggregate, i. e., sands and gravels; crushed rocks such as granite, basalt, quartz, sandstone and limestone; and brick ballast, etc., which have specific gravities between 2.5 and 2.7 produce concrete with unit weight ranging 23 to 26 KN/m³ and crushing strength at 28 days between 15 to 40 MPa are termed normal-weight concrete.

2. **Heavyweight Or High-Density Aggregate:** concrete having unit weight of about 30, 31, 35, 38, 40, 47 and 57KN/m³ can be produced by using typical goethite, limonite, baryte, magnetite, hematite, ferrophosphorus and scrap iron, respectively.
3. **Light Weight Aggregate:** The light weight aggregate having unit weight up to 12KN/m³ are used to manufacture the structural concrete masonry blocks for reduction of the self weight of the structure.

2.6.4 PROPERTIES OF FINE AGGREGATE:

1. Size:

The largest size which may be under the range of fine aggregate is 4.75mm. Using the largest size will give a more dense concrete, but a mixture of all sizes is more desirable and more economical.

2. Shape:

Shape of aggregate plays an important role in coarse aggregate rather than fine aggregate.

3. Strength:

The strength of aggregate alone cannot ensure strength of concrete. Strength of coarse aggregate is more important.

4. Surface Texture:

Generally rough surfaced aggregate is preferable to smooth aggregates. This property is also related with coarse aggregate.

5. Specific Gravity:

Specific gravity of aggregate is the ratio of its density to the density of water.

6. Bulk Density:

This refers to the density of aggregate considered along with volume of voids or empty spaces between the particles. The density of sand falls between 17 to 25 KN/m³.

7. Water Absorption:

Generally, for sand, water absorption is negligible, It is desirable that water absorption should be kept minimum.

8. Soundness:

This refers to expansion and contraction of the aggregate when subjected to temperature variation.

2.6.4 PROPERTIES OF COARSE AGGREGATE

1. **Size:** The size of coarse aggregate depends on the used to which the concrete is to be put. For mass concreting works without complicated reinforcement, larger aggregates of 80 mm, 40mm, 20mm sizes are used.
2. **Shape:** The shape of aggregate is an important characteristic as it affects the workability of concrete. It also affects the strength.
3. **Surface Texture:** It is the property of coarse aggregate deals with roughness and smoothness of aggregate. Rounded aggregate with smooth surface will require less cement paste and hence increase the yield per bag.
4. **Water Absorption:** Some of the aggregate water absorb and porous. Hence, it affect the water cement ratio and the workability of concrete. The porosity of aggregate also the affect if durability of concrete.
5. **7. Soundness:** soundness refer to expansion and contraction of the aggregate. When subjected to temperature various. A good aggregate is that which shows minimum expansion and contraction.
6. **8. Specific Gravity:** It is the ratio of dry weight of aggregate to the weight of equal volume of water.
7. **9. Bulk Density:** The ratio of net weight of aggregate to the volume of aggregate gives bulk density.

2.6.5 GRADING OF AGGREGATE

The particle size distribution of an aggregate as determined by sieve analysis is termed as gradation of aggregates. If all the particles of an aggregate are of uniform size, the compacted mass will contain more voids whereas aggregate comprising particles of various sizes will give a mass with lesser voids. The particle size distribution of a mass of aggregate should be such that the smaller particles fill the voids between the larger particles. The proper grading of an aggregate produces dense concrete and needs less quantity of fine aggregate and cement waste, therefore, it is essential that coarse and fine aggregates be well graded to produce quality concrete.

Grading limits and maximum aggregate size are specified because these properties affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength.

The Grading Curve of Aggregates:

The grading of aggregates is represented in the form of a curve or an S-CURVE. The curve showing the cumulative percentages of the material passing the sieves represented on the ordinate with the sieve openings to the logarithmic scale represented on the abscissa is termed as Grading Curve. The grading curve for a particular sample indicates whether the grading of a given sample conforms to that specified, or it is too coarse or too fine, or deficient in a particular size.

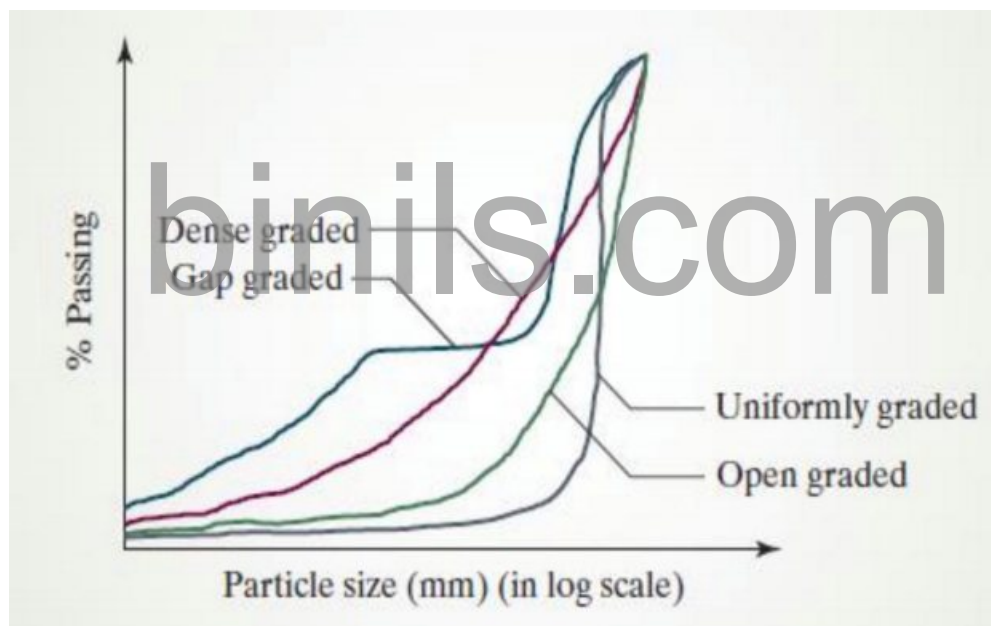


Fig Grading curve

Types of Grading of Aggregates

- 1) Dense-or well-graded aggregate – Has gradation close to the FWHA maximum density grading curve.
- 2) Gap-graded aggregate – Has only a small percentage of particles in the mid-size range.
- 3) Uniformly graded aggregate – Composed mostly of particles of the same size.
- 4) Open-graded aggregate – Contains only a small percentage of small-size particles.

1) Uniform Graded Aggregate

It refers to a gradation that contains most of the particles in a very narrow size range. In essence, all the particles are the same size. The curve is steep and only occupies the narrow size range specified.

- Narrow range of sizes.
- Grain-to-grain contact.
- High void content.
- High permeability.
- Low stability.
- Difficult to compact.

2) Open Graded Aggregate

In this type of gradation of aggregates, only a small percentage of aggregate particles are in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near vertical in the mid-size range, and flat and near-zero in the small-size range.

3) Gap Graded Aggregate

Gap-graded aggregate contains only a small percentage of aggregate particles in the mid-size range. The curve is flat in the mid-size range. Some PCC mix designs use gap graded aggregate to provide a more economical mix since less sand can be used for a given workability. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

- Missing middle sizes.
- No grain-to-grain contact.
- Moderate void content.
- Moderate permeability.
- Low stability.
- Easy to compact.

4) Dense Graded Aggregate

A dense gradation refers to a sample that is approximately of equal amounts of various sizes of aggregate. By having a dense gradation, most of the air voids between the materials are filled with particles. A dense gradation will result in an even curve on the gradation graph.

- Wide range of sizes.
- Grain-to-grain contact.
- Low void content.
- Low permeability.
- High stability.
- Difficult to compact.

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