

**Course Code: CE2102**

**Course name: Concrete Technology**

**Course content:**

**UNIT I: Concrete Big Picture**

**(Contact Hours:8)**

History and significance of concrete as a construction material. Advantages and Disadvantages of concrete. Role of concrete in “Sustainable Infrastructure Development”

**UNIT II: Concrete Constituent Materials**

**(Contact Hours:8)**

Cement- Manufacturing – Basic Cement Chemistry – Hydration – Classification – Tests – Relevant IS Codes

Aggregate – Classification – Characteristics – Properties of aggregates – Tests on aggregates and their significance – Grading – Fineness Modulus - Relevant IS Codes

Water – Mixing water, Curing Water – Tests of water - Relevant IS Codes

Admixtures – Functions – Classifications – Types - Relevant IS Codes.

**UNIT III: Fresh Concrete**

**(Contact Hours:6)**

Workability – definition, tests and interpretation, Rheology of fresh concrete, Effect of constituent materials on workability, Relevant IS Standards.

**UNIT IV: Hardened Concrete**

**(Contact Hours:8)**

Strength criterion, Stress-strain characteristics of concrete, fracture mechanics approach, tensile strength considerations, behavior under compressive strength.

Factors affecting strength of hardened concrete: porosity, gel-space ratio, total voids in concrete, w/c ratio, degree of compaction, age etc.

Dimensional Stability- Elasticity, Shrinkage and creep

Permeability & Durability: Permeability, Sulphate attack, attack by sea water, Acid attack, Alkali- aggregate reaction, corrosion of reinforcement.

**UNIT V: Production of concrete and quality control**

**(Contact Hours:8)**

Batching of materials, Mixing of concrete materials, transpiration, RMC, placing, compaction, finishing and curing, form work.

Factors causing variations in concrete quality, field control, advantages of quality control, statistical quality control.

**UNIT VI: Proportioning of concrete mixes**

**(Contact Hours:7)**

Basic considerations, factors influencing choice of mix design proportions, methods of concrete mix designing – IS method, ACI method, British DoE method

## Unit 1:



**SARDAR SAROVAR DAM :** Sardar Sarovar Project is an inter-State Multi-Purpose project of National importance. It is one of the largest projects under implementation anywhere in the world.



◀ **THE IDUKKI HYDROELECTRIC PROJECT, KERALA :** The reservoir covers nearly 60 square kilometres and has a catchment of 649 square km. Water from the reservoir is taken down to the underground power house at Moolamattom through an underground tunnel, yielding an average gross head of 2182 feet (665 metres). The project has an installed capacity of 780 MW with firm power potential of 230 MW at 100 per cent load factor.

▶ **THE BHAKRA DAM** is a majestic monument across river Sutlej. The construction of this project was started in the year 1948 and was completed in 1963 . It is 740 ft. high above the deepest foundation as straight concrete dam being more than three times the height of Qutab Minar. Bhakra Dam is the highest Concrete Gravity dam in Asia and Second Highest in the world.





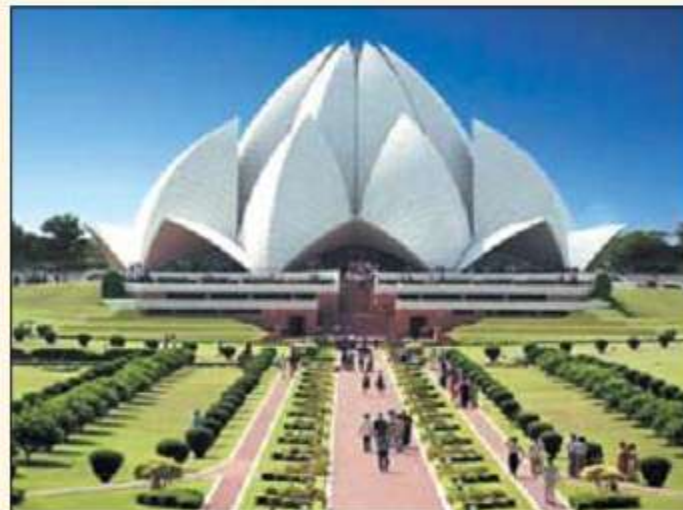


◀  
SAI GANGA approach canal  
for water supply to Chennai  
Metro.



◀  
DELHI METRO Railway Station  
under construction.

▶  
THE BAHÁ'Í HOUSE OF WORSHIP  
known as the Lotus Temple, built  
near New Delhi.





Diamond shaped 'MANI KANCHAN' - Gem & Jewellery Park at Kolkata.



Unconventional building with pleasing architecture.



TARAPUR ATOMIC POWER PROJECT : Reactor Building no. 3 & 4.



Fully automatic construction of concrete pavement.



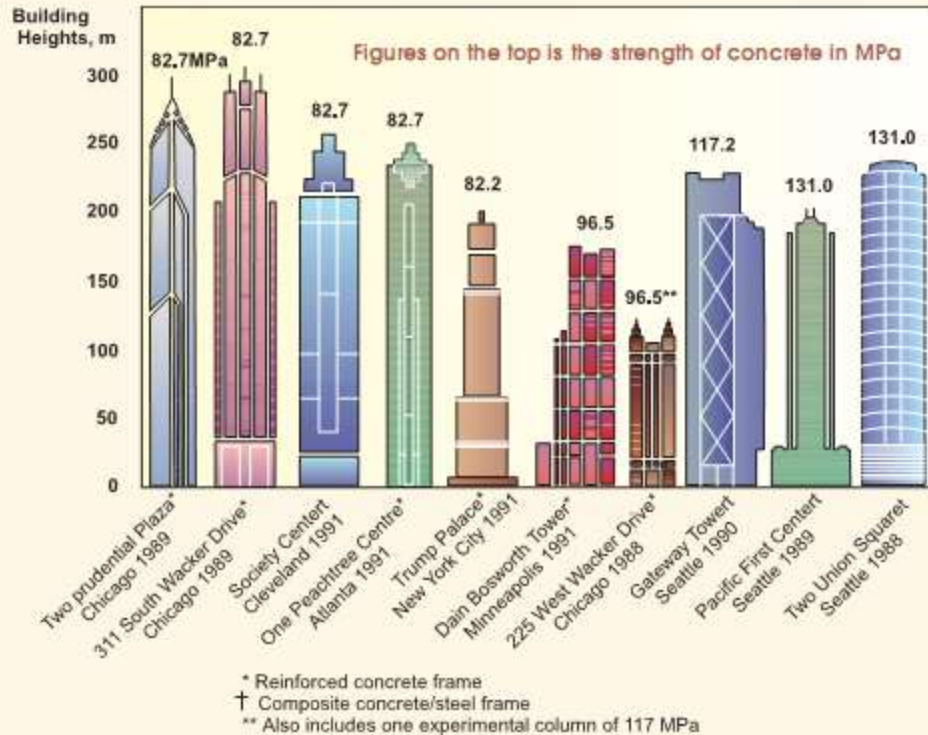
Large oval shaped dome construction for a metro railway station in Delhi





Metro railway pillars

## SOME LANDMARK HIGHRISE BUILDINGS IN THE WORLD



PETRONAS TWIN TOWERS (451 m) in Kuala Lumpur, Malaysia

All the above structures are made of concrete which is the main topic of interest.

History of cementing materials is very old.

Some kind of cementing materials were used by Egyptians, Romans and Indians in their ancient constructions. Early Egyptians mostly used cementing materials, obtained by burning gypsum.

Mortar when analyzed from the Great Pyramid showed that it contained 81.5 per cent calcium sulphate and only 9.5 per cent carbonate. The early Greeks and Romans used cementing materials obtained by burning lime stones.

The remarkable hardness of the mortar used in early Roman brickworks, some of which still exist, is presenting sufficient evidence of the perfection of cementing material had in ancient times. Remarkable hardness of the mortar used by Romans is because of attributed to thoroughness of mixing and long continued ramming.

The Greeks and Romans later came to know that certain volcanic ash and tuff, when mixed with lime and sand yielded mortar possessing superior strength and better durability in fresh or salt water. Roman builders used volcanic tuff found near Pozzuoli village near Mount Vesuvius in Italy. This volcanic tuff or ash mostly siliceous in nature thus acquired the name Pozzolana. Later on, the name Pozzolana was applied to any other material, natural or artificial, having nearly the same composition as that of volcanic tuff or ash found at Pozzuoli.

In India, powdered brick named surkhi has been used in mortar. The Indian practice of thorough mixing and long continued ramming of lime mortar with or without the addition of Surkhi yielded strong and impervious mortar which confirmed the secret of superiority of Roman mortar.

Analyzing some of the structures, it is found that Romans added blood and milk to their mortar and concrete to achieve better workability. Haemoglobin is a powerful air-entraining agent and plasticizer, which is another reason for the durability of Roman structures.

The cementing material made by Romans using lime and natural or artificial Pozzolana retained its position as the chief building material for all work, particularly, for hydraulic construction.

An investigation carried out by John Smeaton (1756), based on the state of art available in those days to find out the best material to withstand the severe action of sea water, is the most important advance in the knowledge of cements, the forerunner to the discoveries and

manufacture of all modern cements. He concluded that **lime-stones which contained considerable proportion of clayey matter yielded better lime possessing** superior hydraulic properties.

In 1776, hydraulic cement was made by calcining nodules of argillaceous lime-stones. In about 1800 the product thus obtained was called Roman cement. This type of cement was in use till about 1850 after which this was outdated by portland cement.

### **Early history of modern cement:**

L.J. Vicat investigated to prepare an artificial hydraulic lime by calcining an intimate mixture of limestone and clay. This process may be regarded as the leading knowledge to the manufacture of Portland cement. James Frost also patented a cement of this kind in 1811 and established a factory in London district.

Joseph Aspdin took the patent of portland cement on 21st October 1824 even though similar procedure had been adopted by other investigators. The fancy name of portland was given owing to the resemblance of this hardened cement to the natural stone occurring at Portland in England. In his process Aspdin mixed and ground hard lime stones and finely divided clay into the form of slurry and **calcined it in a furnace similar to a lime kiln till the CO<sub>2</sub> was expelled**. The mixture so calcined was then ground to a fine powder. Perhaps, a temperature lower than the clinkering temperature was used by Aspdin. Later in 1845 Isaac Charles Johnson burnt a mixture of clay and chalk till the clinkering stage to make better cement and established factories in 1851.

In the early period, cement was used for making mortar only. Later the use of cement was extended for making concrete. Association of Engineers, Consumers and Cement Manufacturers have been established to specify standards for cement. The German standard specification for Portland cement was drawn in 1877. The British standard specification was first drawn up in 1904. The first ASTM specification was issued in 1904.

The early scientific study of cements did not reveal much about the chemical reactions that take place at the time of burning.

Systematic work on the composition and chemical reaction of Portland cement was first begun in



the United States. The study on setting was undertaken by the Bureau of Standards and since 1926 much work on the study of Portland cement was also conducted by the Portland Cement Association, U.K

### **Advantages and disadvantages of concrete:**

Concrete is considered as a chemically combined mass where the inert material acts as a filler and the binding materials act as a binder. The most important binding materials are cement and lime. Inert materials used in concrete are termed as aggregates. Most common aggregates are sand, brick chips, stone chips, gravels, shells etc.

#### **Advantages:**

1. Availability of concrete ingredients easily.
2. Easy handling and moulding of concrete into any shape.
3. Easy transportation from the place of mixing to place of casting before initial set takes place.
4. Ability to pump/spray to fill into cracks and lining of tunnels.
5. When reinforced, all types of the structures are made possible from an ordinary lintel to massive fly overs
6. Monolithic character gives better appearance and much rigidity to the structure.
7. The property of concrete to possess high compressive strength makes a concrete structure more economical than that of steel structure.

#### **Dis-advantages:**

1. Large amount of CO<sub>2</sub> gas will be emitted.
2. Due to low tensile strength, concrete is required to be reinforced to avoid cracks.
3. In long structures expansion joints are required to be provided if there is large temperature variance in the area.
4. Construction joints are provided to avoid cracks due to drying shrinkage and moisture-expansion.
5. Soluble salts in concrete cause efflorescence if moisture reacts with them.

6. Concrete made with ordinary Portland cement, gets integrated in the presence of alkalies, sulfates etc.
7. Sustained loads develop creep in structures.

### **Role of concrete in sustainable infrastructure development:**

In the context of human activity, sustainability has been described as activity or development that meets the needs of the present, without compromising the ability of future generations to meet their own needs.

To assess the sustainability of any system, a balanced consideration of environmental, economic and social aspects is required.

**Environmental aspects:** Concrete projects have superior environmental performance because concrete is durable for nearly 100 years. Due to cement production, large amount of CO<sub>2</sub> will be emitted which should be controlled. Due to excess mining of limestone, large amount of byproducts will be generated. Large amount of byproducts like cement kiln dust will be generated in the manufacture of cement. Alternative materials which are non-exhaustible are to be used in the manufacture of cement.

**Economic aspects:** Cement is a reasonably cheap material and is most important material required for the infrastructure to be developed in the entire world. Concrete is a reasonable durable material and is resistant to corrosion, attack of chemicals, impact etc. Investigations are to be done to make the concrete more durable and increases life span of structures built with it.

**Social aspects:** The construction industry is a vital part of our economy and concrete is an essential part of the construction industry. Construction provides a secure livelihood for hundreds of thousands, and concrete is an integral part of that security. Concrete can be formed in an endless array of shapes to create structures, which are aesthetically and socially pleasing in architecture, civil engineering and landscape architecture. Concrete is used to create buildings that provide safe shelter for human habitation. Without concrete there is no built environment.

## **Unit II: Concrete constituent materials:**

Cement manufacturing:

The process of manufacture of cement consists of grinding the raw materials, mixing them intimately in certain proportions, depending upon their purity and composition, and burning them in a kiln at a temperature of about 1300 to 1500°C. At this temperature, the material sinters and partially fuses to form nodular shaped clinker. The clinker is cooled and ground to fine powder with addition of about 3 to 5% of gypsum. The product formed by using this procedure is Portland cement.

There are two processes known as “wet” and “dry” processes in the manufacture of cement depending upon whether the mixing and grinding of raw materials is done in wet or dry conditions.

Semi-dry process is also there where the raw materials are ground dry and then mixed with about 10-14 per cent of water and further burnt to clinkering temperature.

Wet process remained popular for many years because of accurate mixing of raw materials. Later, due to development of modern techniques, dry process gained importance. In dry process, powdered materials are mixed using compressed air. The dry process requires much less fuel as the materials are already in a dry state, whereas in the wet process the slurry contains about 35 to 50 per cent water. Hence drying slurry requires much fuel.

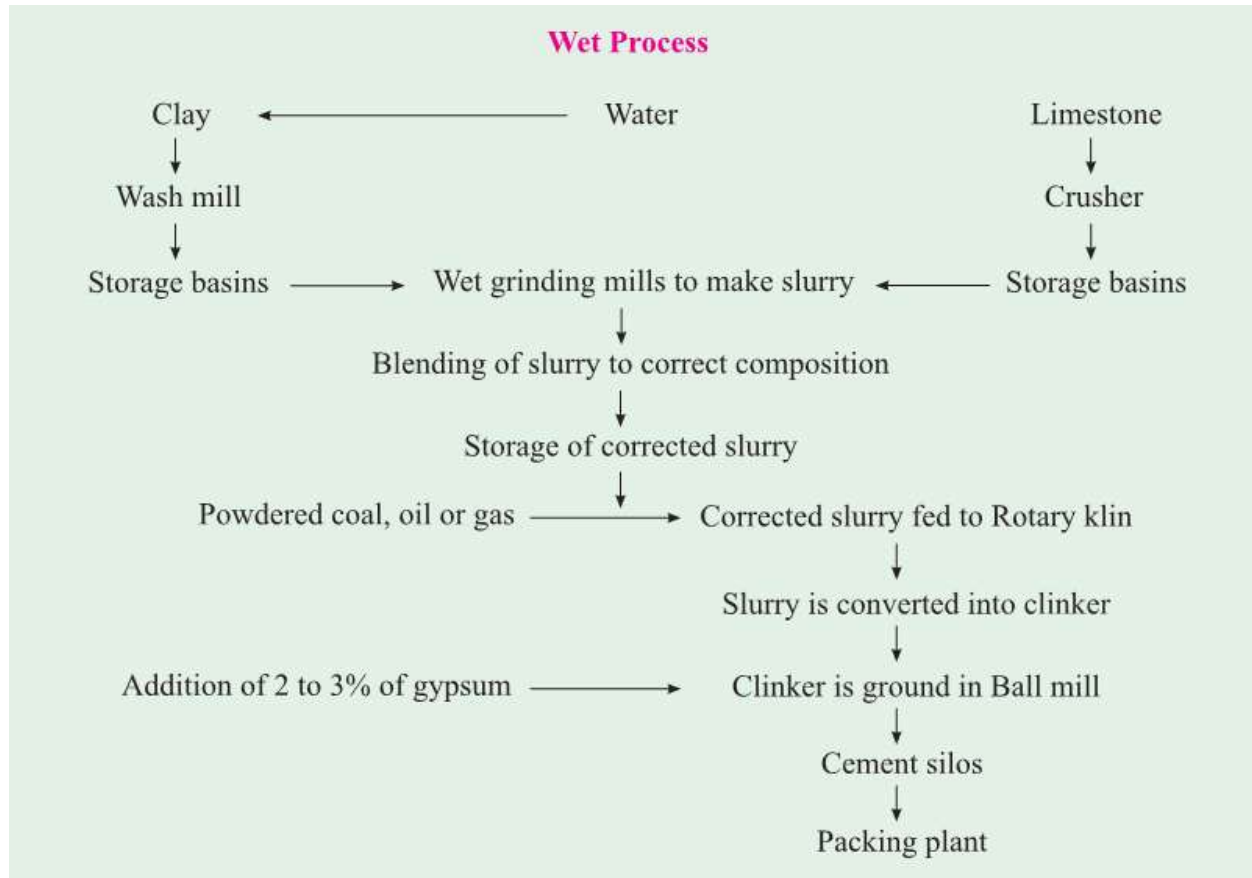
**Wet process:** In the wet process, the limestone brought from the quarries is first crushed to smaller fragments. Then it is taken to a ball or tube mill where it is mixed with clay or shale as the case may be and ground to a fine consistency of slurry with the addition of water. The slurry is a liquid of creamy consistency with water content of about 35 to 50 per cent, wherein particles, crushed to the fineness of Indian Standard Sieve number 9, are held in suspension. The slurry is pumped to slurry tanks or basins where slurry tank or basin is kept in an agitated condition by means of rotating arms with chains or blowing compressed air from the bottom to prevent settling of limestone and clay particles. The composition of the slurry is tested to give the required chemical composition and corrected periodically in the tube mill and also in the slurry



tank by blending slurry from different storage tanks. Finally, the corrected slurry is stored in the final storage tanks and kept in a homogeneous condition by the agitation of slurry.

The corrected slurry is sprayed on to the upper end of a rotary kiln. The rotary kiln is an important component of a cement factory. It is a thick steel cylinder of diameter varying from 3 meters to 8 meters, lined with refractory materials, mounted on roller bearings and capable of rotating about its own axis at a specified speed. The length of the rotary kiln may vary anything from 30 meters to 200 meters. The slurry on being sprayed against a hot surface of flexible chain loses moisture and becomes flakes. These flakes peel off and fall on the floor. The rotation of the rotary kiln causes the flakes to move from the upper end towards the lower end of the kiln subjecting itself to higher and higher temperature. The kiln is fired from the lower end. The fuel is either powered coal, oil or natural gas. By the time the material rolls down to the lower end of the rotary kiln, the dry material undergoes a series of chemical reactions in the hottest part of the kiln, where the temperature is in the order of  $1500^{\circ}\text{C}$ , about 20 to 30 per cent of the materials get fused. Lime, silica and alumina get recombined. The fused mass turns into nodular form of size 3 mm to 20 mm known as clinker. The clinker drops into a rotary cooler where it is cooled under controlled conditions. The clinker is stored in silos or bins. The clinker weighs about 1100 to 1300 g per liter. The liter weight of clinker indicates the quality of clinker.

The cooled clinker is then ground in a ball mill with the addition of 3 to 5 per cent of gypsum in order to prevent flash-setting of the cement. A ball mill consists of several compartments charged with progressively smaller hardened steel balls. The particles crushed to the required fineness are separated by currents of air and taken to storage silos from where the cement is bagged or filled into barrels for bulk supply to dams or other large work sites.



Animation video link of manufacture of cement by wet process:

<https://www.youtube.com/watch?v=YNUYMS9QKK8>

### **Dry process:**

In the dry and semi-dry process the raw materials are crushed dry and fed in correct proportions into a grinding mill where they are dried and reduced to a very fine powder. The dry powder called the raw meal is then further blended and corrected for its right composition and mixed by means of compressed air. The aerated powder tends to behave almost like liquid and in about one hour of aeration a uniform mixture is obtained.

The blended meal is further sieved and fed into a rotating disc called granulator. A quantity of water about 12 per cent by weight is added to make the blended meal into pellets. Water is added to permit air flow for exchange of heat and for further chemical reactions and conversion of the same into clinker in the rotary kiln.

The equipment's used in the dry process kiln is comparatively smaller. The process is quite economical. The total consumption of coal in this method is only about 100 kg when compared

to the requirement of about 350 kg for producing a ton of cement in the wet process.

Animation video link of manufacture of cement by wet process:

<https://www.youtube.com/watch?v=WGVUNVf4Y2I> (watch the video from 5 minutes slot)

### Chemical composition of cement:

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding.

Approximate oxide composition limits of ordinary Portland cement

Oxide	Per cent content
CaO	60–67
SiO <sub>2</sub>	17–25
Al <sub>2</sub> O <sub>3</sub>	3.0–8.0
Fe <sub>2</sub> O <sub>3</sub>	0.5–6.0
MgO	0.1–4.0
Alkalies (K <sub>2</sub> O, Na <sub>2</sub> O)	0.4–1.3
SO <sub>3</sub>	1.3–3.0

Indian standard specification for 33 grade cement, IS 269-1989, specifies the following chemical requirements:

- (a) Ratio of percentage of lime to percentage of silica, alumina and iron oxide; known as Lime Saturation Factor, when calculated by the formula

$$\frac{\text{CaO} - 0.7 \text{SO}_3}{2.8 \text{SiO}_2 + 1.2 \text{Al}_2\text{O}_3 + 0.65 \text{Fe}_2\text{O}_3} \quad \text{Not greater than 1.02 and not less than 0.66}$$

- (b) Ratio of percentage of alumina to that of iron oxide      Not less than 0.66
- (c) Weight of insoluble residue      Not more than 4 per cent
- (d) Weight of magnesia      Not more than 6 per cent
- (e) Total sulphur content, calculated as sulphuric anhydride (SO<sub>3</sub>)      Not more than 2.5%  
C<sub>3</sub>A is 5% or less. Not more than 3%, when C<sub>3</sub>A is more than 5%
- (f) Total loss on ignition      Not more than 5 per cent



Oxides present in the raw materials of cement when subjected to high clinkering temperature combine with each other to form complex compounds. The identification of the major compounds is largely based on R.H. Bogue's work and hence it is called "Bogue's Compounds". Following are the major compounds in the cement:

<i>Name of Compound</i>	<i>Formula</i>	<i>Abbreviated Formula</i>
Tricalcium silicate	3 CaO.SiO <sub>2</sub>	C <sub>3</sub> S
Dicalcium silicate	2 CaO.SiO <sub>2</sub>	C <sub>2</sub> S
Tricalcium aluminate	3 CaO.Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A
Tetracalcium aluminoferrite	4 CaO.Al <sub>2</sub> O <sub>3</sub> .Fe <sub>2</sub> O <sub>3</sub>	C <sub>4</sub> AF

The equations suggested by Bogue for calculating the percentages of major compounds are given below.

$$C_3S = 4.07 (\text{CaO}) - 7.60 (\text{SiO}_2) - 6.72 (\text{Al}_2\text{O}_3) - 1.43 (\text{Fe}_2\text{O}_3) - 2.85 (\text{SO}_3)$$

$$C_2S = 2.87 (\text{SiO}_2) - 0.754 (3\text{CaO.SiO}_2)$$

$$C_3A = 2.65 (\text{Al}_2\text{O}_3) - 1.69 (\text{Fe}_2\text{O}_3)$$

$$C_4AF = 3.04 (\text{Fe}_2\text{O}_3)$$

The oxide shown within the brackets represent the percentages in the raw materials.

In addition to the four major compounds, there are many minor compounds formed in the kiln. The influence of these minor compounds on the properties of cement or hydrated compounds is not significant. Two of the minor oxides namely K<sub>2</sub>O and Na<sub>2</sub>O referred to as alkalis in cement are of some importance.

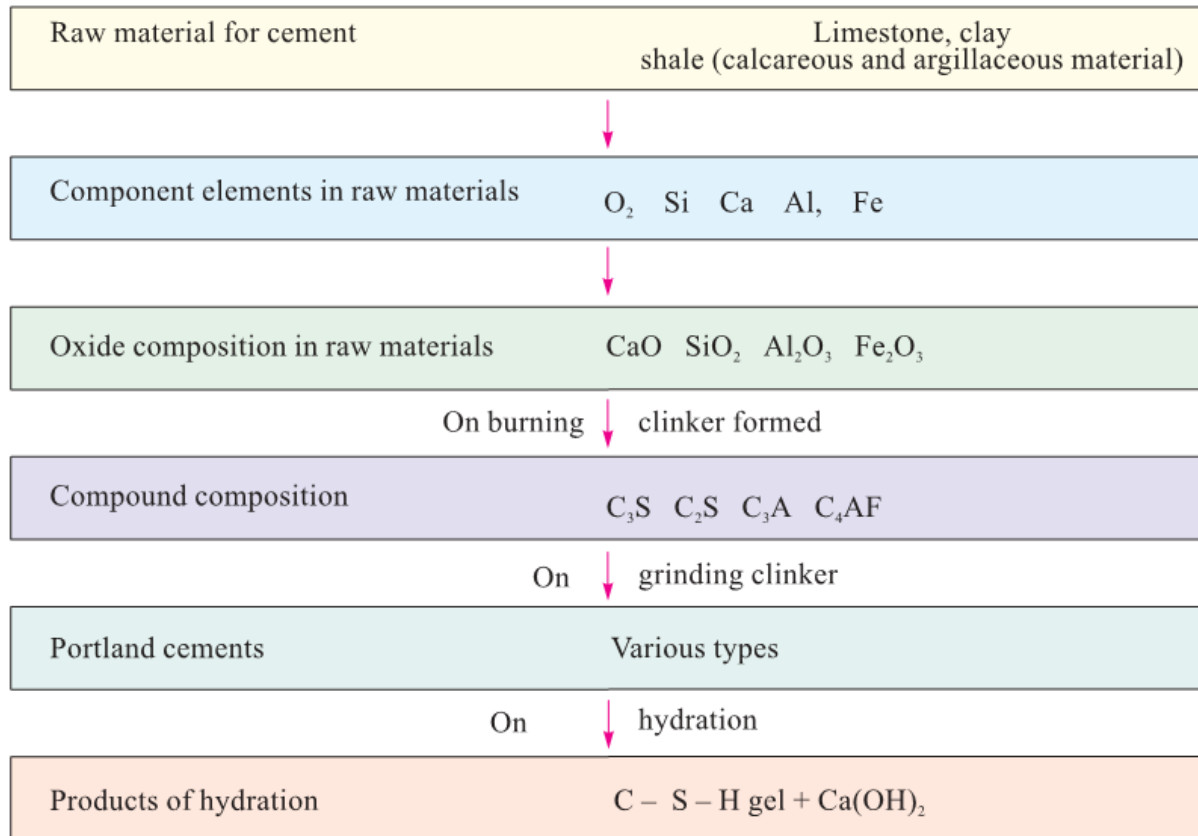
Tricalcium silicate and dicalcium silicate are the most important compounds responsible for strength. Both the above compounds constitute 70 to 80 per cent of cement. The average C<sub>3</sub>S content in modern cement is about 45 per cent and that of C<sub>2</sub>S is about 25 per cent. The sum of the contents of C<sub>3</sub>A and C<sub>4</sub>AF has decreased slightly in modern cements.

An increase in lime content beyond a certain value makes it difficult to combine with other compounds and free lime will exist in the clinker which causes unsoundness in cement. An increase in silica content at the expense of the content of alumina and ferric oxide will make the cement difficult to fuse and form clinker. Cements with a high total alumina and high ferric oxide content is favorable to the production of high early strengths in cement. This is because of the influence of these oxides for the complete combining of the entire quantity of lime present to form tricalcium silicate.

Bogue's compounds  $C_3S$ ,  $C_2S$ ,  $C_3A$  and  $C_4AF$  are sometimes called in literature as Alite, Belite, Celite and Felite respectively.

Portland cement on hydration gives  $C - S - H$  gel +  $Ca(OH)_2$ .

Cement and hydration of cement can be represented as below:



Cement does not bind fine and coarse aggregate. It acquires adhesive property only when mixed with water. The chemical reactions that take place between cement and water is referred as hydration of cement.

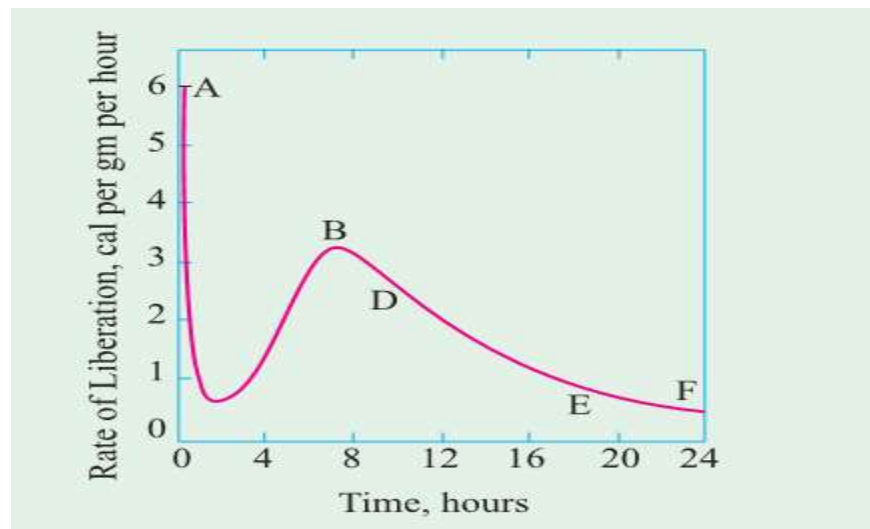
Properties of concrete depend on the chemistry of the reaction between cement and water. On account of hydration certain products are formed. These products are important because they have cementing or adhesive value. The quality, quantity, continuity, stability and the rate of formation of the hydration products are important.

### Heat of hydration:

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration.

The study and control of the heat of hydration becomes important in the construction of concrete

dams and other mass concrete constructions. It has been observed that the temperature in the interior of large mass concrete is 50°C above the original temperature of the concrete mass at the time of placing and this high temperature is found to persist for a prolonged period. The figure below shows the pattern of liberation of heat from setting cement and during early hardening period.



Compound	Heat of hydration at the given age (cal/g)		
	3 days	90 days	13 years
C <sub>3</sub> S	58	104	122
C <sub>2</sub> S	12	42	59
C <sub>3</sub> A	212	311	324
C <sub>4</sub> AF	69	98	102

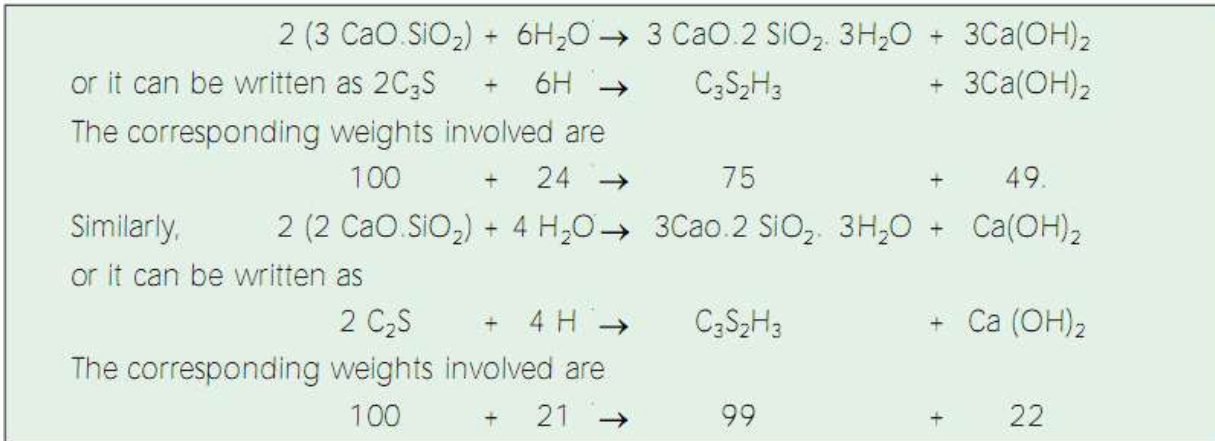
The hydration process is not an instantaneous one. The reaction is faster in the early period and continues indefinitely at a decreasing rate. Complete hydration cannot be obtained under a period of one year or more unless the cement is very finely ground and reground with excess of water to expose fresh surfaces at intervals. It has also been observed that complete hydration under normal condition is possible only for cement particles smaller than 50μ.

### Calcium silicate hydrates:

During the course of reaction of C<sub>3</sub>S and C<sub>2</sub>S with water, calcium silicate hydrate, abbreviated C-S-H and calcium hydroxide, Ca(OH)<sub>2</sub> are formed. Calcium silicate hydrates are the most important products which determine the strength of concrete. Calcium silicate hydrates will be up to 50-60 per cent of the volume of solids in a completely hydrated cement paste.



The following are the approximate equations showing the reactions of C3S and C2S with water.



From the above equations, it is found that C3S produces a comparatively lesser quantity of calcium silicate hydrates and more quantity of Ca(OH)<sub>2</sub> than that formed in the hydration of C2S. Ca(OH)<sub>2</sub> is not a desirable product in the concrete mass but it is soluble in water and gets leached out making the concrete porous, particularly in hydraulic structures. Under such conditions it is useful to use cement with higher percentage of C2S content.

C3S readily reacts with water and produces more heat of hydration. It is responsible for early strength of concrete. Cement with more C3S content is better for cold weather concreting. The quality and density of calcium silicate hydrate formed out of C3S is slightly inferior to that formed by C2S. The early strength of concrete is due to C3S.

C2S hydrates rather slowly. It is responsible for the later strength of concrete. It produces less heat of hydration. The calcium silicate hydrate formed is rather dense and its specific surface is higher. In general, the quality of the product of hydration of C2S is better than that produced in the hydration of C3S.

### **Calcium hydroxide:**

The other product of hydration of C3S and C2S is calcium hydroxide. It constitutes 20 to 25 per cent of the volume of solids in the hydrated paste. The lack of durability of concrete, is an account of the presence of calcium hydroxide. The calcium hydroxide also reacts with sulphates present in soils or water to form calcium sulphate which further reacts with C3A and cause deterioration of concrete. This is known as sulphate attack. To reduce the quantity of Ca(OH)<sub>2</sub> in concrete and to overcome its bad effects by converting it into cementitious product is an advancement in concrete technology. Use of blending materials such as fly ash, silica fume and

such other pozzolanic materials are the steps to overcome bad effect of  $\text{Ca(OH)}_2$  in concrete.

The only advantage is that  $\text{Ca(OH)}_2$ , being alkaline in nature, maintain pH value around 13 in the concrete which resists the corrosion of reinforcements.

### **Calcium aluminate hydrates:**

Due to the hydration of C3A, a calcium aluminate system  $\text{CaO} - \text{Al}_2\text{O}_3 - \text{H}_2\text{O}$  is formed. The reaction of pure C3A with water is very fast and this may lead to flash set. To prevent this flash set, gypsum is added at the time of grinding the cement clinker. The quantity of gypsum added has a bearing on the quantity of C3A present.

The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates very fast it may contribute a little to the early strength.

On hydration, C4AF is believed to form a system of the form  $\text{CaO} - \text{Fe}_2\text{O}_3 - \text{H}_2\text{O}$ . This hydrated product also does not contribute anything to the strength. The hydrates of C4AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

Gypsum and alkalies go into solution quickly and the solubility of C3A is depressed. Depending upon the concentration of aluminate and sulphate ions in solution, the precipitating crystalline product is either the calcium aluminate trisulphate hydrate ( $\text{C}_6\text{AS}_3\text{H}_{32}$ ) or calcium aluminate monosulphate hydrate ( $\text{C}_4\text{ASH}_{18}$ ). The calcium aluminate trisulphate hydrate is known as ettringite.

The amount of gypsum added has significant bearing on the quantity of aluminate in the cement. The maintenance of aluminate-to-sulphate ratio balances the normal setting behavior of cement paste.

Fresh cement paste is a plastic mass consisting of water and cement. With the lapse of time, say one hour, the hardening paste consists of hydrates of various compounds, unhydrated cement particles and water. With further lapse of time the quantity of unhydrated cement left in the paste decreases and the hydrates of the various compounds increase. Some of the mixing water is used up for chemical reaction, and some water occupies the gel-pores and the remaining water remains in the paste. After a sufficiently long time (say a month) the hydrated paste can be considered to be consisting of about 85 to 90% of hydrates of the various compounds and 10 to

15 per cent of unhydrated cement. The mixing water is partly used up in the chemical reactions. Part of it occupies the gel-pores and the remaining water unwanted for hydration or for filling in the gel-pores, causes capillary cavities. These capillary cavities may have been fully filled with water or partly with water or may be fully empty depending upon the age and the ambient temperature and humidity conditions.

### **Water requirements for hydration:**

C3S requires 24% of water by weight of cement and C2S requires 21%. It has also been estimated that on an average 23% of water by weight of cement is required for chemical reaction with Portland cement compounds. This 23% of water chemically combines with cement and, therefore, it is called bound water. A certain quantity of water is imbibed within the gel-pores. This water is known as gel-water. It has been further estimated that about 15 per cent by weight of cement is required to fill up the gel-pores. Therefore, a total 38 per cent of water by weight of cement is required for the complete chemical reactions and to occupy the space within gel-pores. If water equal to 38 per cent by weight of cement is only used it can be noticed that the resultant paste will undergo full hydration and no extra water will be available for the formation of undesirable capillary cavities. On the other hand, if more than 38 per cent of water is used, then the excess water will cause undesirable capillary cavities. Therefore greater the water above the minimum required is used (38 per cent), the more will be the undesirable capillary cavities. **In all this, it is assumed that hydration is taking place in a sealed container, where moisture to and from the paste does not take place.**

Capillary cavities become larger with increased water/cement ratio. Initially the cement particles are closer together. With the progress of hydration, when the volume of cement increases, the product of hydration also increases. The increase in the volume of gel due to complete hydration could fill up the space earlier occupied by water up to a w/c ratio of 0.6 or so. If the w/c ratio is more than 0.7, the increase in volume of the hydrated product would never be sufficient to fill up the voids created by water. Such concrete would ever remain as porous mass.

This is to say that gel occupies more and more space, that once occupied by mixing water. It has been estimated that the volume of gel would be about twice the volume of unhydrated cement.

### **Types of cements:**

Cements exhibit different properties and characteristics depending upon their chemical compositions. By changing the fineness of grinding or the oxide composition, cement can be

made to exhibit different properties. With the extensive use of cement, for widely varying conditions, the types of cement that could be made only by varying the relative proportions of the oxide compositions were not found to be sufficient. Recourses have been taken to add one or two more new materials, known as additives, to the clinker at the time of grinding, or to the use of entirely different basic raw materials in the manufacture of cement. The use of additives, changing chemical composition, and use of different raw materials have resulted in the availability of many types of cements to cater the need of the construction industries for specific purposes.

Cements are classified as Portland cements and non-Portland cements. The distinction is mainly based on the methods of manufacture. Portland and Non-Portland cements generally used are listed below:

### Types of Cement

- |  |  |
|--|--|
| (a) Ordinary Portland Cement             |  |
| (i) Ordinary Portland Cement 33 Grade-   | IS 269: 1989                                   |
| (ii) Ordinary Portland Cement 43 Grade-  | IS 8112: 1989                                  |
| (iii) Ordinary Portland Cement 53 Grade- | IS 12269: 1987                                 |
| (b) Rapid Hardening Cement               | - IS 8041: 1990                                |
| (c) Extra Rapid Hardening Cement         | - -  |
| (d) Sulphate Resisting Cement            | - IS 12330: 1988                               |
| (e) Portland Slag Cement                 | - IS 455: 1989                                 |
| (f) Quick Setting Cement                 | - -  |
| (g) Super Sulphated Cement               | - IS 6909: 1990                                |
| (h) Low Heat Cement                      | - IS 12600: 1989                               |
| (j) Portland Pozzolana Cement            | - IS 1489 (Part I) 1991 (fly ash based)        |
|  | - IS 1489 (Part II) 1991 (calcined clay based) |
| (k) Air Entraining Cement                | - -  |
| (l) Coloured Cement: White Cement        | - IS 8042: 1989                                |
| (m) Hydrophobic Cement                   | - IS 8043: 1991                                |
| (n) Masonry Cement                       | - IS 3466: 1988                                |
| (o) Expansive Cement                     | - -  |
| (p) Oil Well Cement                      | - IS 8229: 1986                                |
| (q) Rediset Cement                       | - -  |
| (r) Concrete Sleeper grade Cement        | - IRS-T 40: 1985                               |
| (s) High Alumina Cement                  | - IS 6452: 1989                                |
| (t) Very High Strength Cement            | - -  |

### ASTM classification of cement:

As per ASTM, cement is designated as Type I, Type II, Type III, Type IV, Type V and other



minor types like Type IS, Type IP and Type IA IIA and IIIA.

#### Type I

For use in general concrete construction where the special properties specified for Types II, III, IV and V are not required (Ordinary Portland Cement).

#### Type II

For use in general concrete construction exposed to moderate sulphate action, or where moderate heat of hydration is required.

#### Type III

For use when high early strength is required (Rapid Hardening Cement).

#### Type IV

For use when low heat of hydration is required (Low Heat Cement).

#### Type V

For use when high sulphate resistance is required (Sulphate Resisting Cement).

ASTM standard also have cement of the type IS. This consists of an intimate and uniform blend of Portland cement of type I and fine granulated slag. The slag content is between 25 and 70 per cent of the weight of Portland Blast-Furnace Slag Cement.

#### Type IP

This consist of an intimate and uniform blend of Portland cement (or Portland Blast Furnace Slag Cement) and fine pozzolana in which the pozzolana content is between 15 and 40 per cent of the weight of the total cement.

#### Type IA, IIA and IIIA

These are type I, II or III cement in which air-entraining agent is inter ground where air-entrainment in concrete is desired.

As per IS classification:

#### **Ordinary Portland cement:**

The OPC was classified into three grades, namely 33 grade, 43 grade and 53 grade depending upon the strength of the cement at 28 days when tested as per IS 4031-1988. If the 28 days strength is not less than 33N/mm<sup>2</sup>, it is called 33 grade cement, if the strength is not less than 43N/mm<sup>2</sup>, it is called 43 grade cement, and if the strength is not less than 53 N/mm<sup>2</sup>, it is called 53 grade cement.

In the modern construction activities, higher grade cements have become so popular.

**Rapid hardening cement:**

This cement is similar to ordinary Portland cement but it develops strength rapidly. Hence it is also called high early strength cement. Rapid hardening cement which develops higher rate of development of strength should not be confused with quick-setting cement which only sets quickly. Rapid hardening cement develops at the age of three days, the same strength as that is expected of ordinary Portland cement at seven days.

The rapid rate of development of strength is attributed to the higher fineness of grinding (specific surface not less than 3250 sq. cm per gram) and higher C3S and lower C2S content. A higher fineness of cement particles expose greater surface area for action of water and also higher proportion of C3S results in quicker hydration. Consequently, rapid hardening cement gives out much greater heat of hydration during the early period. Therefore, rapid hardening cement should not be used in mass concrete construction.

The use of rapid heading cement is recommended in the following situations:

- (a) In pre-fabricated concrete construction.
- (b) Where formwork is required to be removed early for re-use elsewhere,
- (c) Road repair works,
- (d) In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage.

**Extra rapid hardening cement:**

Extra rapid hardening cement is obtained by inter grinding calcium chloride with rapid hardening Portland cement. The normal addition of calcium chloride should not exceed 2 per cent by weight of the rapid hardening cement. It is necessary that the concrete made by using extra rapid hardening cement should be transported, placed and compacted and finished within about 20 minutes. It is also necessary that this cement should not be stored for more than a month. Extra rapid hardening cement accelerates the setting and hardening process. A large quantity of heat is evolved in a very short time after placing. The acceleration of setting, hardening and evolution of this large quantity of heat in the early period of hydration makes the cement very suitable for concreting in cold weather. The strength of extra rapid hardening cement is about 25 per cent higher than that of rapid hardening cement at one or two days and 10–20 per cent higher at 7 days. The gain of strength will disappear with age and at 90 days the strength of extra rapid hardening cement or the ordinary portland cement may be nearly the same.

**Sulphate resisting cement:**

Ordinary Portland cement is susceptible to the attack of sulphates, in particular to the action of magnesium sulphate. Sulphates react both with the free calcium hydroxide in set-cement to form calcium sulphate and with hydrate of calcium aluminate to form calcium sulphoaluminate, the volume of which is approximately 227% of the volume of the original aluminates. Their expansion within the frame work of hardened cement paste results in cracks and subsequent disruption. Solid sulphates do not attack the cement compound. Sulphates in solution permeate into hardened concrete and attack calcium hydroxide, hydrated calcium aluminate and even hydrated silicates. The above is known as sulphate attack. Sulphate attack is greatly accelerated if accompanied by alternate wetting and drying which normally takes place in marine structures in the zone of tidal variations. To remedy the sulphate attack, the use of cement with low C3A content is found to be effective. Such cement with low C3 A and comparatively low C4AF content is known as Sulphate Resisting Cement. In other words, this cement has high silicate content. The specification generally limits the C3A content to 5 per cent.

The use of sulphate resisting cement is recommended under the following conditions:

- (a) Concrete to be used in marine condition;
- (b) Concrete to be used in foundation and basement, where soil is infested with sulphates;
- (c) Concrete used for fabrication of pipes which are likely to be buried in marshy region or sulphate bearing soils;
- (d) Concrete to be used in the construction of sewage treatment works.

**Portland slag cement:**

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and granulated blast furnace slag (blast furnace slag is a waste product from steel manufacturing plants) in suitable proportions and grinding the mixture to get a thorough and intimate mixture between the constituents. It may also be manufactured by separately grinding Portland cement clinker, gypsum and ground granulated blast furnace slag and later mixing them intimately. It has low heat of hydration and is relatively better resistant to chlorides, soils and water containing excessive amount of sulphates or alkali metals, alumina and iron, as well as, to acidic waters, and therefore, this can be used for marine works.

The quantity of granulated slag mixed with portland clinker will range from 25-65 per cent. Early strength is mainly due to the cement clinker fraction and later strength is that due to the

slag fraction.

The rate of hardening of Portland blast furnace slag cement in mortar or concrete is somewhat slower than that of ordinary Portland cement during the first 28 days, but thereafter increases.

The major advantages currently recognized are:

- (a) Reduced heat of hydration;
- (b) Refinement of pore structure;
- (c) Reduced permeability
- (d) Increased resistance to chemical attack.

Combining GGBS and OPC at mixer is treated as equivalent to factory made PSC.

#### **Quick setting cement:**

This cement sets very early. The early setting property is brought out by reducing the gypsum content at the time of clinker grinding. This cement is required to be mixed, placed and compacted very early. It is used mostly in under water construction where pumping is involved. Use of quick setting cement in such conditions reduces the pumping time and makes it economical. Quick setting cement may also find its use in some typical grouting operations.

#### **Super sulphated cement:**

Super sulphated cement is manufactured by grinding together a mixture of 80-85 per cent granulated slag, 10-15 per cent hard burnt gypsum, and about 5 per cent Portland cement clinker. The product is ground finer than that of Portland cement. Specific surface must not be less than 4000 cm<sup>2</sup> per gm.

This cement is more sensitive to deterioration during storage than Portland cement. Super-sulphated cement has a low heat of hydration of about 40-45 calories/gm at 7 days and 45-50 at 28 days. This cement has high sulphate resistance. Because of this property this cement is particularly recommended for use in foundation, where chemically aggressive conditions exist and also used in the marine works. It is also used where buried pipelines are to be used in sulphate bearing soils. The substitution of granulated slag is responsible for better resistance to sulphate attack.

#### **Low heat cement:**

Hydration of cement is an exothermic action which produces large quantity of heat during hydration. In mass concrete construction, such as dams, where temperature rise by the heat of hydration can become excessively large and cracks will form in large body of concrete. Hence,



there is a need to produce cement which produces less heat or the same amount of heat, at a low rate during the hydration process. Low-heat evolution is achieved by reducing the contents of C3S and C3A which are the compounds evolving the maximum heat of hydration and increasing C2S. A reduction of temperature will retard the chemical action of hardening and so further restrict the rate of evolution of heat. The rate of evolution of heat will, therefore, be less and evolution of heat will extend over a longer period. Therefore, the feature of low-heat cement is a slow rate of gain of strength. But the ultimate strength of low-heat cement is the same as that of ordinary Portland cement. As per the Indian Standard Specification the heat of hydration of low-heat Portland cement shall be as follows:

7 days — not more than 65 calories per gm.

28 days — not more than 75 calories per gm.

The specific surface of low heat cement as found out by air-permeability method is not less than 3200 sq. cm/gm. The 7 days strength of low heat cement is not less than 16 MPa in contrast to 22 MPa in the case of ordinary Portland cement. Other properties, such as setting time and soundness are same as that of ordinary Portland cement.

#### **Portland pozzolana cement:**

Portland Pozzolana cement (PPC) is manufactured by the intergrinding of OPC clinker with 10 to 25 per cent of pozzolanic material (as per the latest amendment, it is 15 to 35%). A pozzolanic material is essentially a silicious or aluminous material which while in itself possessing no cementitious properties, which will, in finely divided form and in the presence of water, react with calcium hydroxide, liberated in the hydration process, at ordinary temperature, to form compounds possessing cementitious properties. The pozzolanic materials generally used for manufacture of PPC are calcined clay (IS 1489 part 2 of 1991) or fly ash (IS 1489 part I of 1991). Fly ash is a waste material, generated in the thermal power station, when powdered coal is used as a fuel. These are collected in the electrostatic precipitator.

Calcium silicates produce considerable quantities of calcium hydroxide, which is by and large a useless material from the point of view of strength or durability. If such useless mass could be converted into a useful cementitious product, it considerably improves quality of concrete. The use of fly ash performs such a role. The pozzolanic action is shown below:



Portland pozzolana cement produces less heat of hydration and offers greater resistance to the

attack of aggressive waters than ordinary Portland cement. Moreover, it reduces the leaching of calcium hydroxide when used in hydraulic structures. It is particularly useful in marine and hydraulic construction and other mass concrete constructions.

#### Advantages of PPC

- (a) In PPC, costly clinker is replaced by cheaper pozzolanic material - Hence economical.
- (b) Soluble calcium hydroxide is converted into insoluble cementitious products resulting in improvement of permeability. Hence it offers, around durability characteristics, particularly in hydraulic structures and marine construction.
- (c) PPC consumes calcium hydroxide and does not produce calcium hydroxide as much as that of OPC.
- (d) It generates reduced heat of hydration and that too at a low rate.
- (e) PPC being finer than OPC and also due to pozzolanic action, it improves the pore size distribution and also reduces the micro cracks.

All the above advantages of PPC are mainly due to the slow conversion of calcium hydroxide in the hydrated cement paste into cementitious product. In one investigation, 20 per cent calcium hydroxide in one year old OPC paste was found to be only 8.4 per cent calcium hydroxide in a similarly hydrated paste containing 30 per cent pozzolana.

A few of the disadvantages are that the rate of development of strength is initially slightly slower than OPC. Secondly reduction in alkalinity reduces the resistance to corrosion of steel reinforcement. But as permeability of PPC is low, corrosion of steel reinforcement will not be there. Setting time is generally longer.

#### **Air entraining cement:**

This cement is made by mixing a small amount of an air-entraining agent with ordinary Portland cement clinker at the time of grinding. The following types of air-entraining agents could be used:

- (a) Alkali salts of wood resins.
- (b) Synthetic detergents of the alkyl-aryl sulphonate type.
- (c) Calcium lignosulphate derived from the sulphite process in paper making.
- (d) Calcium salts of glues and other proteins obtained in the treatment of animal hides.

These agents in powder, or in liquid forms are added to the extent of 0.025–0.1 per cent by weight of cement clinker.

Air-entraining cement will produce at the time of mixing, tough, tiny, discrete non-coalescing air bubbles in the body of the concrete which will modify the properties of plastic concrete with respect to workability, segregation and bleeding.

**Colored concrete (white cement):**

Colored cement consists of Portland cement with 5-10 per cent of pigment. The pigment cannot be satisfactorily distributed throughout the cement by mixing, and hence, it is usual to grind the cement and pigment together. The process of manufacture of white Portland cement is nearly same as OPC. The raw materials used are high purity limestone (96%  $\text{CaCO}_3$  and less than 0.07% iron oxide). The other raw materials are china clay with iron content of about 0.72 to 0.8%, silica sand, flourspar as flux and selenite as retarder.

**Hydrophobic cement:**

Hydrophobic cement is obtained by grinding ordinary Portland cement clinker with water repellant film-forming substance such as oleic acid, and stearic acid. The water-repellant film formed around each grain of cement, reduces the rate of deterioration of the cement during long storage, transport, or under unfavorable conditions. The film is broken out when the cement and aggregate are mixed together at the mixer exposing the cement particles for normal hydration. The film forming water-repellant material will entrain certain amount of air in the body of the concrete which incidentally will improve the workability of concrete.

The hydrophobic cement is made actually from ordinary Portland cement clinker. After grinding, the cement particle is sprayed in one direction and film forming materials such as oleic acid, or stearic acid, or pentachlorophenol, or calcium oleate are sprayed from another direction such that every particle of cement is coated with a very fine film of this water repellant material which protects them from the bad effect of moisture during storage and transportation.

**Masonry cement:**

Ordinary cement mortar, though good when compared to lime mortar with respect to strength and setting properties, is inferior to lime mortar with respect to workability, water-retentivity, shrinkage property and extensibility. Masonry cement is a type of cement which is particularly made with such combination of materials, which when used for making mortar, incorporates all the good properties of lime mortar and discards all the not ideal properties of cement mortar. This kind of cement is mostly used, as the name indicates, for masonry construction. It contains certain amount of air-entraining agent and mineral admixtures to improve the plasticity and

water retentivity.

### **Expansive cement:**

Concrete made with ordinary Portland cement shrinks while setting due to loss of free water. Concrete also shrinks continuously for long time. This is known as drying shrinkage. Cement used for grouting anchor bolts or grouting machine foundations or the cement used in grouting the pre-stressed concrete ducts, if shrinks, the purpose for which the grout is used will be to some extent defeated. A slight expansion with time will prove to be advantageous for grouting purpose. This type of cement which suffers no overall change in volume on drying is known as expansive cement. Cement of this type has been developed by using an expanding agent and a stabilizer very carefully. Proper material and controlled proportioning are necessary in order to obtain the desired expansion. Generally, about 8-20 parts of the sulphoaluminate clinker are mixed with 100 parts of the Portland cement and 15 parts of the stabilizer. Since expansion takes place only so long as concrete is moist, curing must be carefully controlled.

**Special grade cement, oil well cement, rediset cement, high alumina cement, very high strength cement are other types of cements.**

**Macro defect free cement, densely packed system, pressure densification and warm pressuring, high early strength cement, pyrament cement and magnesium phosphate cement are some types of very high strength cements.**

### **Testing of cement**

Cement can be tested either in lab or in field. Hence testing of cement is brought under 2 categories:

- a) Field testing
- b) Lab testing

#### **Field Testing**

When cement is used for minor works, field testing is sufficient. The following are the field tests:

- (a) When the cement bag is opened, there should not be any visible lumps. The colour of the cement should normally be greenish grey.
- (b) Cement must give you a cool feeling when hand is placed in bag of cement. There should not be any lump inside.
- (c) Take a pinch of cement and feel-between the fingers. It should give a smooth and not a gritty feeling.

(d) Take a handful of cement and throw it on a bucket full of water, the particles should float for some time before they sink.

(e) Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. After 24 hours the cake should retain its original shape and at the same time it should also set and attain some strength.

If a sample of cement satisfies the above field tests it may be concluded that the cement is not bad.

When cement is to be used for major and important works, lab testing of cement is definitely necessary as field testing of cement do not really indicate that the cement is really good for important works.

The following tests are usually conducted in the laboratory.

- (a) Fineness test
- (b) Setting time test
- (c) Strength test
- (d) Soundness test
- (e) Heat of hydration test
- (f ) Chemical composition test

#### **Fineness Test:**

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence faster the development of strength.

Maximum number of particles in a sample of cement should have a size less than about 100 microns. The smallest particle may have a size of about 1.5 microns. By and large an average size of the cement particles may be taken as about 10 micron. The particle size fraction below 3 microns has been found to have the predominant effect on the strength at one day while 3-25 micron fraction has a major influence on the 28 days strength. Increase in fineness of cement is also found to increase the drying shrinkage of concrete. In commercial cement it is suggested that there should be about 25-30 per cent of particles of less than 7 micron in size.

Fineness of cement is tested by sieving.



**Sieve Test:**

Weigh correctly 100 grams of cement and take it on a standard IS Sieve No. 9 (90 microns). Break down the air-set lumps in the sample with fingers. Continuously sieve the sample giving circular and vertical motion for a period of 15 minutes. Mechanical sieving devices may also be used. Weigh the residue left on the sieve. This weight shall not exceed 10% for ordinary cement.

**Standard Consistency Test:**

For finding out initial setting time, final setting time and soundness of cement, and strength a parameter known as standard consistency has to be used. The standard consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate to a depth of 33-35 mm from the top of the mold. The apparatus is called Vicat Apparatus. This apparatus is used to find out the percentage of water required to produce a cement paste of standard consistency. The standard consistency of the cement paste is some time called normal consistency (CPNC).

**Procedure to determine Standard consistency:**

Take about 500 gms of cement and prepare a paste with a weighed quantity of water (say 24 per cent by weight of cement) for the first trial. Water and cement is to be mixed thoroughly and filled into the Vicat mould within 3-5 minutes. After completely filling the mould, shake the mould to expel air. A standard plunger, 10 mm diameter, 50 mm long is attached and brought down to touch the surface of the paste in the test block and quickly released allowing it to sink into the paste by its own weight. Take the reading by noting the depth of penetration of the plunger. Conduct a 2nd trial (say with 25 per cent of water) and find out the depth of penetration of plunger. Similarly, conduct trials with higher and higher water/cement ratios till such time the plunger penetrates for a depth of 33-35 mm from the top. That particular percentage of water which allows the plunger to penetrate only to a depth of 33-35 mm from the top is known as the percentage of water required to produce a cement paste of standard consistency. This percentage is usually denoted as 'P'. The test is required to be conducted in a constant temperature ( $27^{\circ} + 2^{\circ}\text{C}$ ) and constant humidity (90%).

**Setting time test:**

Setting time is again divided as initial setting time and final setting time. Initial setting time is regarded as the time elapsed between the moment that the water is added to the cement, to the time that the paste starts losing its plasticity. The final setting time is the time elapsed between

the moment the water is added to the cement, and the time when the paste has completely lost its plasticity and has attained sufficient firmness to resist certain definite pressure.

In actual construction dealing with cement paste, certain time is required for mixing, transporting, placing, compacting and finishing. During this time cement paste, mortar or concrete should be in plastic condition. The time interval for which the cement products remain in plastic condition is known as the initial setting time. Normally a minimum of 30 minutes is given for mixing and handling operations.

Once the concrete is placed in the final position, compacted and finished, it should lose its plasticity in the earliest possible time so that it is least vulnerable to damages from external destructive agencies. This time should not be more than 10 hours which is often referred to as final setting time.

**Procedure:**

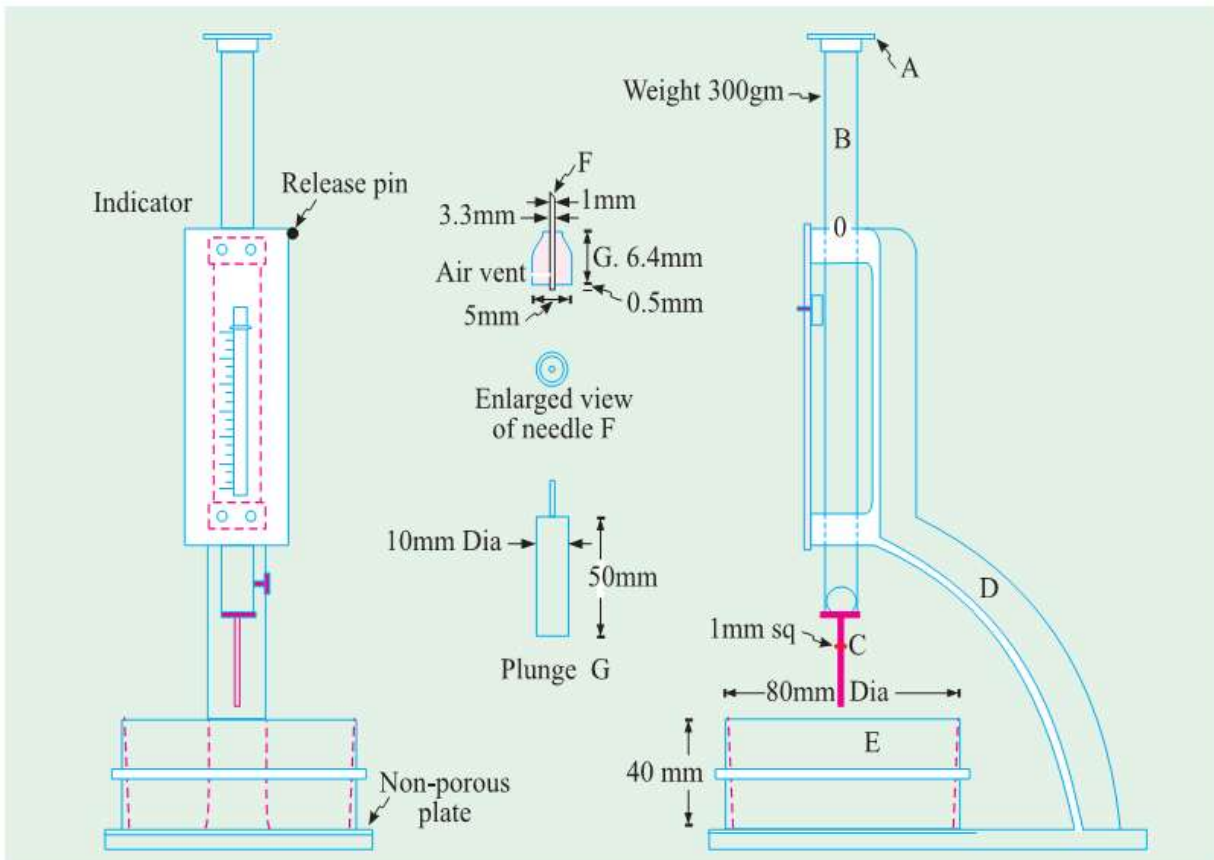
The Vicat Appartus is used for setting time test also. The following procedure is adopted. Take 500 gm. of cement sample and guage it with 0.85 times the water required to produce cement paste of standard consistency (0.85 P). The paste shall be gauged and filled into the Vicat mould in specified manner within 3-5 minutes. Start the stop watch the moment water is added to the cement. The temperature of water and that of the test room, at the time of gauging shall be within  $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$ .



Vicat Apparatus and Accessories.

### Initial Setting Time:

Lower the needle (Needle C shown in fig) gently and bring it in contact with the surface of the test block and quickly release. Allow it to penetrate into the test block. In the beginning, the needle will completely pierce through the test block. But after some time when the paste starts losing its plasticity, the needle may penetrate only to a depth of 33-35 mm from the top. The period elapsing between the time when water is added to the cement and the time at which the needle penetrates the test block to a depth equal to 33-35 mm from the top is taken as initial setting time.



### Final Setting Time

Replace the needle (C) of the Vicat apparatus by a circular attachment (F) shown in the above figure. The cement shall be considered as finally set when, upon, lowering the attachment gently cover the surface of the test block, the center needle makes an impression, while the circular cutting edge of the attachment fails to do so. In other words the paste has attained such hardness that the center needle does not pierce through the paste more than 0.5 mm.

### Strength test:

Strength tests are not made on neat cement (cement alone) paste because of difficulties of excessive shrinkage and subsequent cracking of neat cement. Strength of cement is indirectly found on cement sand mortar in specific proportions. The standard sand is used for finding the strength of cement. It shall conform to IS 650-1991. Take 555 gms of standard sand, 185 gms of cement (i.e., ratio of cement to sand is 1:3) in a non-porous enamel tray and mix them with a trowel for one minute, then add water of quantity  $(P/4) + 3.0$  per cent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform color. The time of mixing should not be less than 3 minutes nor more than 4 minutes. Immediately after mixing, the mortar is filled into a cube mould of size 7.06 cm. The area of the face of the cube will be equal to 50 sq cm. Compact the mortar either by hand compaction in a standard specified manner or on the vibrating equipment (12000 RPM) for 2 minutes. Keep the compacted cube in the mould at a temperature of  $27^{\circ}\text{C} \pm 2^{\circ}\text{C}$  and at least 90 per cent relative humidity for 24 hours. Where the facility of standard temperature and humidity room is not available, the cube may be kept under wet gunny bag to simulate 90 per cent relative humidity. After 24 hours the cubes are removed from the mould and immersed in clean fresh water until taken out for testing.

Three cubes are tested for compressive strength at the periods mentioned in the below table. The compressive strength shall be the average of the strengths of the three cubes for each period respectively. The strength requirements for various types of cement are shown in below table.

#### **Soundness Test:**

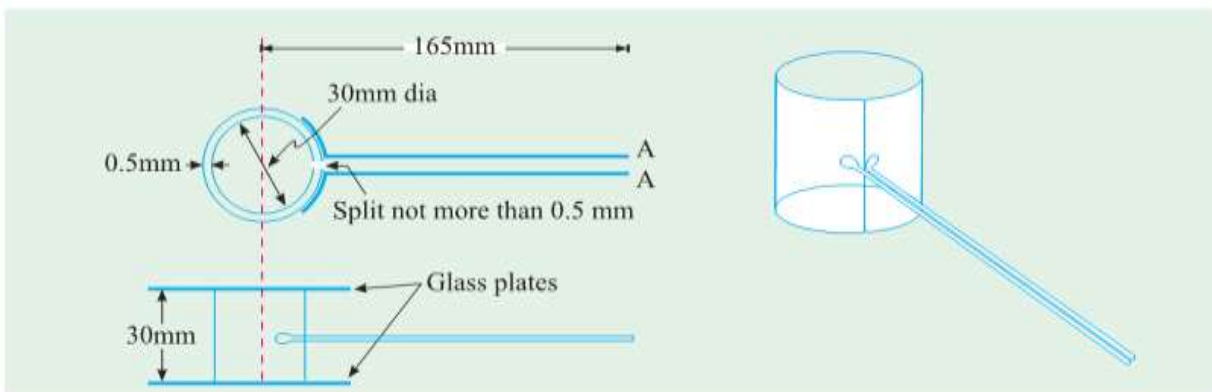
It is very important that the cement after setting shall not undergo any appreciable change of volume. This will cause serious difficulties for the durability of structures when such cement is used. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance. The unsoundness in cement is due to the presence of excess of lime than that could be combined with acidic oxide at the kiln. This is also due to inadequate burning or insufficiency in fineness of grinding or thorough mixing of raw materials. It is also likely that too high a proportion of magnesium content or calcium sulphate content may cause unsoundness in cement. For this reason the magnesia content allowed in cement is limited to 6 per cent. If the addition of gypsum is more than that could be combined with C3A, excess of gypsum will remain in the cement in free state. This excess of gypsum leads to an expansion and consequent disruption of the set cement paste.

**Table 2.5. Physical Characteristics of Various Types of Cement.**

Sl. No.	Type of Cement	Fineness (m <sup>2</sup> /kg) Min.	Soundness by		Setting time		Compressive Strength			
			(Le chatelier mm) Max.	Autoclave (%) Max.	Initial (mts) min.	Final (mts) max.	1 Day min. MPa	3 Days min. MPa	7 Days min. MPa	28 Days min. MPa
1.	33 Grade OPC (IS 269-1989)	225	10	0.8	30	600	N S	16	22	33
2.	43 Grade OPC (IS 8112-1989)	225	10	0.8	30	600	N S	23	33	43
3.	53 Grade OPC (IS 12269-1987)	225	10	0.8	30	600	N S	27	37	53
4.	SRG (IS 12330-1988)	225	10	0.8	30	600	N S	10	16	33
5.	PPC (IS 1489-1991) Part I	300	10	0.8	30	600	N S	16	22	33
6.	Rapid Hardening (IS 8041-1990)	325	10	0.8	30	600	16	27	N S	N S
7.	Slag Cement (IS 445-1989)	225	10	0.8	30	600	N S	16	22	33
8.	High Alumina Cement (IS 6452-1989)	225	5	N S	30	600	30	35	N S	N S
9.	Super Sulphated Cement (IS 6909-1990)	400	5	N S	30	600	N S	15	22	30
10.	Low Heat Cement (IS 12600-1989)	320	10	0.8	60	600	N S	10	16	35
11.	Masonry Cement (IS 3466-1988)	*	10	1	90	1440	N S	N S	2.5	5
12.	BS-140	370	5	0.8	60	600	N S	N S	37.5	N S

\*N S – Not specified.

Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportion of sulphates. Unsoundness in cement does not come to surface for a considerable period of time. Therefore, accelerated tests are required to detect it. The apparatus consists of a small split cylinder of spring brass or other suitable metal. It is 30 mm in diameter and 30 mm high. On either side of the split are attached two indicator arms 165 mm long with pointed ends. Cement is gauged with 0.78 times the water required for standard consistency (0.78 P), in a standard manner and filled into the mould kept on a glass plate.





The mould is covered on the top with another glass plate. The whole assembly is immersed in water at a temperature of  $27^{\circ}\text{C} - 32^{\circ}\text{C}$  and kept there for 24 hours.

Measure the distance between the indicator points. Submerge the mould again in water. Heat the water and bring to boiling point in about 25-30 minutes and keep it boiling for 3 hours. Remove the mould from the water, allow it to cool and measure the distance between the indicator points. The difference between these two measurements represents the expansion of cement. This must not exceed 10 mm for ordinary, rapid hardening and low heat Portland cements. If in case the expansion is more than 10 mm as tested above, the cement is said to be unsound.

The Le Chatelier test detects unsoundness due to free lime only. This method of testing does not indicate the presence and after effect of the excess of magnesia. Indian Standard Specification stipulates that a cement having a magnesia content of more than 3 per cent shall be tested for soundness by Autoclave test which is sensitive to both free magnesia and free lime. In this test a neat cement specimen  $25 \times 25$  mm is placed in a standard autoclave and the steam pressure inside the autoclave is raised in such a rate as to bring the gauge pressure of the steam to 21 kg/sq cm in 1 – 1.25 hour from the time the heat is turned on. This pressure is maintained for 3 hours. The autoclave is cooled and the length is measured again. The expansion permitted for all types of cements is given in Table 2.5. The high steam pressure accelerates the hydration of both magnesia and lime. No satisfactory test is available for deduction of unsoundness due to an excess of calcium sulphate. But its content can be easily determined by chemical analysis.

### **Heat of hydration:**

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This can be easily observed if cement is gauged with water and placed in a thermos flask. Much attention has been paid to the heat evolved during the hydration of cement in the interior of mass concrete dams. It is estimated that about 120 calories of heat is generated in the hydration of 1 gm of cement. A temperature rise of about  $50^{\circ}\text{C}$  has been observed in the interior of mass concrete dams. This unduly high temperature developed at the interior of a concrete dam causes serious expansion of the body of the dam and with the subsequent cooling considerable shrinkage takes place resulting in serious cracking of concrete.

The use of lean mix, use of pozzolanic cement, artificial cooling of constituent materials and incorporation of pipe system in the body of the dam as the concrete work progresses for circulating cold brine solution through the pipe system to absorb the heat, are some of the

methods adopted to offset the heat generation in the body of dams due to heat of hydration of cement.

Test for heat of hydration is essentially required to be carried out for low heat cement only. When tested in a standard manner the heat of hydration of low heat Portland cement shall not be more than 65 cal/gm at 7 days and 75 cal/g at 28 days.

#### Chemical Composition Test:

Ratio of percentage of lime to percentage of silica, alumina and iron oxide, when calculated by the formulae,

$$\frac{\text{CaO} - 0.7 \text{SO}_3}{2.8 \text{SiO}_2 + 1.2 \text{Al}_2\text{O}_3 + 0.65 \text{Fe}_2\text{O}_3}$$

The above ratio should not be greater than 1.02 and not less than 0.66

The above is called lime saturation factor per cent.

#### Chemical characteristics of various types of cement

Sr. No.	Type of Cement	Lime Saturation Factor (%)	Alumina Iron Ratio (%) Min.	Insoluble Residue (%) Max.	Magnesia (%) Max.	Sulphuric Anhydride	Loss on Ignition (%) Max.
1	33 Grade OPC (IS 269-1989)	0.66 Min. 1.02 Max.	0.66	4	6	2.5% Max. When C <sub>3</sub> A is 5 or less 3% Max. When C <sub>3</sub> A is greater than 5	5
2	43 Grade OPC (IS 8112-1989)	0.66 Min. 1.02 Max.	0.66	2	6	2.5% Max. When C <sub>3</sub> A is 5 or less 3% Max. When C <sub>3</sub> A is greater than 5	5
3	53 Grade OPC (IS 12269-1987)	0.8 Min. 1.02 Max.	0.66	2	6	2.5% Max. When C <sub>3</sub> A is 5 or less 3% Max. When C <sub>3</sub> A is greater than 5	4
4	Sulphate Resisting Cement (IS 12330-1988)	0.66 Min. 1.02 Max.	N S	4	6	2.5% Max.	5

5	Portland Pozzolana Cement (IS 1489-1991) Part I	N S	N S	$x + \frac{4(100-x)}{100}$	6	3% Max.	5
6	Rapid Hardening Cement (IS 8041-1990)	0.66 Min. 1.02 Max.	0.66	4	6	2.5% Max. When C <sub>3</sub> A is 5 or less 3% Max. When C <sub>3</sub> A is greater than 5	5
7	Slag Cement (IS 455-1989)	N S	N S	4	8	3% Max.	5
8	High Alumina Cement (IS 6452-1989)	N S	N S	N S	N S	N S	N S
9	Super Sulphated-Cement (IS 6909-1990)	N S	N S	4	10	6% Min.	N S
10	Low Heat Cement (IS 12600-1989)	N S	0.66	4	6	2.5% Max. When C <sub>3</sub> A is 5 or less 3% Max. When C <sub>3</sub> A is greater than 5	5
11	IRS-T40	0.8 Min. 1.02 Max.	0.66	2	5	3.5% Max.	4

x – Declared percentage of flyash. N S – Not specified.

### Model test certificate to be issued by the manufacturing company

#### 53 Grade Portland Cement

#### Birla Super

#### Week no. 35

#### Physical Analysis

Fineness:		Requirements of I.S. 12269-1987
Specific Surface	303 m <sup>2</sup> /kg	Should not be less than 225 m <sup>2</sup> /kg
Soundness		
Expansion of unaerated cement		
a) By Le chatelier mould	0.50 m.m.	Should not exceed 10 m.m.
b) By Autoclave	0.0936 %	Should not exceed 0.8%
Setting Time:		
a) Initial set	130 mts.	Should not be less than 30 mts.
b) Final set	195 mts.	Should not exceed 600 mts.
Compressive strength:		
a) 3 days	42.3 MPa	Should not be less than 27 M Pa
b) 7 days	51.6 MPa	Should not be less than 37 M Pa
c) 28 days (Week No. 32)	71.3 MPa	Should not be less than 53 M Pa
Temperature during testing	27.0 °C	Should be 27°C ± 2°C
Standard Consistency	29.7 %	

Chemical Analysis			
Particulars			
Lime Saturation Factor (L.S.F.)	0.92	Should not be less than	0.80 and exceed 1.02
Alumina Iron Ratio	1.16	Should not be less than	0.66
Loss on Ignition (LOI)	1.29 %	Should not exceed	4%
Insoluble Residue (I.R.)	0.84 %	Should not exceed	2%
Sulphuric Anhydride (SO <sub>3</sub> )	2.03 %	Should not exceed	3%
Magnesia (MgO)	1.16 %	Should not exceed	6%
Alkalies	0.46 %	Should not exceed	0.6%
Chlorides	0.0162 %	Should not exceed	0.05%

### Classification of aggregates:

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. Earlier, aggregates were considered as chemically inert materials but now it has been recognized that some of the aggregates are chemically active and also that certain aggregates exhibit chemical bond at the interface of aggregate and paste. Aggregates occupy 70-80 of volume of concrete.

The study of aggregates can best be done under the following sub-headings:

Classification, Size, Shape, Texture, Strength, Specific gravity and bulk density, Cleanliness, Soundness, Chemical properties, Durability, Sieve analysis, Grading

a) Aggregates can be classified as (i) Normal weight aggregates, (ii) Light weight aggregates and (iii) Heavy weight aggregates. In this chapter the properties of normal weight aggregates will only be discussed.

Normal weight aggregates can be further classified as natural aggregates and artificial aggregates.

Sand, Gravel, Crushed rock such as Granite, Quartzite, Basalt, sandstone will come under natural aggregates.

Broken brick, air cooled slag, sintered fly ash, bloated clay will come under artificial aggregates. Aggregates can also be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate.

### b) Size:

80 mm size is the maximum size that could be conveniently used for concrete making. Using the largest possible maximum size will result in (i) reduction of the cement content (ii) reduction in

water requirement (iii) reduction of drying shrinkage. However, the maximum size of aggregate that can be used in any given condition may be limited by the following conditions:

- (i) Thickness of section; (ii) Spacing of reinforcement;
- (iii) Clear cover; (iv) Mixing, handling and placing techniques

For heavily reinforced concrete member, the nominal maximum size of aggregate should usually be restricted to 5 mm less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement, whichever is smaller. But from various other practical considerations, for reinforced concrete work, aggregates having a maximum size of 20 mm are generally considered satisfactory.

Aggregates are divided into two categories from the consideration of size (i) Coarse aggregate and (ii) Fine aggregate. The size of aggregate bigger than 4.75 mm is considered as coarse aggregate and aggregate whose size is 4.75 mm and less is considered as fine aggregate.

### c) Shape:

The shape of aggregates is an important characteristic since it affects the workability of concrete. Type of crusher used and parent rock affects shape of aggregates.

From the standpoint of economy in cement requirement for a given water/cement ratio, rounded aggregates are preferable to angular aggregates. On the other hand, angular aggregates needs more cement due to its high specific surface area. Also angular aggregates create good interlocking between aggregates.

Flat particles in concrete aggregates will have particularly objectionable influence on the workability, cement requirement, strength and durability. In general, excessively flaky aggregate makes very poor concrete.

### Shape of particles

Classification	Description	Examples
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravels; desert, seashore and wind-blown sands
Irregular or Partly rounded	Naturally irregular or partly shaped by attrition, having rounded edges	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; screes
Flaky	Material, usually angular; of which the thickness is small relative to the width and/or length	Laminated rocks



### **Procedure to determine angularity of aggregates:**

Angularity is based on the percentage voids in the aggregate after compaction in a specified manner. The test gives a value termed the angularity number. The method of determination is described in IS: 2386 (Part I) 1963.

A quantity of single sized aggregate is filled into metal cylinder of three litre capacity. The aggregates are compacted in a standard manner and the percentage of void is found out. The void can be found out by knowing the specific gravity of aggregate and bulk density or by pouring water to the cylinder to bring the level of water upto the brim. If the void is 33 per cent the angularity of such aggregate is considered zero. If the void is 44 per cent the angularity number of such aggregate is considered 11. In other words, if the angularity number is zero, the solid volume of the aggregate is 67 per cent and if angularity number is 11, the solid volume of the aggregate is 56 per cent. The normal aggregates which are suitable for making the concrete may have angularity number anything from zero to 11. Angularity number zero represents the most practicable rounded aggregates and the angularity number 11 indicates the most angular aggregates that could be tolerated for making concrete not so unduly harsh and uneconomical.





Poorly shaped crushed aggregate. It will make poor concrete.



Barmac crushed 20 mm cubical aggregate. It will make good concrete.



Good aggregate resulted from Barmac crusher.



20 mm crushed angular aggregates not so good for concrete.

Generally, rounded aggregates are smooth textured and angular aggregates are rough textured. Some engineers prohibit the use of rounded aggregate as it yields poor concrete, due to lack of bond between the smooth surface of the aggregate and cement paste.

Angular aggregates are superior to rounded aggregates from the following two points of view:

- (a) Angular aggregates exhibit a better interlocking effect in concrete, which property makes it superior in concrete used for roads and pavements.
- (b) The total surface area of rough textured angular aggregate is more than smooth rounded aggregate for the given volume. By having greater surface area, the angular aggregate may show higher bond strength than rounded aggregates.

The higher surface area of angular aggregate with rough texture requires more water for a given workability than rounded aggregates. This means that for a given set of conditions from the point of view of water/cement ratio and the consequent strength, rounded aggregate gives higher strength. Superimposing plus and minus points in favour and against these two kinds of

aggregates it can be summed up as follows:

For water/cement ratio below 0.4 the use of crushed aggregate has resulted in strength up to 38 per cent higher than the rounded aggregate. With an increase in water/cement ratio the influence of roughness of surface of the aggregate gets reduced, presumably because the strength of the paste itself becomes paramount, and at a water/cement ratio of 0.65, no difference in strength of concrete made with angular aggregate or rounded aggregate has been observed.

### **Texture:**

Surface texture depends on hardness, grain size, pore structure, structure of the rock, and the degree to which forces acting on the particle surface have smoothed or roughened it. Hard, dense, fine-grained materials will generally have smooth fracture surfaces.

As surface smoothness increases, contact area decreases, hence a highly polished particle will have less bonding area with the matrix than a rough particle of the same volume.

### **Strength:**

Strong aggregates cannot make strong concrete, but to make strong concrete, strong aggregates are an essential requirement. In other words, from a weak rock or aggregate strong concrete cannot be made. By and large naturally available mineral aggregates are strong enough for making normal strength concrete. The test for strength of aggregate is required to be made in the following situations:

- (i) For production of high strength and ultra-high strength concrete.
- (ii) When contemplating to use aggregates manufactured from weathered rocks.
- (iii) Aggregate manufactured by industrial process.

### **Aggregate crushing value:**

Strength of rock is found out by making a test specimen of cylindrical shape of size 25 mm diameter and 25 mm height. This cylinder is subjected to compressive stress. Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. Generally, this test is made on single sized aggregate passing 12.5 mm and retained on 10 mm sieve.

To determine crushing value, about 6.5 kg material consisting of aggregates passing 12.5 mm and retained on 10 mm sieve is taken. The aggregate in a surface dry condition is filled into the standard cylindrical measure in three layers approximately of equal depth. Each layer is tamped 25 times with the tamping rod and finally leveled off using the tamping rod as straight edge.

Weight of the sample contained in the cylinder measure is taken as A. The cylinder of the test apparatus with aggregate filled in a standard manner is put in position on the base-plate and the aggregate is carefully levelled and the plunger inserted horizontally on this surface. The plunger should not jam in the cylinder.



Aggregate Crushing Value Apparatus.

The apparatus, with the test sample and plunger in position, is placed on the compression testing machine and is loaded uniformly upto a total load of 40 tons in 10 minutes time. The load is then released and the whole of the material removed from the cylinder and sieved on a 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed (B).

$$\text{Aggregate crushing value} = \frac{B}{A} * 100$$

Where B is the weight of fraction passing 2.36 mm sieve, A is the weight of surface dry sample taken in mold.

This percentage is referred as aggregate crushing value. The crushing value of aggregate is restricted to 30 percent for concrete used for roads and pavements and 45 per cent may be

permitted for other structures.

### **Aggregate impact value:**

The aggregate impact value gives relative measure of the resistance of an aggregate to sudden shock or impact.

The test sample consists of aggregate passing through 12.5 mm and retained on 10 mm I.S. Sieve. The aggregate shall be dried in an oven for a period of four hours at a temperature of 100°C to 110°C and cooled. The aggregate is filled about one-third full and tamped with 25 strokes by the tamping rod. A further similar quantity of aggregate is added and tamped in the standard manner. The measure is filled to over-flowing and then struck off level. The net weight of the aggregate in the measure is determined (weight A)

The mold is fixed to the base of the machine and a metal hammer of weight 14 Kgs falling from a height of 38 cms is dropped on to the aggregate. The test sample is subjected to 15 such blows. The crushed aggregate is removed from the cup and the whole of it is sieved on 2.36 mm I.S. Sieve. The fraction passing the sieve is weighed to an accuracy of 0.1 gm. (weight B). The fraction retained on the sieve is also weighed (weight C). If the total weight (B + C) is less than the initial weight A by more than one gram, the result shall be discarded and a fresh test made. Two tests are made. The ratio of the weight of fines formed to the total sample weight in each test is expressed as percentage.

$$\text{Aggregate impact value} = \frac{B}{A} * 100$$

Where B is the weight of fraction passing 2.36 mm sieve, A is the weight of oven dry sample taken in mold.

IS 283-1970 specifies that aggregate impact value shall not exceed 45 per cent by weight for aggregate used for concrete other than wearing surface and 30 per cent by weight, for concrete for wearing surfaces, such as run ways, roads and pavements.

### **Aggregate abrasion value:**

Testing the aggregate with respect to its resistance to wear is an important test for aggregate to be used for road constructions, ware house floors and pavement construction. Three tests are in common use to test aggregate for its abrasion resistance. (i) Deval attrition test (ii) Dorry abrasion test (iii) Los Angeles test.

### **Deval Attrition Test:**

In the Deval attrition test, particles of known weight are subjected to wear in an iron cylinder

rotated 10000 times at certain speed. The proportion of material crushed finer than 1.7 mm size is expressed as a percentage of the original material taken. This percentage is taken as the attrition value of the aggregate. This test has been covered by IS 2386 (Part IV) – 1963. It is mentioned that, wherever possible, Los angeles test should be used.

#### **Dorry Abrasion Test:**

This test is not covered by Indian Standard Specification. The test involves in subjecting a cylindrical specimen of 25 cm height and 25 cm diameter to the abrasion against rotating metal disk sprinkled with quartz sand. The loss in weight of the cylinder after 1000 revolutions of the table is determined. The hardness of the rock sample is expressed in an empirical formula

$$\text{Hardness} = 20 - (\text{Loss in Grams})/3$$

Good rock should show an abrasion value of not less than 17. A rock sample with a value of less than 14 would be considered poor.

#### **Los Angeles Test**

Indian Standard 2386 (Part IV) of 1963 describes Los Angeles test.

The applicability of the method to all types of commonly used aggregate makes this method popular.

The following table gives the details of charge which consists of cast iron spheres or steel spheres approximately 48 mm in diameter and each weighing between 390 to 445 gm.

<i>Grading</i>	<i>Number of spheres</i>	<i>Weight of charge (gm)</i>
<i>A</i>	12	5000 ± 25
<i>B</i>	11	4584 ± 25
<i>C</i>	8	3330 ± 20
<i>D</i>	6	2500 ± 15
<i>E</i>	12	5000 ± 25
<i>F</i>	12	5000 ± 25
<i>G</i>	12	5000 ± 25

The test sample consist of clean aggregate which has been dried in an oven at 105°C to 110°C and it should conform to one of the grading shown in Table below:

Test sample and abrasive charge are placed in the Los Angeles Abrasion testing machine and the machine is rotated at a speed of 20 to 33 revolutions/min. For grading A, B, C and D, the machine is rotated for 500 revolutions. For grading E, F and G, it is rotated 1000 revolutions.

Sieve Size		Weight in gm. of Test Sample For Grade						
Passing	Retained on	A	B	C	D	E	F	G
mm	mm							
80	63	.	.	.	.	2500	.	.
63	50	.	.	.	.	2500	.	.
50	40	.	.	.	.	5000	5000	.
40	25	1250	.	.	.	.	5000	5000
25	20	1250	.	.	.	.	.	5000
20	12.5	1250	2500	.	.	.	.	.
12.5	10	1250	2500	.	.	.	.	.
10	6.3	.	.	2500	.	.	.	.
6.3	4.75	.	.	2500	.	.	.	.
4.75	2.36	.	.	.	5000	.	.	.

At the completion of the above number of revolution, the material is discharged from the machine and a preliminary separation of the sample made on a sieve coarser than 1.7 mm IS Sieve. Finer portion is then sieved on a 1.7 mm IS Sieve. The material coarser than 1.7 mm IS sieve is washed, dried in an oven at 105° to 110°C to a substantially constant weight and accurately weighed to the nearest gram. The difference between the original weight and the final weight of the test sample is expressed as a percentage of the original weight of the test sample.

The loss in weight expressed as percentage of the original weight taken gives the abrasion value of the aggregate. The percentage of wear should not be more than 16 per cent for concrete aggregates. The abrasion value should not be more than 30 per cent for wearing surfaces and not more than 50 per cent for concrete other than wearing surface.

### **Bulk Density:**

The bulk density or unit weight of an aggregate gives valuable information regarding the shape and grading of the aggregate. For a given specific gravity, the angular aggregates show a lower bulk density. The bulk density of aggregate is measured by filling a container of known volume in a standard manner and weighing it. Bulk density shows how densely the aggregate is packed when filled in a standard manner. The bulk density depends on the particle size distribution and shape of the particles.

The higher the bulk density, the lower is the void content to be filled by sand and cement. The sample which gives the minimum voids or the one which gives maximum bulk density is taken



as the right sample of aggregate for making economical mix.

The method of determining bulk density also gives the method for finding out void content in the sample of aggregate. For determination of bulk density, the aggregates are filled in the container and then they are compacted in a standard manner. The weight of the aggregate gives the bulk density calculated in kg/litre or kg/m<sup>3</sup>. Knowing the specific gravity of the aggregate in saturated and surface-dry condition, the void ratio can also be calculated

$$\text{Percentage voids} = \frac{G_s - \gamma}{G_s} \times 100$$

where  $G_s$  = specific gravity of the aggregate and  $\gamma$  = bulk density in kg/liter.

### **Specific Gravity:**

In concrete technology, specific gravity of aggregates is made use of in design calculations of concrete mixes. Specific gravity of aggregate is also required in calculating the compacting factor in connection with the workability measurements.

Average specific gravity of the rocks vary from 2.6 to 2.8.

### **Absorption and Moisture Content:**

Some of the aggregates are porous and absorptive. Porosity and absorption of aggregate will affect the water/cement ratio and hence the workability of concrete. The porosity of aggregate will also affect the durability of concrete when the concrete is subjected to freezing and thawing and also when the concrete is subjected to chemically aggressive liquids.

The water absorption of aggregate is determined by measuring the increase in weight of an oven dry sample when immersed in water for 24 hours. The ratio of the increase in weight to the weight of the dry sample expressed as percentage is known as absorption of aggregate. Aggregate absorbs water in concrete and thus affects the workability and final volume of concrete. The rate and amount of absorption within a time interval equal to the final set of the cement will only be a significant factor rather than the 24 hours absorption of the aggregate.

The absorption capacity of the coarse aggregate is of the order of about 0.5 to 1 per cent by weight of aggregate.

The natural fine aggregates often contain free moisture anything from one to ten per cent or more.

In case of weigh batching, determination of free moisture content of the aggregate is necessary and then correction of water/cement ratio to be effected in this regard. But when volume

batching is adopted, the determination of moisture content of fine aggregate does not become necessary but the consequent bulking of sand and correction of volume of sand to give allowance for bulking becomes necessary.

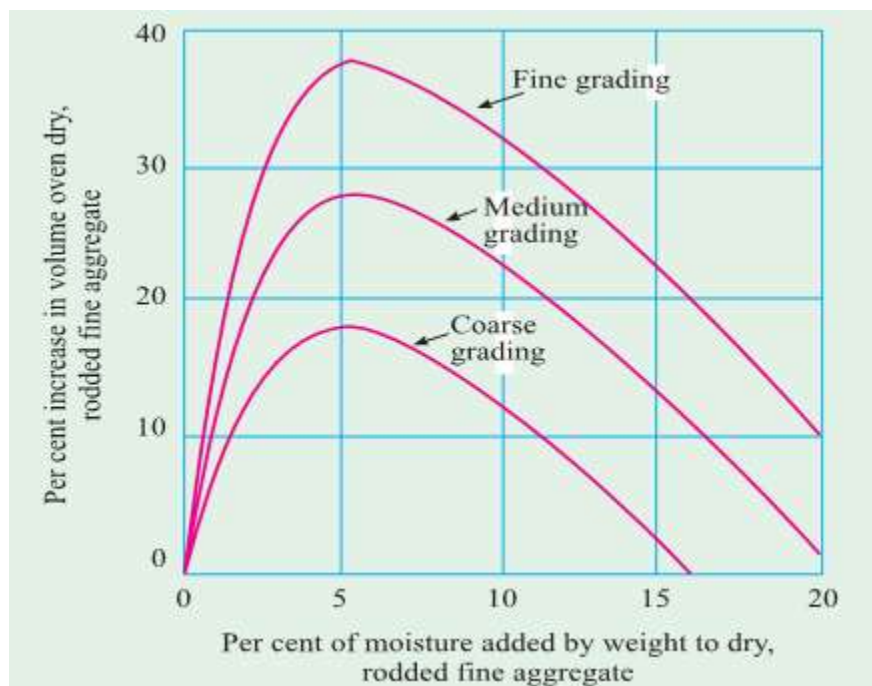
### **Bulking of Aggregates:**

Free moisture content in fine aggregate results in bulking of volume. Bulking phenomenon can be explained as follows:

Free moisture forms a film around each particle. This film of moisture exerts what is known as surface tension which keeps the neighboring particles away from it. Similarly, the force exerted by surface tension keeps every particle away from each other. Therefore, no point contact is possible between the particles. This causes bulking of the volume. The extent of surface tension and consequently how far the adjacent particles are kept away will depend upon the percentage of moisture content and the particle size of the fine aggregate.

Bulking increases with the increase in moisture content upto a certain limit and beyond that the further increase in the moisture content results in the decrease in the volume and at a moisture content representing saturation point, the fine aggregate shows no bulking.

Fine sand bulks more and coarse sand bulks less. From this it follows that the coarse aggregate also bulks but the bulking is so little that it is always neglected. Extremely fine sand and particularly the manufactured fine aggregate bulks as much as about 40 per cent



The extent of bulking can be estimated by a simple field test. A sample of moist fine aggregate is filled into a measuring cylinder in the normal manner. Note down the level, say  $h_1$ . Pour water into the measuring cylinder and completely inundate the sand and shake it. Since the volume of the saturated sand is the same as that of the dry sand, the inundated sand completely offsets the bulking effect. Note down the level of the sand say,  $h_2$ . Then  $h_1 - h_2$  shows the bulking of the sample of sand under test.

$$\text{Percentage of bulking} = \frac{h_1 - h_2}{h_2} \times 100$$

**Cleanliness:**

The concrete aggregates should be free from impurities and deleterious substances which are likely to interfere with the process of hydration, prevention of effective bond between the aggregates and matrix. The impurities sometimes reduce the durability of the aggregate.

The organic matters will interfere with the setting action of cement and also interfere with the bond characteristics with the aggregates. The presence of moss or algae will also result in entrainment of air in the concrete which reduces its strength.

To determine organic matter in sand, the sample of sand is mixed with a liquid containing 3 per cent solution of sodium hydroxide in water. It is kept for 24 hours and the colour developed is compared with a standard colour card. If the colour of the sample is darker than the standard colour card, it is inferred that the content of the organic impurities in the sand is more than the permissible limit. In that case either the sand is rejected or is used after washing.

**Soundness of Aggregate:**

Soundness refers to the ability of aggregate to resist excessive changes in volume as a result of changes in physical conditions. These physical conditions that affect the soundness of aggregate are the freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions and wetting and drying in salt water. Aggregates which are porous, weak and containing any undesirable extraneous matters undergo excessive volume change when subjected to the above conditions. Aggregates which undergo more than the specified amount of volume change are said to be unsound aggregates. If concrete is liable to be exposed to the action of frost, the coarse and fine aggregate which are going to be used should be subjected to soundness test.

The soundness test consists of alternative immersion of carefully graded and weighed test sample

in a solution of sodium or magnesium sulphate and oven drying it under specified conditions. The accumulation and growth of salt crystals in the pores of the particles is thought to produce disruptive internal forces similar to the action of freezing of water or crystallization of salt. Loss in weight, is measured for a specified number of cycles. Soundness test is specified in IS 2386 (Part V). As a general guide, it can be taken that the average loss of weight after 10 cycles should not exceed 12 per cent and 18 per cent when tested with sodium sulphate and magnesium sulphate respectively.

A low loss of weight is an evidence of good durability, whereas a high loss of weight places the aggregate in questionable category.

### **Alkali Aggregate Reaction:**

Some of the aggregates contain reactive silica, which reacts with alkalis present in cement i.e., sodium oxide and potassium oxide. The reaction starts with attack on the reactive siliceous minerals in the aggregate by the alkaline hydroxide derived from the alkalies in cement. As a result, the alkali silicate gels of unlimited swelling type are formed. It is interesting to note that only such aggregates which contain reactive silica in particular proportion and in particular fineness are found to exhibit tendencies for alkali-aggregates reaction. It is possible to reduce its tendency by altering either the proportion of reactive silica or its fineness.

Factors Promoting the Alkali-Aggregate Reaction are:

- (i) Reactive type of aggregate; (ii) High alkali content in cement;
- (iii) Availability of moisture; (iv) Optimum temperature conditions.

(i) Mortar Bar Expansion Test devised by Stanton has proved to be a very reliable test in assessing the **reactivity or otherwise of the aggregate**. A specimen of size 25 mm x 25 mm and 250 mm length is cast, cured and stored in a standard manner as specified in IS : 2386 (Part VII 1963). Measure the length of the specimen periodically, at the ages of 1, 2, 3, 6, 9, and 12 months. Find out the difference in the length of the specimen to the nearest 0.001 per cent and record the expansion of the specimen. The aggregate under test is considered harmful if it expands more than 0.05 per cent after 3 months or more than 0.1 per cent after six months.

(ii) High Alkali Content in Cement:

The high alkali content in cement is one of the most important factors contributing to the alkali-aggregate reaction. Many specifications restrict the alkali content expressed as Na<sub>2</sub>O equivalent (Na<sub>2</sub>O + 0.658 K<sub>2</sub>O) to less than 0.6 per cent. Cement meeting this specification is designated as

low alkali cement. Field experience has never detected serious deterioration of concrete through the process of alkali-aggregate reaction when cement contained alkalies less than 0.6 per cent.

(iii) Availability of Moisture:

Progress of chemical reactions involving alkali-aggregate reaction in concrete requires the presence of water. It has been seen in the field and laboratory that lack of water greatly reduces this kind of deterioration. Therefore, alkali-aggregate reaction will not occur in the interior of mass concrete. The deterioration will be more on the surface. It is suggested that reduction in deterioration due to alkali-aggregate reaction can be achieved by the application of waterproofing agents to the surface of the concrete with a view to preventing additional penetration of water into the structure.

(iv) Temperature Condition:

The ideal temperature for the promotion of alkali-aggregate reaction is in the range of 10 to 38°C. If the temperatures condition is more than or less than the above, it may not provide an ideal situation for the alkali-aggregate reaction.

**Control of Alkali-Aggregate Reaction:**

Alkali-aggregate reaction can be controlled by the following methods:

- (i) Selection of non-reactive aggregates;
- (ii) By the use of low alkali cement;
- (iii) By the use of corrective admixtures such as pozzolanas;
- (iv) By controlling the void space in concrete;
- (v) By controlling moisture condition and temperature.

**Grading of aggregates:**

One of the most important factors for producing workable concrete is good gradation of aggregates. Good grading implies that a sample of aggregates contains all standard fractions of aggregate in required proportion such that the sample contains minimum voids. A sample of the well graded aggregate containing minimum voids will require minimum paste to fill up the voids in the aggregates. Minimum paste will mean less quantity of cement and less quantity of water, which will further mean increased economy, higher strength, lower-shrinkage and greater durability.

One of the practical methods of arriving at the practical grading by trial and error method is to mix aggregates of different size fractions in different percentages and to choose the one sample

which gives maximum weight or minimum voids per unit volume, out of all the alternative samples.

### **Sieve analysis:**

Sieve analysis is conducted to determine the particle size distribution in a sample of aggregate, which is called gradation.

The aggregates used for making concrete are normally of the maximum size 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 600 micron, 300 micron and 150 micron. The aggregate fraction from 80 mm to 4.75 mm is termed as coarse aggregate and those fractions from 4.75 mm to 150 micron are termed as fine aggregate.

In sieve analysis, sieves are placed one over the other in order of size with larger sieve on the top. Sieving can be done either manually or mechanically.

In the manual operation the sieve is shaken giving movements in all possible direction to give chance to all particles for passing through the sieve. Operation should be continued till such time that almost no particle is passing through. Mechanical devices are actually designed to give motion in all possible direction. It is more systematic and efficient than hand-sieving.

**Table 3.8. Minimum weight of sample for Sieve Analysis  
(IS: 2386 (Part I) – 1963)**

<i>Maximum size present in substantial proportions</i>	<i>Minimum weight of sample to be taken for sieving</i>
mm	kg
63	50
50	35
40 or 31.5	15
25	5
20 or 16	2
12.5	1
10	0.5
6.3	0.2
4.75	0.2
2.36	0.1

Fineness modulus (FM) is a term used to denote coarseness or fineness of the material. FM is also obtained from sieve analysis of aggregates.

Fineness modulus is an empirical factor obtained by adding the cumulative percentages of

aggregate retained on each of the standard sieves ranging from 80 mm to 150 micron and dividing this sum by an arbitrary number 100. The larger the figure, the coarser is the material.

FM is used in relation to fine aggregates only.

Fine sand	:	Fineness Modulus	:	2.2 - 2.6
Medium sand	:	F.M.	:	2.6 - 2.9
Coarse sand	:	F.M.	:	2.9 - 3.2

Sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

**Table 3.9. The typical Example of the Sieve Analysis**

IS Sieve Size	Coarse Aggregate				Fine Aggregate			
	Weight retained weight kg	Cumulative weight retained kg	Cumulative percentage retained	Cumulative percentage passing	Weight retained gm	Cumulative weight retained gm	Cumulative percentage weight retained	Cumulative percentage passing
80 mm	0	0	0	100	-	-	-	-
40 mm	0	0	0	100	-	-	-	-
20 mm	6	6	40	60	-	-	-	-
10 mm	5	11	73.3	26.7	0	0	0	100
4.75 mm	4.0	15.00	100	00	10	10	2	98
2.36 mm	-	-	100	00	50	60	12	88
1.18 mm	-	-	100	00	50	110	22	78
600 micron	-	-	100	00	95	205	41	59
300 micron	-	-	100	00	175	380	76	24
150 micron	-	-	100	00	85	465	93	7
lower than 150 micron	-	-	-	00	35	500	-	-
Total	15 kg	-	713.3	-	500 gm	-	246	-
F.M. = $\frac{713.3}{100} = 7.133$					F.M. = $\frac{246}{100} = 2.46$			

Aggregates are often mixed together to obtain required gradation. Sometimes two or more fractions of coarse aggregate are mixed first and then the combined coarse aggregate is mixed with fine aggregate to obtain the desired grading.

Sand is divided into 4 zones like zone 1, zone 2, zone 3 and zone 4 depending on the percentage of material passing through the sieves.



**Table 3.14. Grading Limits for Coarse Aggregate IS: 383-1970**

IS Sieve Designation	Percentage passing for single sized aggregate nominal size (by weight)						Percentage passing for Graded aggregate of nominal size (by weight)			
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	—	—	—	—	—	100	—	—	—
63 mm	85-100	100	—	—	—	—	—	—	—	—
40 mm	0-30	85-100	100	—	—	—	95-100	100	—	—
20 mm	0-5	0-20	85-100	100	—	—	30-70	95-100	100	100
16 mm	—	—	—	85-100	100	—	—	—	90-100	—
12.5 mm	—	—	—	—	85-100	100	—	—	—	90-100
10 mm	—	0-5	0-20	0-30	0-45	85-100	10-35	25-55	30-70	40-85
4.75 mm	—	—	0-5	0-5	0-10	0-20	0-5	0-10	0-10	0-10
2.36 mm	—	—	—	—	—	0-5	—	—	—	—

**Table 3.15. Grading limits of fine aggregates IS: 383-1970**

I.S. Sieve Designation	Percentage passing by weight for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

**Table 3.16. Grading limits of all-in-aggregates**

<i>I.S. Sieve Designation</i>	<i>Percentage by weights passing for all in-aggragate of</i>	
	<i>40 mm Nominal size</i>	<i>20 mm Nominal size</i>
80 mm	100	-
40 mm	95-100	100
20 mm	45-75	95-100
4.75 mm	25-45	30-50
600 micron	8-30	10-35
150 micron	0-6	0-6

Experience has shown that usually very coarse sand or very fine sand is unsatisfactory for concrete making. The coarse sand results in harshness bleeding and segregation, and the fine sand requires a comparatively greater amount of water to produce the necessary fluidity.

### Testing of aggregates

#### Test for Determination of Flakiness Index

The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm. The test is not applicable to sizes smaller than 6.3 mm. This test is conducted by using a metal thickness gauge. A sufficient quantity of aggregate is taken such that a minimum number of 200 pieces of any fraction can be tested. Each fraction is gauged in turn for thickness on the metal gauge. The total amount passing in the guage is weighed to an accuracy of 0.1 per cent of the weight of the samples taken. The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.

**Table 3.18. Shows Dimensions of Thickness and Length Gauges (IS: 2386 (Part I) – 1963)**

<i>Size of Aggregate Thickness</i>		<i>Length of Gauge* mm</i>	<i>Gauget mm</i>
<i>Passing through IS Sieve</i>	<i>Retained on IS Sieve</i>		
63 mm	50 mm	33.90	-
50 mm	40 mm	27.00	81.0
40 mm	25 mm	19.50	58.5
31.5 mm	25 mm	16.95	-
25 mm	20 mm	13.50	40.5
20 mm	16 mm	10.80	32.4
16 mm	12.5 mm	8.55	25.6
12.5 mm	10.0 mm	6.75	20.2
10.0 mm	6.3 mm	4.89	14.7

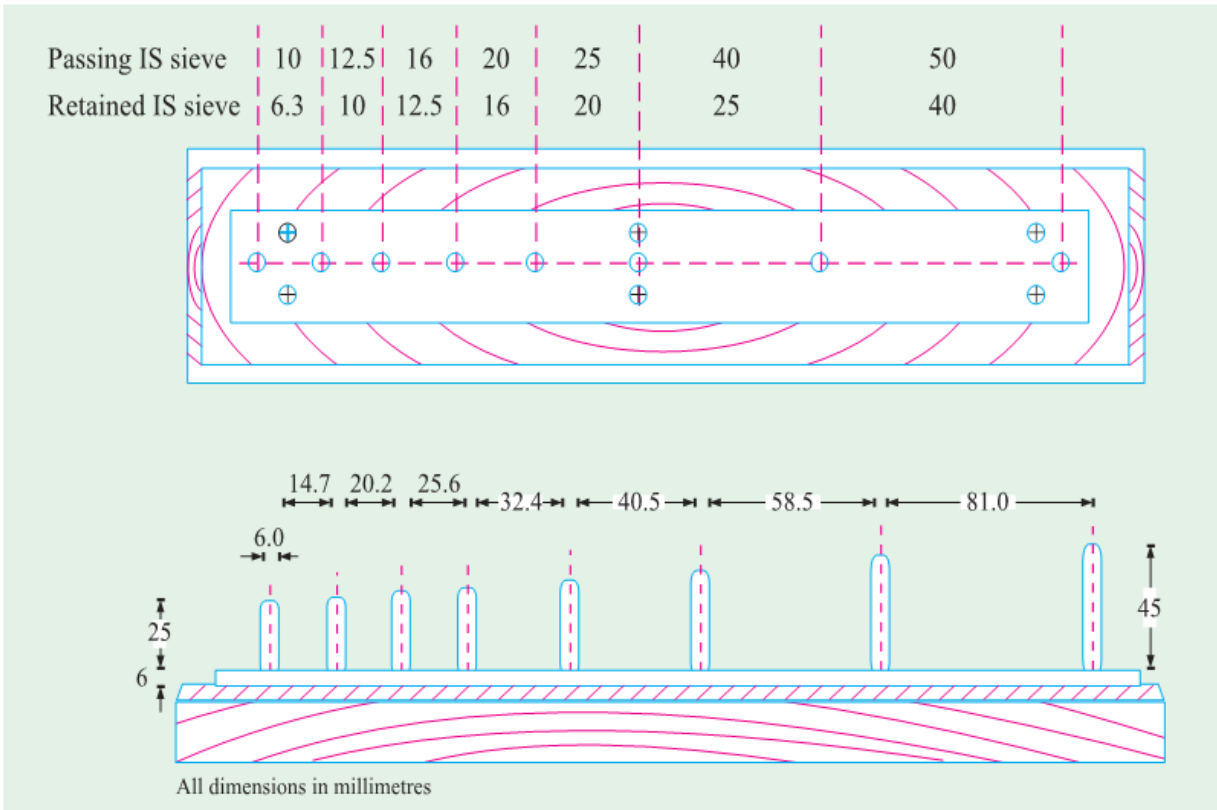
\* This dimension is equal to 0.6 times the mean Sieve size.

† This dimension is equal to 1.8 times the mean Sieve size.

### Test for Determination of Elongation Index:

The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension. The elongation index is not applicable to sizes smaller than 6.3 mm.

This test is conducted by using metal length gauge as shown below.



A sufficient quantity of aggregate is taken to provide a minimum number of 200 pieces of any fraction to be tested. Each fraction shall be gauged individually for length on the metal gauge. The gauge length used shall be that specified in column of 4 of Table 3.18 for the appropriate size of material. The total amount retained by the gauge length shall be weighed to an accuracy of at least 0.1 per cent of the weight of the test samples taken. The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable.



Length Gauge.

## Water

Carbonates and bi-carbonates of sodium and potassium effect the setting time of cement. While sodium carbonate may cause quick setting, the bi-carbonates may either accelerate or retard the setting.

Salts of Manganese, Tin, Zinc, Copper and Lead cause a marked reduction in strength of concrete. Sodium iodate, sodium phosphate, and sodium borate reduce the initial strength of concrete to an extra-ordinarily high degree. Another salt that is detrimental to concrete is sodium sulphide and even a sulphide content of 100 ppm warrants testing. Silts and suspended particles are undesirable as they interfere with setting, hardening and bond characteristics. A turbidity limit of 2,000 ppm has been suggested.

The table below shows the tolerable concentration of some impurities in mixing water.

**Table 4.1. Tolerable Concentrations of Some Impurities in Mixing Water**

Impurity	Tolerable Concentration
Sodium and potassium carbonates and bi-carbonates	1,000 ppm (total). If this is exceeded, it is advisable to make tests both for setting time and 28 days strength.
Chlorides	10,000 ppm.
Sulphuric anhydride	3,000 ppm.
Calcium chloride	2 per cent by weight of cement in non-pre-stressed concrete.
Sodium iodate, sodium sulphate, sodium arsenate, sodium borate	very low.
Sodium sulphide	Even 100 ppm warrants testing.
Sodium hydroxide	0.5 per cent by weight of cement, provided quick set is not induced.
Silt and suspended particles	2,000 ppm. Mixing water with a high content of suspended solids should be allowed to stand in a settling basin before use.
Total dissolved salts	15,000 ppm.
Organic material	3,000 ppm. Water containing humic acid or such organic acids may adversely affect the hardening of concrete: 780 ppm. of humic acid are reported to have seriously impaired the strength of concrete. In the case of such waters therefore, further testing is necessary.
pH	shall not be less than 6.

The initial setting time of the test block made with a cement and the water proposed to be used shall not differ by  $\pm 30$  minutes from the initial setting time of the test block made with same cement and distilled water.

**Table 4.2. Permissible limit for solids as per IS 456 of 2000**

Material	Tested as per	Permissible limit Max.
Organic	IS 3025 (pt 18)	200 mg/l
Inorganic	IS 3025 (pt 18)	3000 mg/l
Sulphates (as $\text{SO}_3$ )	IS 3025 (pt 24)	400 mg/l
Chlorides (as Cl)	IS 3025 (pt 32)	2000 mg/l for concrete work not containing embedded steel and 500 mg/l for reinforced concrete work
Suspended	IS 3025 (pt 17)	2000 mg/l

### Admixtures:

Admixture is defined as a material, other than cement, water and aggregates that is used as an ingredient of concrete and is added to the batch immediately before or during mixing. Additive can also be a material which is added at the time of grinding cement clinker at the cement factory.

These days concrete is being used for wide varieties of purposes to make it suitable in different conditions. In these conditions ordinary concrete may fail to exhibit the required quality performance or durability. In such cases, admixture is used to modify the properties of ordinary concrete so as to make it more suitable for any situation.

The following admixtures are studied in this topic:

- i) Plasticizers
- ii) Superplasticizers
- iii) Retarders and Retarding Plasticizers
- iv) Accelerators and Accelerating Plasticizers
- v) Air-entraining Admixtures
- vi) Pozzolanic or Mineral Admixtures
- vii) Damp-proofing and Waterproofing Admixtures
- viii) Gas forming Admixtures

- ix) Air-detraining Admixtures
- x) Alkali-aggregate Expansion Inhibiting Admixtures
- xi) Workability Admixtures
- xii) Grouting Admixtures
- xiii) Corrosion Inhibiting Admixtures
- xiv) Bonding Admixtures
- xv) Fungicidal, Germicidal, Insecticidal Admixtures
- xvi) Colouring Admixtures

**Plasticizers (Water Reducers):**

The use of super-plasticizer has become almost an universal practice to reduce water/cement ratio for the given workability, which naturally increases the strength. Moreover, the reduction in water/cement ratio improves the durability of concrete. Calcium, sodium and ammonium lignosulphonates are the mostly used plasticizers. Plasticizers are used in the amount of 0.1% to 0.4% by weight of cement. At these doses, at constant workability the reduction in mixing water is expected to be of the order of 5% to 15%. This naturally increases the strength. The increase in workability that can be expected, at the same w/c ratio, may be anything from 30 mm to 150 mm slump.

**Retarders:**

A retarder is an admixture that slows down the chemical process of hydration so that concrete remains plastic and workable for a longer time than concrete without the retarder. Calcium sulphate (gypsum) is the most commonly used retarder. In addition to gypsum there are number of other materials found to be suitable for this purpose. They are: starches, cellulose products, sugars, acids or salts of acids. Other admixtures which have been successfully used as retarding agents are Lignosulphonic acids and their salts, hydroxylated carboxylic acids and their salts which in addition to the retarding effect also reduce the quantity of water requirement for a given workability.

**Accelerators:**

Accelerators are added to concrete to increase the rate of early strength development in concrete to

- i) permit earlier removal of formwork;
- ii) reduce the required period of curing;

- iii) advance the time that a structure can be placed in service;
- iv) in the emergency repair work.

Calcium chloride, some of the soluble carbonates, silicates fluosilicates and some of the organic compounds such as triethenolamine are commonly used accelerators.

#### **Air-entraining Admixture:**

Air entrained concrete is made by mixing a small quantity of air entraining agent or by using air entraining cement. These air entraining agents incorporate millions of non-coalescing air bubbles, which will act as flexible ball bearings and will modify the properties of plastic concrete regarding workability, segregation, bleeding and finishing quality of concrete. It also modifies the properties of hardened concrete regarding its resistance to frost action and permeability.

The following types of air entraining agents are used for making air entrained concrete.

- (a) Natural wood resins
- (b) Animal and vegetable fats and oils, such as tallow, olive oil and their fatty acids such as stearic and oleic acids.
- (c) Various wetting agents such as alkali salts or sulphated and sulphonated organic compounds.

#### **Pozzolan or Mineral Admixtures:**

Best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

- (a) Lower the heat of hydration and thermal shrinkage;
- (b) Increase the watertightness;
- (c) Reduce the alkali-aggregate reaction;
- (d) Improve resistance to attack by sulphate soils and sea water;
- (e) Improve extensibility;
- (f ) Lower susceptibility to dissolution and leaching;
- (g) Improve workability;
- (h) Lower costs.

Pozzolan materials are siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds, possessing cementitious properties.

Examples of Natural Pozzolans are Clay and Shales, Opalinc Cherts, Diatomaceous Earth,



Volcanic Tuffs and Pumicites.

Examples of artificial pozzolans are Fly ash, Blast Furnace Slag, Silica Fume, Rice Husk ash, Metakaoline, Surkhi.