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Part view of Cement Factory

Courtesy : Grasim Industries Cement Division

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Types of Cement and Testing of Cement

In the previous chapter we have discussed various properties of Portland cement in general. We have seen that 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. In the past continuous efforts were made to produce different kinds of cement, suitable for different situations by changing oxide composition and fineness of grinding. 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 to the need of the construction industries for specific purposes. In this chapter we shall deal with the properties and use of various kinds of cement. These cements are classified as Portland cements and non-Portland cements. The distinction is mainly based on the methods of manufacture. The Portland and Non-Portland cements generally used are listed below: Indian standard specification number is also given against these elements.*

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

Before we discuss the above cements, for general information, it is necessary to see how Portland cement are classified under the ASTM (American Society for Testing Materials) standards. 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).

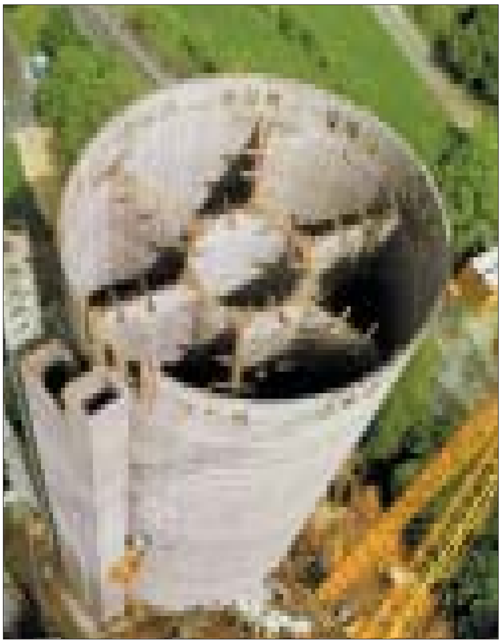
Type IV

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 consist 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.



Cross Section of Multi-compartment Silo for storing different types of cement.

Courtesy : Grasim Industries Cement Division

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 interground where air-entrainment in concrete is desired.

Ordinary Portland Cement

Ordinary Portland cement (OPC) is by far the most important type of cement. All the discussions that we have done in the previous chapter and most of the discussions that are going to be done in the coming chapters relate to OPC. Prior to 1987, there was only one grade of OPC which was governed by IS 269-1976. After 1987 higher grade cements were introduced in India. 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^2, it is called 33 grade cement, if the strength is not less than 43N/mm^2, it is called 43 grade cement, and if the strength is not less then 53 N/mm^2, it is called 53 grade cement. But the actual strength obtained by these cements at the factory are much higher than the BIS specifications.

The physical and chemical properties of 33, 43 and 53 grade OPC are shown in Table 2.5 and 2.6.

It has been possible to upgrade the qualities of cement by using high quality limestone, modern equipments, closer on line control of constituents, maintaining better particle size distribution, finer grinding and better packing. Generally use of high grade cements offer many advantages for making stronger concrete. Although they are little costlier than low grade cement, they offer 10-20% savings in cement consumption and also they offer many other hidden benefits. One of the most important benefits is the faster rate of development *of strength. In the modern construction activities, higher grade cements have become so popular that 33 grade cement is almost out of the market. Table 2.9 shows the grades of cement manufactured in various countries of the world.*

The manufacture of OPC is decreasing all over the world in view of the popularity of blended cement on account of lower energy consumption, environmental pollution, economic and other technical reasons. In advanced western countries the use of OPC has come down to about 40 per cent of the total cement production. In India for the year 1998-99 out of the total cement production i.e., 79 million tons, the production of OPC in 57.00 million tons i.e., 70%. The production of PPC is 16 million tone i.e., 19% and slag cement is 8 million tons i.e., 10%. In the years to come the use of OPC may still come down, but all the same the OPC will remain as an important type for general construction.

The detail testing methods of OPC is separately discribed at the end of this chapter.

Rapid Hardening Cement (IS 8041–1990)

This cement is similar to ordinary Portland cement. As the name indicates it develops strength rapidly and as such it may be more appropriate to call it as high early strength cement. It is pointed out that 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 C_3S and lower C_2S content.

A higher fineness of cement particles expose greater surface area for action of water and also higher proportion of C_3S results in quicker hydration. Consequently, capid 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.

The physical and chemical requirements of rapid hardening cement are shown in Tables 2.5 and 2.6 respectively.

Extra Rapid Hardening Cement

Extra rapid hardening cement is obtained by intergrinding 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.

There is some evidence that there is small amount of initial corrosion of reinforcement when extra rapid hardening cement is used, but in general, this effect does not appear to be progressive and as such there is no harm in using extra rapid hardening cement in reinforced concrete work. However, its use in prestress concrete construction is prohibited.

In Russia, the attempt has been made to obtain the extra rapid hardening property by grinding the cement to a very fine degree to the extent of having a specific surface between 5000 to 6000 sq. cm/gm. The size of most of the particles are generally less than 3 microns[2.1]. It is found that this very finely ground cement is difficult to store as it is liable to air-set. It is not a common cement and hence it is not covered by Indian standard.

Sulphate Resisting Cement (IS 12330–1988)

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 hadened cement paste results in cracks and subsequent disruption. Solid sulphate 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 C_3A content is found to be effective. Such cement with low C_3A and comparatively low C_4AF content is known as Sulphate Resisting Cement. In other words, this cement has a high silicate content. The specification generally limits the C_3A content to 5 per cent.

Tetracalcium Alumino Ferrite (C_3AF) varies in Normal Portland Cement between to 6 to 12%. Since it is often not feasible to reduce the Al_2O_3 content of the raw material, Fe_2O_3 may be added to the mix so that the C_4AF content increases at the expense of C_3A. IS code limits the total content of C_4AF and C_3A, as follows.

$$2C_3A + C_4AF \text{ should not exceed } 25\%.$$

In many of its physical properties, sulphate resisting cement is similar to ordinary Portland cement. 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;

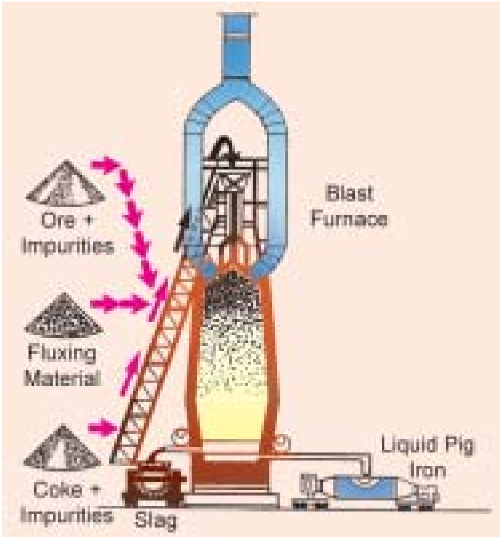
(c) Concrete used for fabrication of pipes which are likely to be buried in marshy region or sulphate bearing soils;

(d) Concrete to be used in the construction of sewage treatment works.

Portland Slag Cement (PSC) (IS 455–1989)

Portland slag cement is obtained by mixing Portland cement clinker, gypsum and *granulated blast furnace slag 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. The resultant product is a cement which has physical properties similar to those of ordinary Portland cement. In addition, 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 with advantage.*

The manufacture of blast furnace slag cement has been developed primarily to utilize blast furnace slag, a waste product from blast furnaces. The development of this type of cement has considerably increased the total output of cement production in India and has, in addition, provided a scope for profitable use for an otherwise waste product. During 98-99 India produced 10% slag cement out of 79 million tons.



Schematic representation of production of blast furnace slag.

The quantity of granulated slag mixed with portland clinker will range from 25-65 per cent. In different countries this cement is known in different names. The quantity of slag mixed also will vary from country to country the maximum being upto 85 per cent. Early strength is mainly due to the cement clinker fraction and later strength is that due to the slag fraction. Separate grinding is used as an easy means of verying the slag clinker proportion in the finished cement to meet the market demand. Recently, under Bombay Sewage disposal project at Bandra, they have used 70% ground granulated blast furnace slag (GGBS) and 30% cement for making grout to fill up the trench around precast sewer 3.5 m dia embedded 40 m below MSL.

Portland blast furnace cement is similar to ordinary Portland cement with respect to fineness, setting time, soundness and strength. It is generally recognised that 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, so that at 12 months the strength becomes close to or even exceeds those of Portland cement. The heat of hydration of Portland blast furnace cement is lower than that of ordinary Portland cement. So this cement can be used in mass concrete structures with advantage. However, in cold weather the low heat of hydration of Portland blast furnace cement coupled with moderately low rate of strength development, can lead to frost damage.

Extensive research shows that the presence of GGBS leads to the enhancement of the intrinsic properties of the concrete both in fresh and hardened states. The major advantages currently recognised are:

(a) Reduced heat of hydration;

(b) Refinement of pore structure;

(c) Reduced permeability;

(*d*) Increased resistance to chemical attack.

It is seen that in India when the Portland blast furnace slag cement was first introduced it met with considerable suspicion and resistance by the users. This is just because some manufacturers did not use the right quality of slag. It has been pointed out that only glassy granulated slag could be used for the manufacture of slag cement. Air-cooled crystallined slag cannot be used for providing cementitious property. The slag which is used in the manufacture of various slag cement is chilled very rapidly either by pouring it into a large body of water or by subjecting the slag stream to jets of water, or of air and water. The purpose is to cool the slag quickly so that crystallisation is prevented and it solidifies as glass. The product is called granulated slag. Only in this form the slag should be used for slag cement. It the slag prepared in any other form is used, the required quality of the cement will not be obtained.

Portland slag cement exhibits very low diffusivity to chloride ions and such slag cement gives better resistance to corrosion of steel reinforcement.

Table 2. 1. Diffusion of chloride ions at 25°C in cement pastes of w/c 0.5

Type of cement	Diffusivity ($\times 10^{-9}$ cm^2/s)
SRPC*	100.0
OPC	44.7
70% OPC/30% Fly ash	14.7
35% OPC/ 65% GGBS	4.1

SRPC* – Sulphate resisting Portland cement.

Application of GGBS Concrete

In recent years the use of GGBS concrete is well recognised. Combining GGBS and OPC at mixer is treated as equivalent to factory made PSC. Concrete with different properties can be made by varying the proportions of GGBS.

While placing large pours of concrete it is vital to minimise the risk of early age thermal cracking by controlling the rate of temperature rise. One of the accepted methods is through the use of GGBS concrete containing 50% to 90% GGBS. Generally, a combination of 70% GGBS and 30% OPC is recommended. Resistance to chemical attack may be enhanced by using GGBS in concrete. Resistance to acid attack may be improved through the use of 70% GGBS. To counter the problem of sulphate and chloride attack 40% to 70% GGBS may be used. There is a general consensus among concrete technologists that the risk of ASR can be minimised by using at least 50% GGBS. GGBS concrete is also recommended for use in water retaining structures. Aggressive water can affect concrete foundations. In such conditions GGBS concrete can perform better.

Quick Setting Cement

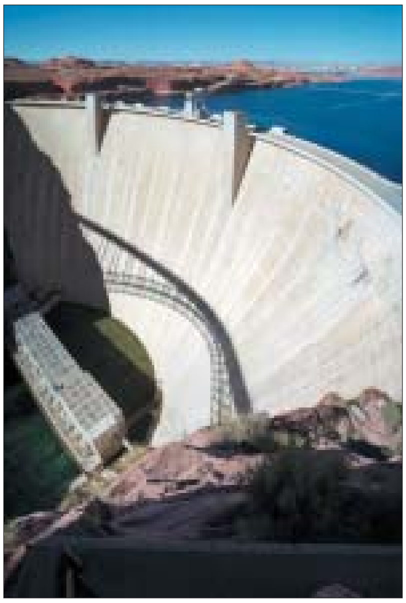
This cement as the name indicates sets very early. The early setting property is brought out by reducing the gypsum content at the time of clinker grinding. This cement is required to be mixed, placed and compacted very early. It is used mostly in under water construction where pumping is involved. Use 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 (IS 6909–1990)

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^2 per gm. The super-sulphated cement is extensively used in Belgium, where it is known as "ciment metallurgique sursulfate." In France, it is known as "ciment sursulfate".

This cement is rather 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. As super-sulphated cement has more resistance than Portland blast furnace slag cement to attack by sea water, it is also used in the marine works. Other areas where super-sulphated cement is recommended include the fabrication of reinforced concrete pipes which are likely to be buried in sulphate bearing soils. The substitution of granulated slag is responsible for better resistance to sulphate attack.

Super-sulphated cement, like high alumina cement, combines with more water on hydration than Portland cements. Wet curing for not less than 3 days after casting is essential as the premature drying out results in an undesirable or powdery surface layer. When we use super sulphated cement the water/cement ratio should not be less than 0.5. A mix leaner than about 1:6 is also not recommended.



Law heat cement is made use of in construction of massive dams.

Low Heat Cement (IS 12600-1989)

It is well known that hydration of cement is an exothermic action which produces large quantity of heat during hydration. This aspect has been discussed in detail in Chapter 1. Formation of cracks in large body of concrete due to heat of hydration has focussed the attention of the concrete technologists to produce a kind of cement which produces less heat or the same amount of heat, at a low rate during the hydration process. Cement having this property was developed in U.S.A. during 1930 for use in mass concrete construction, such as dams, where temperature rise by the heat of hydration can become excessively large. A low-heat evolution is achieved by reducing the contents of C_3S and C_3A which are the compounds evolving the maximum heat of hydration and increasing C_2S. 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 (IS 1489–1991)

The history of pozzolanic material goes back to Roman's time. The descriptions and details of pozzolanic material will be dealt separately under the chapter 'Admixtures'. However a brief description is given below.

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. (It is called pulverised fuel ash in UK). More information on fly ash as a mineral admixture is given in chapter 5.

It may be recalled that 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:

$$\text{Calcium hydroxide} + \text{Pozzolana} + \text{water} \rightarrow C - S - H \ \text{(gel)}$$

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. Portland pozzolana cement can generally be used where ordinary Portland cement is usable. However, it is important to appreciate that the addition of pozzolana does not contribute to the strength at early ages. Strengths similar to those of ordinary Portland cement can be expected in general only at later ages provided the concrete is cured under moist conditions for a sufficient period. In India there is apprehension in the minds of the user to use the Portland pozzolana cement for structural works. It can be said that this fear is not justified. If the Portland pozzolana cement is manufactured by using the right type of reactive pozzolanic material, the Portland pozzolanic cement will not be in any way inferior to ordinary Portland cement except for the rate of development of strength upto 7 days. It is only when inferior pozzolanic materials, which are not of reactive type and which do not satisfy the specifications limit for pozzolanic materials, are used the cement would be of doubtful quality. The advantages of PPC can be summerised as follows.

Technically PPC has considerable advantages over OPC when made by using optimum percentage of right quality of fly ash.

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, alround 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.*

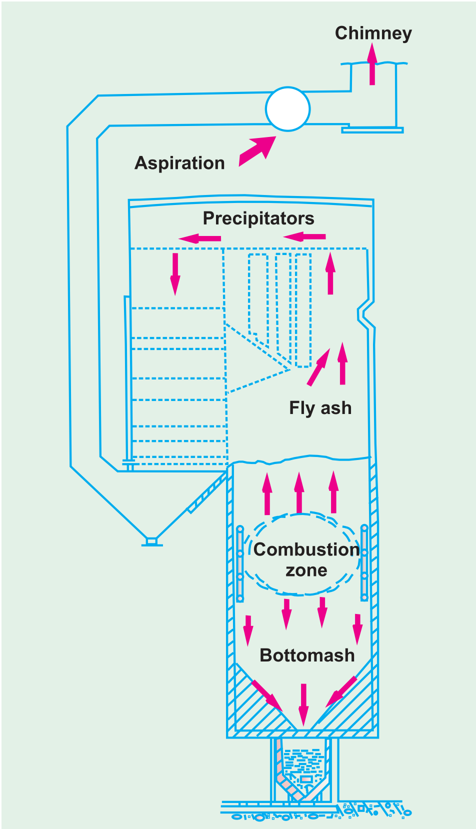
(d) *It generates reduced heat of hydration and that too at a low rate.*

(e) *PPC being finer than OPC and also due to pozzolanic action, it improves the pore size distribution and also reduces the microcracks at the transition zone.*

(f) *Reduction in permeability of PPC offers many other alround advantages.*

(g) *As the fly ash is finer and of lower density, the bulk volume of 50 kg bag is slightly more than OPC. Therefore, PPC gives more volume of mortar than OPC.*

(h) *The long term strength of PPC beyond a couple of months is higher than OPC if enough moisture is available for continued pozzolanic action.*



Schematic representation of the formation of fly ash.

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. It may be noted that due to the dilution and leaching also certain reduction in calcium hydroxide may have taken place. Giving consideration to that effect, the calcium hydroxide should have been 14%. But the fact is that only 8.4% has remained goes to prove that 5.6% of calcium hydroxide was converted by the pozzolanic activity. Fig. 2.1 shows the typical reduction of $Ca(OH)_2$.

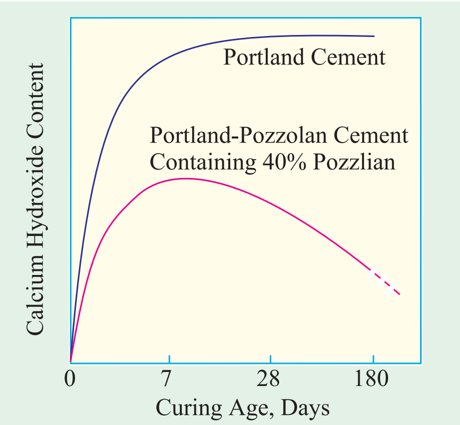


Fig. 2.1. Shows typical reduction of $Ca(OH)_2$

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 considering the fact that PPC significantly improve the permeability of concrete, increases the resistance to corrosion of reinforcement. The setting time is nominally longer.

Status of PPC in India

Over 60 million tones of fly ash is generated from over 75 thermal power stations. But the qualities of such fly ash are generally not satisfactory to be used in PPC. In western countries fly ash generated in thermal power plants are further processed to render it fit for using in PPC. Because of the poor quality of fly ash, lack of awareness and fear psychics on the part of users, PPC is not popular. In India only 19% of total cement production is PPC. (1998-1999) and about 10% is slag cement. Government of India has set up an organisation called Fly Ash mission to promote the use of fly ash as mineral admixture or in manufacturing PPC. It has been realised by all experts in the world that more and more blended cement has to be used for sustainable development of any country.

Due to the shortage of electrical power, many cement factories have their own dedicated thermal power plant. They use their own fly ash for manufacturing PPC. As they know the importance of the qualities of fly ash, they take particular care to produce fly ash of good qualities to be used in PPC. The PPC produced by such cement plant is of superior quality. The chemical and physical qualities of properties of such PPC show much superior values than what is prescribed in BIS standard. The physical and chemical properties of PPC as given in IS: 1489 (part-I) 1991 is given in table 2.5

Birla Plus, Suraksha, Silicate Cement, Birla Bonus are some of the brand names of PPC in India.

Grading of PPC

In many countries, PPC is graded like OPC depending upon their compressive strength at 28 days. In India, so far PPC is considered equivalent to 33 grade OPC, strengthwise, although some brand of PPC is as good as even 53 grade OPC. Many cement manufacturers have requested BIS for grading of PPC just like grading of OPC. They have also requested for upper limits of fly ash content from 25% to 35%. Recently BIS has increased the fly ash content in PPC from 10–25% to 15–35%.

Application

Portland pozzolana cement can be used in all situations where OPC is used except where high early strength is of special requirement. As PPC needs enough moisture for sustained pozzolanic activity, a little longer curing is desirable. Use of PPC would be particularly suitable for the following situations:

(*a*) *For hydraulic structures;*

(*b*) *For mass concrete structures like dam, bridge piers and thick foundation;*

(*c*) *For marine structures;*

(*d*) *For sewers and sewage disposal works etc.*

Air-Entraining Cement

Air-entraining cement is not covered by Indian Standard so far. 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. There are other additives including animal and vegetable fats, oil and their acids could be used. Wetting agents, aluminium powder, hydrogen peroxide could also be used. Air-entraining cement will produce at the time of mixing, tough, tiny, discrete non-coalesceing air bubbles in the body of the concrete which will modify the properties of plastic concrete with respect to workability, segregation and bleeding. It will modify the properties of hardened concrete with respect to its resistance to frost action. Air-entraining agent can also be added at the time of mixing ordinary Portland cement with rest of the ingredients. More about this will be dealt under the chapter "Admixtures."

Coloured Cement (White Cement IS 8042–1989)

For manufacturing various coloured cements either white cement or grey Portland cement is used as a base. The use of white cement as a base is costly. With the use of grey cement only red or brown cement can be produced.

Coloured 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 properties required of a pigment to be used for coloured cement are the durability of colour under exposure to light and weather, a fine state of division, a chemical composition such that the pigment is neither effected by the cement nor detrimental to it, and the absence of soluble salts.

The process of manufacture of white Portland cement is nearly same as OPC. As the raw materials, particularity the kind of limestone required for manufacturing white cement is only available around Jodhpur in Rajasthan, two famous brands of white cement namely Birla White and J.K. White Cements are manufactured near Jodhpur. The raw materials used are high purity limestone (96% $CaCo_3$ 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. The fuels used are refined furnace oil (RFO) or gas. Sea shells and coral can also be used as raw materials for production of white cement.

The properties of white cement is nearly same as OPC. Generally white cement is ground finer than grey cement. Whiteness of white cement as measured by ISI scale shall not be less than 70%. Whiteness can also be measured by Hunters Scale. The value as measured by Hunters scale is generally 90%. The strength of white cement is much higher than what is stated in IS code 8042 of 1989. A typical test result of Birla White is shown in Table 2.2.

Table 2.2. Typical Properties of Birla White Portland Cement[2.2]

Characteristics	IS: 8042. 1989	Birla White
1. CHEMICAL		
a. Insoluble residue %	Max 2.0	0.60
b. Iron Oxide %	Max 1.0	0.20
c. Magnesium Oxide %	Max 6.0	0.80
d. Sulphur Trioxide %	Max 3.0	2.90
e. Alumina/Iron Oxide %	Min 0.66	9.00
f. Lime Saturation Factor	0.66-1.09	0.90
g. Loss on Ignition %		< 3%

2. PHYSICAL		
a. Degree of Whitenesses %		
ISI scale	Min 70	88+
Hunters scale		91+
b. Fineness, Blaine M^2/kg.	Min 225	450*
(Specific Surface)		
c. Setting Time		
1. Intial-minutes	Min 30	80
2. Final-minutes	Max 600	120
d. Compressive Strength		
(Cement and Std. Sand Mortar 1:3)		
3 days (Mpa)	Min 14.4	45
7 days (Mpa)	Min 19.8	55
28 days (Mpa)	Min 29.7	67
e. Soundness		
1. Lechateliers method (mm)	Max 10	1.00
2. Autoclave expansion %	Max 0.8	Negligible
f. Retention of 63 micron sieve %	—	1.00

Hydrophobic cement (IS 8043-1991)

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 unfavourable 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. In India certain places such as Assam, Shillong etc., get plenty of rainfall in the rainy season had have high humidity in other seasons. The transportation and storage of cement in such places cause deterioration in the quality of cement. In such far off places with poor communication system, cement perforce requires to be stored for long time. Ordinary cement gets deteriorated and loses some if its strength, whereas the hydrophobic cement which does not lose strength is an answer for such situations.

The properties of hydrophobic cement is nearly the same as that ordinary Portland cement except that it entrains a small quantity of air bubbles. 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 transporation. The cost of this cement is nominally higher than ordinary Portland cement.

Masonry Cement (IS 3466 : 1988)

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 so 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 prestress concrete ducts, if shrinks, the purpose for which the grout is used will be to some extent defeated. There has been a search for such type of cement which will not shrink while hardening and thereafter. As a matter of fact, 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. The use of expanding cement requires skill and experience.

One type of expansive cement is known as shrinkage compensating cement. This cement when used in concrete, with restrained expansion, induces compressive stresses which approximately offset the tensile stress induced by shrinkage. Another similar type of cement is known as Self Stressing cement. This cement when used in concrete induces significant compressive stresses after the drying shrinkage has occurred. The induced compressive stresses not only compensate the shrinkage but also give some sort of prestressing effects in the tensile zone of a flexural member.

IRS-T 40 Special Grade Cement

IRS-T-40 special grade cement is manufactured as per specification laid down by ministry of Railways under IRS-T40: 1985. It is a very finely ground cement with high C_3S content designed to develop high early strength required for manufacture of concrete sleeper for Indian Railways. This cement can also be used with advantage for other applications where high early strength concrete is required. This cement can be used for prestressed concrete elements, high rise buildings, high strength concrete.

IRS-T 40 special grade cement was originally made for manufacturing concrete sleeper for railway line.

Oil-Well Cement (IS 8229-1986)

Oil-wells are drilled through stratified sedimentary rocks through a great depth in search of oil. It is likely that if oil is struck, oil or gas may escape through the space between the steel casing and rock formation. Cement slurry is used to seal off the annular space between steel casing and rock strata and also to seal off any other fissures or cavities in the sedimentary rock layer. The cement slurry has to be pumped into position, at considerable depth where the prevailing temperature may be upto 175°C. The pressure required may go upto 1300 kg/cm^2. The slurry should remain sufficiently mobile to be able to flow under these conditions for periods upto several hours and then hardened fairly rapidly. It may also have to resist corrosive conditions from sulphur gases or waters containing dissolved salts. The type of cement suitable for the above conditions is known as Oil-well cement. The desired properties of Oil-well cement can be obtained in two ways: by adjusting the compound composition of cement or by adding retarders to ordinary Portland cement. Many admixtures have been patented as retarders. The commonest agents are starches or cellulose products or acids. These retarding agents prevent quick setting and retains the slurry in mobile condition to facilitate penetration to all fissures and cavities. Sometimes workability agents are also added to this cement to increase the mobility.

Rediset Cement

Acclerating the setting and hardening of concrete by the use of admixtures is a common knowledge. Calcium chloride, lignosulfonates, and cellulose products form the base of some of admixtures. The limitations on the use of admixtures and the factors influencing the end properties are also fairly well known.

High alumina cement, though good for early strengths, shows retrogression of strength when exposed to hot and humid conditions. A new product was needed for use in the precast concrete industry, for rapid repairs of concrete roads and pavements, and slip-forming. In brief, for all jobs where the time and strength relationship was important. In the PCA laboratories of USA, investigations were conducted for developing a cement which could yield high strengths in a matter of hours, without showing any retrogression. Regset cement was the result of investigation. Associated Cement Company of India have developed an equivalent cement by name "REDISET" Cement.

Properties of "Rediset"[2.3]

(i) *The cement allows a handling time of just about 8 to 10 minutes.*
(ii) *The strength pattern of REDISET and regset in mortar and concrete is given below:*

Table 2.3. Compressive Strength MPa[2.3]

	4 hours	24 hours	28 days
ACC "REDISET" mortar, 1:3 mix	20	42	42 (Actual tests)
ACC "REDISET" 1: 5.5 mix concrete	21	25	32 (Actual tests)
USA Regset mortar 1: 2.75 mix	7.0	18	42 (From literature)
USA Regset concrete, 6 bags	9.0	16	42 (From literature)

(*iii*) The strength pattern is similar to that of ordinary Portland cement mortar or concrete after one day or 3 days. What is achieved with "REDISET" in 3 to 6 hours can be achieved with normal concrete only after 7 days.

(*iv*) "REDISET" releases a lot of heat which is advantageous in winter concreting but excess heat liberation is detrimental to mass concrete.

(*v*) The rate of shrinkage is fast but the total shrinkage is similar to that of ordinary Portland cement concrete.

(*vi*) The sulphate resistance, is however, very poor.

Applications

"REDISET" can be used for:

(*a*) very-high-early (3 to 4 hours) strength concrete and mortar,

(*b*) patch repairs and emergency repairs,

(*c*) quick release of forms in the precast concrete products industry,

(*d*) palletisation of iron ore dust,

(*e*) slip-formed concrete construction,

(*f*) construction between tides.

High Alumina Cement (IS 6452 : 1989)

High alumina cement is obtained by fusing or sintering a mixture, in suitable proportions, of alumina and calcareous materials and grinding the resultant product to a fine powder. The raw materials used for the manufacture of high alumina cement are limestone and bauxite. These raw materials with the required proportion of coke were charged into the furnace. The furnace is fired with pulverised coal or oil with a hot air blast. The fusion takes place at a temperature of about 1550-1600°C. The cement is maintained in a liquid state in the furnace. Afterwards the molten cement is run into moulds and cooled. These castings are known as pigs. After cooling the cement mass resembles a dark, fine gey compact rock resembling the structure and hardeness of basalt rock.

The pigs of fused cement, after cooling are crushed and then ground in tube mills to a finess of about 3000 sq. cm/gm.

Hydration of High Alumina Cement

The important reaction during the setting of the high alumina cement (HAC) is the formation of monocalcium aluminate decahydrate (CAH_{10}), dicalcium aluminate octahydrate (C_2AH_8) and alumina gel (AH_n). These aluminates give high strength to HAC concrete but they are metastable and at normal temperature convert gradually to tricalcium alumina hexahydrate (C_3AH_6) and gibbsite which are more stable. The change in composition is accompanised by a loss of strength and by a change in crystal form from hexagonal to cubical form with the release of water which results in increased porosity of concrete. The precise manner in which these changes take place depends on the temperature, water/cement ratio and chemical environment.

The change in composition accompanied by loss of strength and change in crystal form from hexagonal to cubic shape is known as conversion.

Experimental evidence suggests that in the important reaction of the conversion from CAH_{10} to C_3AH_6 and alumina hydrate, temperature effects the decomposition. The higher the temperature, the faster the rate of conversion. Experimental studies have also shown that the *higher the water/cement ratio, the greater is the rate of conversion. The hydration and conversion can be shown as follows:*

$$CA + 10H \longrightarrow CAH_{10}; \qquad ...(1)$$

$$3CA\ H_{10} \longrightarrow C_3AH_6 + 2\ AH_3 + 18H \qquad ...(2)$$

It should be noted that this reaction liberates all the water needed for the conversion process to continue. The conversion reaction will result in a reduction in volume of the solids and an increase in the porosity, since the overall dimensions of specimens of cement paste or concrete remain sensibly constant.

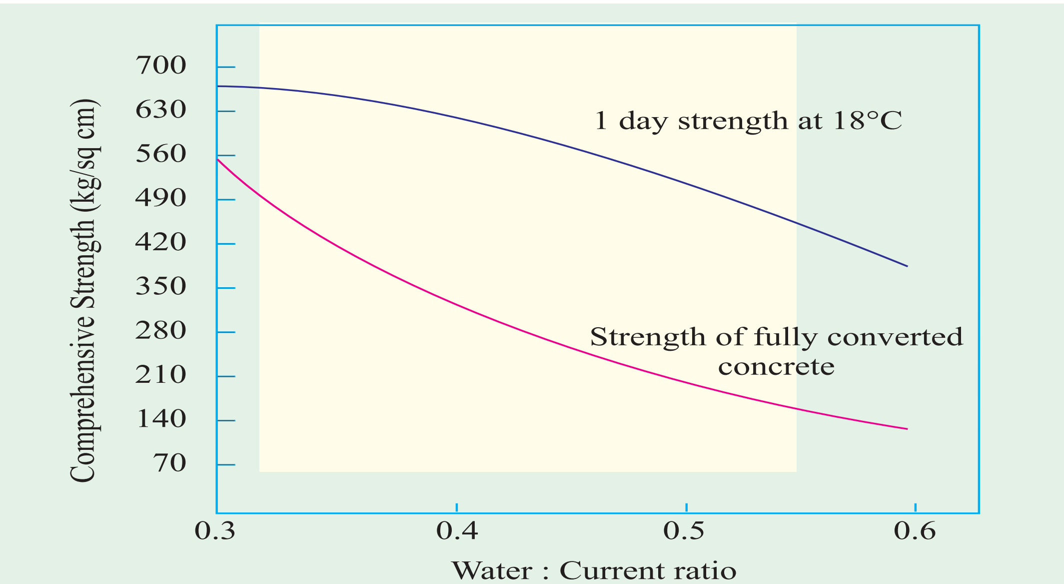
High Alumina Cement Concrete

The use of high alumina cement concrete commenced in the U.K. in 1925 following its introduction in France where it had been developed earlier to make concrete resistant to chemical attack, particularly in marine conditions. The capability of this concrete to develop a high early strength offers advantages in structural use. However, its high cost prevented extensive use of high alumina cement for structural purposes. All the same during 1930's many structures were built in European countries using high alumina cement. Following the collapse of two roof beams in a school at Stepney in U.K. in February 1974, the Building Research Establishment (BRE) of U.K. started field studies and laboratory tests to establish the degree of risk likely in buildings with precast prestressed concrete beams made with high alumina cement. The results of the BRE investigations are summarised below:

1. Measurements of the degree of conversion of the concrete used in the buildings indicated that high alumina cement concrete reaches a high level of conversion within a few years. The concrete specimens cut from beams indicated that some concrete suffered substantial loss of strength when compared to one day strength on which the design was earlier based, (Fig. 2.2).

2. Long term laboratory tests have shown that:

(a) If concrete with a free water/cement ratio less than 0.4 is stored in water at 18°C throughout its initial curing period and its subsequent life, a minimum strength will



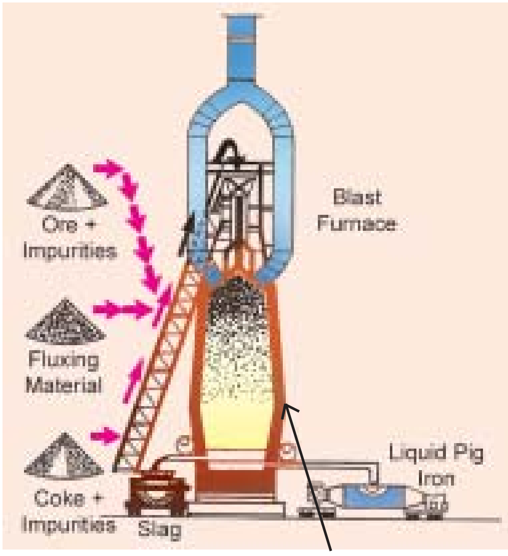
be reached after about 5 years and this minimum will not be appreciably less than the strength at one day.

(*b*) *If concrete is stored in water at 38°C, after one day at 18°C, it converts rapidly to high limit and reaches a minimum strength in about 3 months which is very substantially less than the strength at one day.*

(*c*) *If concrete is stored in water at 18°C for a long period (upto $8^1/_2$ years) and is immersed in water at 38°C it will rapidly convert and lose strength to the minimum level, reached for continuous storage at 38°C.*

(*d*) *Since the temperature at 38°C represents an upper limit of what is likely to be reached during curing of these sections or in normally heated building, and the precise level is not critical, it is recommended that design should be based on the minimum strength at this temperature.*

(*e*) *Highly converted high alumina cement concrete is vulnerable to chemical attack in the presence of long term wetness and a chemically aggressive agent, which may be more serious risk for concretes with greater water/cement ratio.*



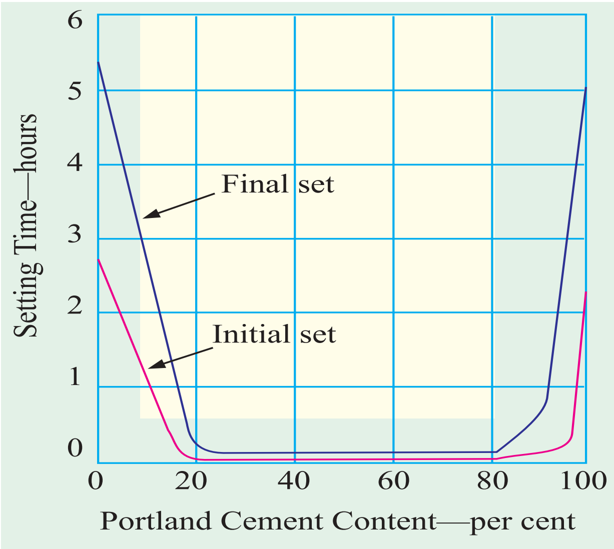
Refractory concrete made with High Alumina cement is used as refactory lining in furnaces and fire pits.

One of the most advantages of high alumina cement concrete is the very high rate of strength development. About 20 per cent of the ultimate strength is achieved in one day. It also achieves a substantial strength even at 6 to 8 hours.

Refractory Concrete

An important use of high alumina cement is for making refractory concrete to withstand high temperatures in conjunction with aggregate having heat resisting properties. It is interesting to note that high alumina cement concrete loses considerable strength only when subjected to humid condition and high temperature. Desiccated high alumina cement concrete on subjecting to the high temperature will undergo a little amount of conversion and will still have a satisfactory residual strength. On complete desiccation the resistance of alumina cement to dry heat is so high that the concrete made with this cement is considered as one of the refractory materials. At a very high temperature alumina cement concrete exhibits good ceramic bond instead of hydraulic bond as usual with other cement concrete.

Crushed firebrick is one of the most commonly used aggregates for making refractory concrete with high alumina cement. Such concrete can withstand temperature upto about 1350°C. Refractory concrete for withstanding temperature upto 1600°C can be produced by using aggregates such as silimanite, carborundum, dead-burnt magnesite. The refractory concrete is used for foundations of furnaces, coke ovens, boiler settings. It is also used in fire pits, construction of electric furnaces, ordinary furnaces and kilns. High alumina cement can be used for making refractory mortars.



High alumina cement is a slow setting but rapid hardening cement. Its setting time can be reduced considerably by mixing it with certain proportions of ordinary Portland cement. In situations such as stopping of ingress of water or for construction between tides or for reducing pumping time in some underwater construction a particular mixture of high alumina cement and ordinary Portland cement is adopted. Fig. 2.3 shows setting time of mixtures of Portland and alumina cement. It can be seen from Fig. 2.3 that when either cement constitutes between 20-80 per cent of mixture, flash set may occur. The values shown in the graph is only approximate. The actual proportioning and the resultant setting time are required to be actually found out by trial when such a combination is practised.

Very High Strength Cement

(*a*) Macro-defect-free cements (MDF)[2.4]. *The engineering of a new class of high strength cement called Macro-defect-free (MDF) cements is an innovation. MDF refers to the absence of relatively large voids or defects which are usually present in conventional mixed cement pastes because of entrapped air and inadequate dispersion. Such voids and defects limit the strength. In the MDF process 4-7% of one of several water-soluble polymers (such as hydroxypropylmethyle cellulose, polyacrylamide of hydrolysed polyvinylacetate) is added as rheological aid to permit cement to be mixed with very small amount of water. Control of particle size distribution was also considered important for generating the strength. At final processing stage entrapped air is removed by applying a modest pressure of 5 MPa.*

With this process a strength of 300 MPa for calcium aluminate system and 150 MPa for Portland cement system can be achieved.

(*b*) Densely Packed System (DSP). *New materials termed DSP (Densified system containing homegeneously arranged ultre-fine particles) is yet another innovation in the field of high strength cement. Normal Portland cement and ultra-fine silica fume are mixed. The size of cement particles may very from 0.5 to 100µ and that of silica fume varies from 0.005 to 0.5µ. Silica fume is generally added from 5 to 25 %. A compressive strength of 270 MPa have been achieved with silica fume substituted paste.*

The formation of typical DSP is schematically represented in Fig. 2.4.

(*c*) Pressure Densification and Warm Pressing. *For decades uncertainties existed regarding the theoretical strength of hydrated cement paste. Before 1970, the potential strength of cement paste at theoretical density (What T.C. Powers called "intrinsic strength") had never been achieved because of considerable porosity (20 to 30% or more) always remain ofter completing hydration of cement. A new approach has ben developed for achieving very high strength by a method called "Warm Pressing" (applying heat and pressure simultaneously) to cement paste.*

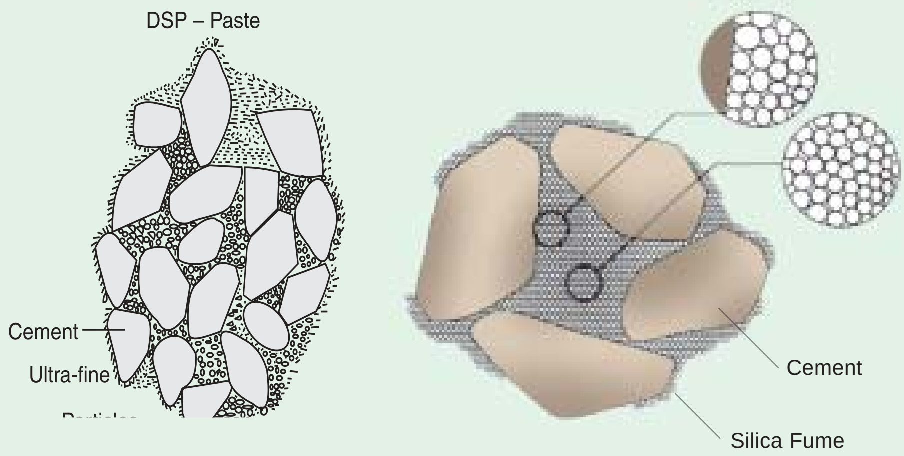


Fig. 2.4. Packing of DSP (Silica fume) paste.

Some modest increase in strength was achieved by application of pressure alone. Compressive strength as much as 650 MPa and tensile strength up to 68 MPa have been obtained by warm pressing Portland and calcium aluminate cements. Enormous increases in strength resulted from the removal of most of the porosity and generation of very homogeneous, fine micro-structures with the porosities as low as 1.7%.

(*d*) High Early Strength Cement. *Development of high early strength becomes an important factor, sometimes, for repair and emergency work. Research has been carried out in the recent past to develop rapid setting and hardening cement to give materials of very high early strength.*

Lithium salts have been effectively used as accelerators in high alumina cement. This has resulted in very high early strength in cement and a marginal reduction in later strength. Strength as high as 4 MPa has been obtained within 1 hour and 27 MPa has been obtained within 3 hours time and 49 MPa in one day.

(*e*) Pyrament Cement. *Some cement industries in USA have developed a super high early strength and durable cement called by trade name "Pyrament Cement". This product is a blended hydraulic cement. In this cement no chlorides are added during the manufacturing process. Pyrament cement produces a high and very early strength of concrete and mortar which can be used for repair of Air Field Run-ways. In India Associated Cement Company in collaboration with R & D Engineers, Dighi, Pune have also produced high early strength cement for rapid repair of airfields.*

The Pyrament cement showed the following strength. Refer Table 2.4.

(*f*) Magnesium Phosphate Cement (MPC). *Magnesium Phosphate Cement, an advanced cementing material, giving very high early strength mortar and concrete has been developed by Central Road Research Institute, New Delhi. This cement can be used for rapid repair of damaged concrete roads and airfield pavements. This is an important development for emergency repair of airfields, launching pads, hard standing and road pavements suffering damage due to enemy bombing and missile attack.*

Table. 2.4. Typical Properties of Conctete and Mortar with Pyrament Cement.

Material	*Compressive strength MPa*	*Flexural Strength MPa*
Hardened Concrete		
4 hours	*17*	*3.45*
1 day	*34*	*5.52*
28 days	*69*	*8.27*
Hardened Mortar		
2 hours	*17*	*—*
3 hours	*24*	*4.1*
1 day	*41*	*6.9*
7 days	*69*	*10.3*

The MPC has been found to possess unique hydraulic properties, in particular, a controlled rapid set and early strength development. MPC is a prepacked mixture of dead burnt magnesite with fine aggregate mixed with phosphate. It sets rapidly and yields durable high strength cement mortar. This new cement has a bright future as an alternative to costly synthetic resins currently in use for emergency repair of concrete pavements.

The following materials are used for making MPC:

Magnesite ($MgCO_3$) when calcined at or above 1500°C gives dead burnt magnesite (DBM). This material is ground to a fineness of 300-350 m^2/kg (Blaines). This is mixed with commercially available crystalline Mono Ammonium Phosphate after grinding into fine powder passing 600µ seive, and other ingredients like sodium tri-polyphosphate in the form of fine powder, di-sodium tetraborate (Borax), fine aggregate (crushed dolomite sand) and water.

The DBM and sand mixture is added into cold phosphate and borax solution (12-15°C) and mixed for one minute. This mix is applied for the purpose of repair. It is air cured and is ready for opening traffic within 4-5 hours.

TESTING OF CEMENT

Testing of cement can be brought under two categories:

(*a*) *Field testing*

(*b*) *Laboratory testing.*

Field Testing

It is sufficient to subject the cement to field tests when it is used for minor works. The following are the field tests:

(*a*) *Open the bag and take a good look at the cement. There should not be any visible lumps. The colour of the cement should normally be greenish grey.*

(*b*) *Thrust your hand into the cement bag. It must give you a cool feeling. 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.*

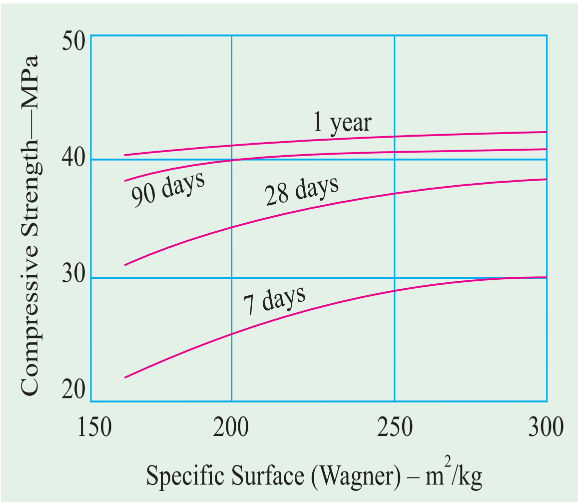
(*e*) Take about 100 grams of cement and a small quantity of water and make a stiff paste. From the stiff paste, pat a cake with sharp edges. Put it on a glass plate and slowly take it under water in a bucket. See that the shape of the cake is not disturbed while taking it down to the bottom of the bucket. 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. The above tests do not really indicate that the cement is really good for important works. For using cement in important and major works it is incumbent on the part of the user to test the cement in the laboratory to confirm the requirements of the Indian Standard specifications with respect to its physical and chemical properties. No doubt, such confirmations will have been done at the factory laboratory before the production comes out from the factory. But the cement may go bad during transportation and storage prior to its use in 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, (Fig. 2.5). The fineness of grinding has increased over the years. But now it has got nearly stabilised. Different cements are ground to different fineness. The disadvantages of fine grinding is that it is susceptible to air-set and early deterioration. 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 in two ways :

(*a*) By seiving.

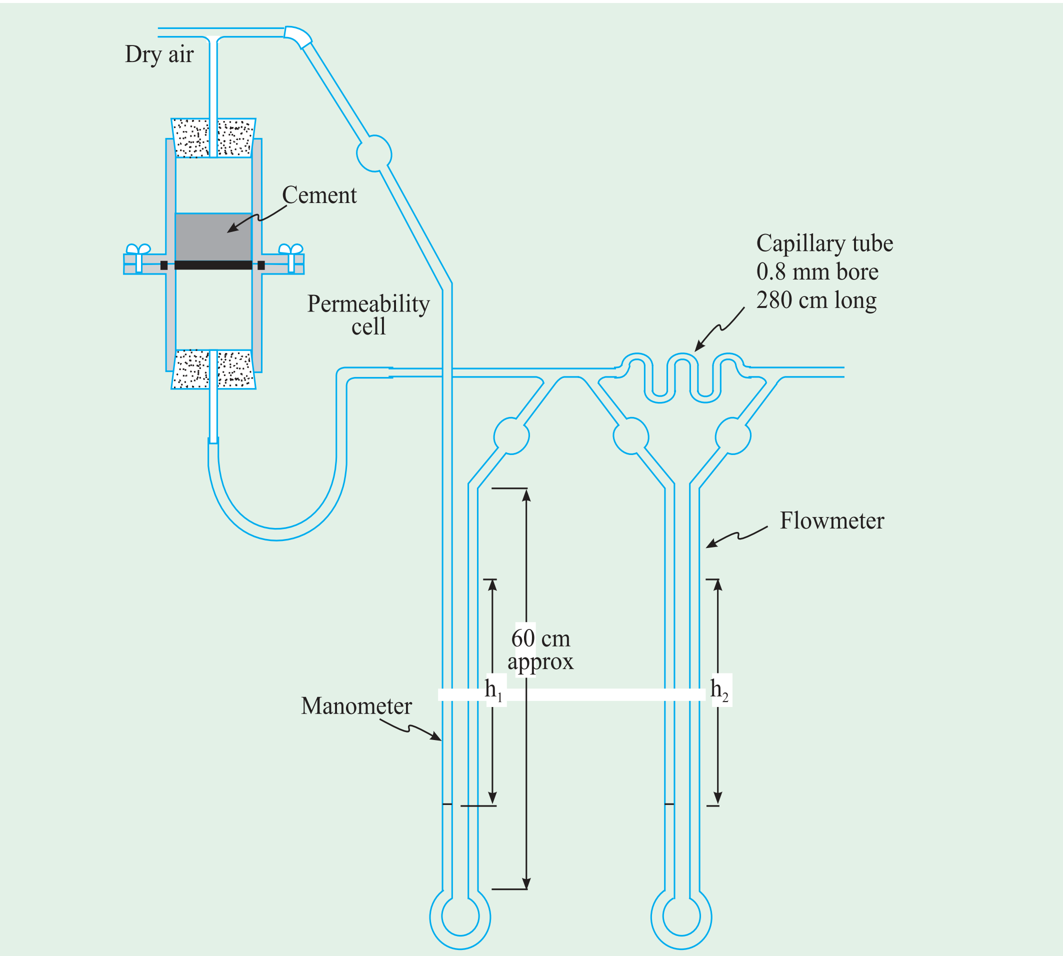
(*b*) By determination of specific surface (total surface area of all the particles in one gram of cement) by air-premeability appartus. Expressed as cm^2/gm or m^2/kg. Generally Blaine Airpermeability appartus is used.

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. Sieve test is rarely used.

Air Permeability Method

This method of test covers the procedure for determining the fineness of cement as represented by specific surface expressed as total surface area in sq. cm/gm. of cement. It is also expressed in m^2/kg. Lea and Nurse Air Permeability Appartus is shown in Fig. 2.6. This appartus can be used for measuring the specific surface of cement. The principle is based on the relation between the flow of air through the cement bed and the surface area of the particles comprising the cement bed. From this the surface area per unit weight of the body material can be related to the permeability of a bed of a given porosity. The cement bed in the permeability cell is 1 cm. high and 2.5 cm. in diameter. Knowing the density of cement the weight required to make a cement bed of porosity of 0.475 can be calculated. This quantity of cement is placed in the permeability cell in a standard manner. Slowly pass on air



through the cement bed at a constant velocity. Adjust the rate of air flow until the flowmeter shows a difference in level of 30-50 cm. Read the difference in level (h_1) of the manometer and the difference in level (h_2) of the flowmeter. Repeat these observations to ensure that steady conditions have been obtained as shown by a constant value of h_1/h_2. Specific surface S_w is calculated from the following formula:

$$S_w = K\sqrt{h_1 / h_2} \quad \text{and} \quad K = \frac{14}{d\,(1-\xi)}\sqrt{\frac{\xi^3 A}{CL}}$$

where, ξ = Porosity, *i.e.*, 0.475

A = Area of the cement bed

L = Length (cm) of the cement bed

d = Density of cement, and

C = Flowmeter constant.

The specific surface for various cements is shown in Table 2.5.

Fineness can also be measured by Blain Air Permeability apprartus. This method is more commonly employed in India. Fig. 2.7 shows the sketch of Blaine type Air Permeability appartus.

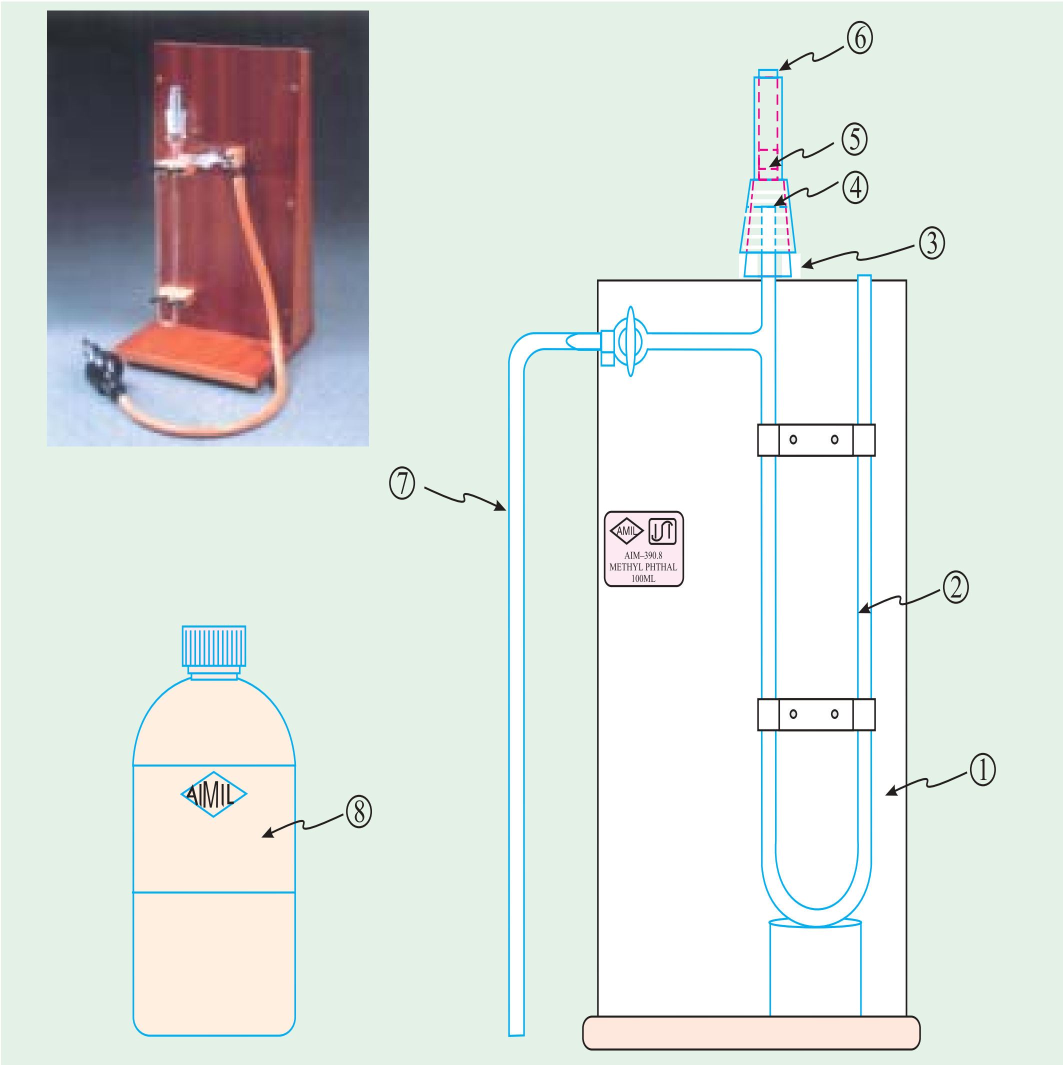
Standard Consistency Test

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. It is pertinent at this stage to describe the procedure of conducting standard consistency test. 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 mould shown in Fig. 2.8. The appartus is called Vicat Appartus. This appartus 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).

The following procedures is adopted to find out 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. The paste must be prepared in a standard manner 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° $\pm$ 2°C) and constant humidity (90%).

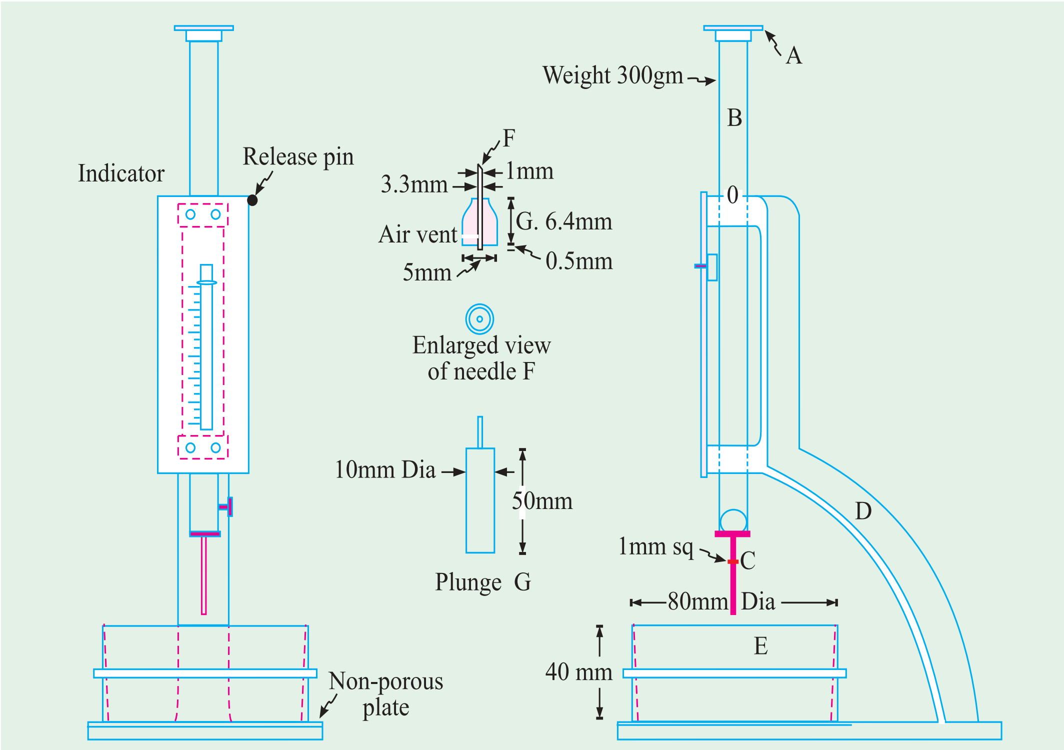
Setting Time Test

An arbitraty division has been made for the setting time of cement as initial setting time and final setting time. It is difficult to draw a rigid line between these two arbitrary divisions.



For convenience, 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, mortar or concrete 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. The constituents and fineness of cement is maintained in such a way that the concrete remains in plastic condition for certain minimum time. 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. Table 2.5 shows the setting time for different cements.

The Vicat Appartus shown in Fig. 2.8 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 guaged 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°C ± 2°C.

Initial Setting Time

Lower the needle (C) 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


Vicat Apparatus and Accessories.


Automatic Vicat Apparatus.

needly 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 appartus by a circular attachment (F) shown in the Fig 2.8. The cement shall be considered as finally set when, upon, lowering the attachment gently cover the surface of the test block, the centre 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 centre needle does not pierce through the paste more than 0.5 mm.

Strength Test

The compressive strength of hardened cement is the most important of all the properties. Therefore, it is not surprising that the cement is always tested for its strength at the laboratory before the cement is used in important works. Strength tests are not made on neat cement 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 (Ennore 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 $\frac{P}{4}$ + 3.0 per cent of combined weight of cement and sand and mix the three ingredients thoroughly until the mixture is of uniform colour. 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..

Moulding of 70.7 mm Mortar Cube Vibrating Machine.

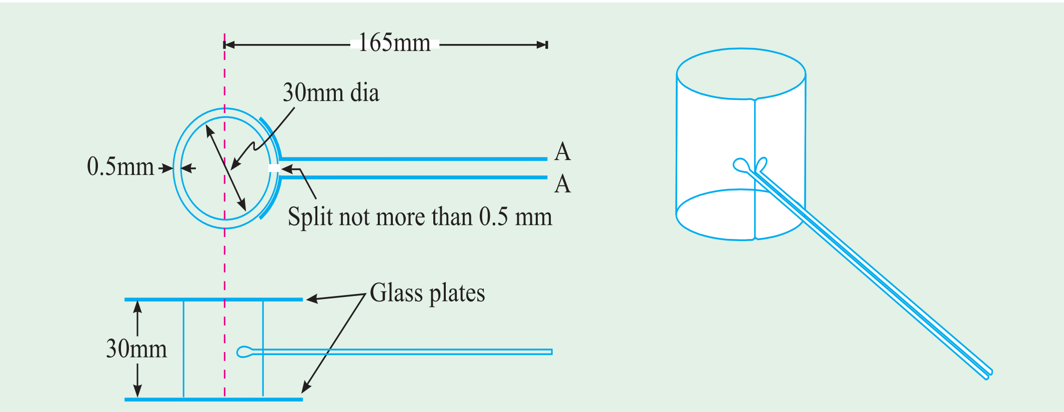
Keep the compacted cube in the mould at a temperature of 27°C ± 2°C and at least 90 per cent relative humidity for 24 hours. Where the facility of standard temperature and humidity room is not available, the cube may be kept under wet gunny bag to simulate 90 per cent relative humidity. After 24 hours 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 Table 2.5. The periods being reckoned from the completion of vibration. 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 is shown in Table 2.5.

Soundness Test

It is very important that the cement after setting shall not undergo any appreciable change of volume. Certain cements have been found to undergo a large expansion after setting causing disruption of the set and hardened mass. 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. It can be recalled that, to prevent flash set, calcium sulphate is added to the clinker while grinding. The quantity of gypsum added will vary from 3 to 5 per cent depending upon C_3A *content. If the addition of gypsum is more than that could be combined with* C_3A*, 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.*



Autoclave.

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 considarable period of time. Therefore, accelerated tests are required to detect it. There are number of such tests in common use. The appartus is shown in Fig. 2.9. It 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°C – 32°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.


Automatic / Manual 5 litre Mortar Mixer.

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 × 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 – $1^1/_4$ hour from the time the heat is turned on. This pressure is maintained for 3 hours. The autoclave is cooled and the length 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 a 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. From this it can be assessed the total quantum of heat produced in a conservative system such as the interior of a mass concrete dam. A temperature rise of about 50°C has been observed. 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.


Heat of hydration Apparatus.

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. This test is carried out over a few days by vaccum flask methods, or over a longer period in an adiabatic calorimeter. 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

A fairly detailed discussion has been given earlier regarding the chemical composition of cement. Both oxide composition and compound composition of cement have been discussed. At this stage it is sufficient to give the limits of chemical requirements. The Table 2.6 shows the various chemical compositions of all types of cements.

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

$$\frac{CaO - 0.7\,SO_3}{2.8\,SiO_2 + 1.2\,Al_2O_3 + 0.65\,Fe_2O_3}$$ *: Not greater than 1.02 and not less than 0.66*

The above is called lime saturation factor per cent.

Table 2.5 gives the consolidated physical requirements of various types of cement.

Table 2.6 gives the chemical requirements of various types of cement.

Test Certificate

Every cement company is continuously testing the cement manufactured in their factory. They keep a good record of both physical and chemical properties of the cement manufactured applying a batch number. Batch number indicates date, month and year.

They also issue test certificate. Every purchaser is eligible to demand test certificate.

A typical test certificate of Birla super 53 grade cement for the week number 35 is given in Table 2.7 for general information.

Some cement companies also work out the standard deviation and coefficient of variation for 3 months or 6 months or for one year period subjecting the various parameters obtained from their test results. Table 2.8 shows the typical standard deviation for 3 days, 7 days and 28 days strength in respect of 53 grade cement Birla super. Standard deviation has been worked out for the whole year from Jan. 99 to Dec. 99.

The properties of cements, particularly the strength property shown in Table No. 2.5 is tested as per the procedures given by BIS. In different countries cement is tested as per their own country's code of practice. There are lot of variations in the methods of testing of cement with respect to w/c ratio, size and shape of specimen, material proportion, compacting methods and temperature. Strength of cement as indicated by one country may not mean the same in another country. This will present a small problem when export or import of cement from one country to another country is concerned. Table No. 2.9. Shows the cements testing procedure and various grades of cement manufactured in some countries. There is suggestion that all the countries should follow one method recommended by International standards organisation for testing of cement. If that system is adopted properties indicated by any one country will mean the same to any other country.

Table 2.5. Physical Characteristics of Various Types of Cement.

Sl.No.	Type of Cement	Fineness (m^2/kg) Min.	Soundness By: Le chatelier (mm) Max.	Soundness By: Autoclave (%) Max.	Setting Time: Initial (mts) min.	Setting Time: Final (mts) max.	Compressive Strength: 1 Day min. MPa	Compressive Strength: 3 Days min. MPa	Compressive Strength: 7 Days min. MPa	Compressive Strength: 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.	SRC (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.	IRS-T-40	370	5	0.8	60	600	N S	N S	37.5	N S

*N S – Not specified.

Table. 2.6. 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_3A is 5 or less 3% Max. When C_3A 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_3A is 5 or less 3% Max. When C_3A 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_3A is 5 or less 3% Max. When C_3A 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_3A is 5 or less 3% Max. When C_3A 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_3A is 5 or less 3% Max. When C_3A 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.

Table 2.7. Typical Test Certificate

53 Grade Portland Cement
Birla Super
Week no. 35
Physical Analysis

Fineness:		Requirements of I.S. 12269-1987	
Specific Surface	303 m^2/kg	Should not be less than	225 m^2/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 Consistencey	29.7 %		

Chemical Analysis

Particulars			
Lime Saturation Factor (L.S.F.)	0.92	Should not be less than	0.80 and not 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_3)	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%

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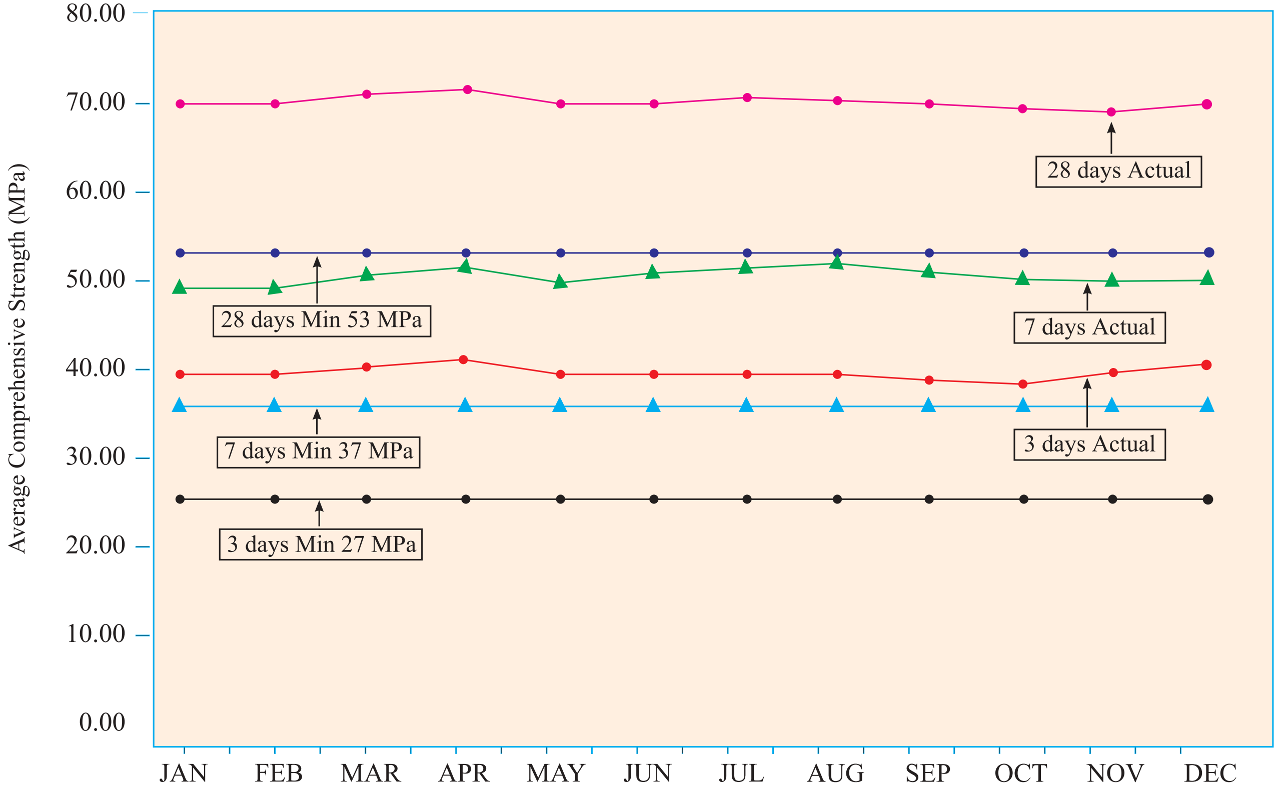
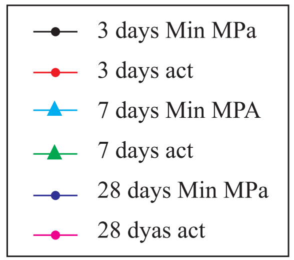
OFFICER (QC) **Sr. MANAGER (QC)**

Table 2.8. Consistency Curves for the year 1999

Birla Super Cement - OPC 53 Grade
(IS 12269 - 1987)





Strength in MPa	*S.D.**	*C.O.V.***
3 days	*0.57*	*1.41*
7 days	*0.74*	*1.46*
28 days	*0.50*	*0.71*

*** Standard Deviation**
**** Coefficient of Variation**

Table 2.9. Brief Summary of Cement Testing Procedure and grades of Cement in various contries.

Country	Grade	TESTING PROCEDURE				COMPRESSIVE STRENGTH MPa			
		Material	Size of Cube mm.	Compaction	W/C ratio	1 day	3 days	7 days	28 days
India	33	1:3 Mortar	70.6 (50 cm^2)	Vibration 12000/min For 2 min	0.39 to 0.45	-	16	22	33
	43	-	-	-	-	-	23	33	43
	53	-	-	-	-	-	12	37	53
Germany	30	Mortar	Prism 40 × 40 × 160 (25 cm^2) **	Vibration	0.5	-	12	-	30
	35		-	-	-	-	15	-	35
	40		-	-	-	-	20	-	40
	45		-	-	-	-	25	-	45
	50		-	-	-	25	-	-	50
	55		-	-	-	25	-	-	55
China	275	1:2.5 Mortar	-	-	0.44	-	-	16	28
	325	-	-	-	-	-	12	19	33
	425	-	-	-	-	-	16	25	43
	525	-	-	-	-	-	21	32	53
	625	-	-	-	-	-	27	41	63
	725	-	-	-	-	-	36	-	73
U.S.S.R.	400	1:3 Mortar	Prism 40 × 40 × 160 **	-	0.4	-	-	-	40
	500	-	-	-	-	-	-	-	50
	550	-	-	-	-	-	-	-	55
	600	-	-	-	-	-	-	-	60
U.K.	OPC	Mortar 1:3	70.6	Vibration 12000 ± 400 for 2 min	0.4	-	23	-	42
	-	Concrete 1:2.5:3.5	101.6	Tamping	0.6	-	13	-	30
U.S.A.	OPC Type 1	Mortar 1:2.75	50	Tamping	0.485	-	13	20	29

* P/4 + 3%, where P is standard consistency.

** After bending test, one half of the prism is stressed along the longer edges with loading area restricted to 25cm^2.

Additional General Information on Cement and other Pozzolanic Materials

Comparison of Physical Characteristics of OPC

Item	ASTM C-150, Type			EN 197-1, Strength Class			BIS, Strength Grades			
	I	III	V	32.5	42.5	52.5	33	43	53	SRC
Fineness, m^2/kg	280	– @	280				225			
IST, minutes	45			75	60	45	30			
FST, minutes	375 (Maximum)						600 (Maximum)			
Compressive Strength, Mpa (Minimum) at										
1 day	–	12	–	–	–	–	–	–	–	–
2 days	–	–	–	–/10*	10/20	20/30	–		–	–
3 days	12	24	8	–	–	–	16	23	27	10
7 days	19	–	15	16		–	22	33	37	16
28 days	28	–	21	32.5	42.5	52.5	33	43	53	33
28 days (max)	–			52.5	62.5	–	–			

@ denotes no value specified

* first values for N (Normal), next for R (Rapid)

Comparison of Low heat Cements

Cement	Fineness, m^2/kg	Heat of hydration, Cal/gm, at		Compressive strength, Mpa, at		
		7 days	28 days	3 days	7 days	28 days
ASTM type IV	280	60	70	–@	7	17
IS : 12600	320	65	75	10	16	35

@ – denotes not specified.

Comparison of Chemical Characteristics of OPC

Items (mad values)	ASTM C150, Types					EN 197-1	BIS OPC grades			
	I	II	III	IV	V		33	43	53	SRC
IR	0.75	3	0.75	0.75	0.75	5	4	3	3	4
LOI	3	-	3	2.5	3	5	5	5	4	5
MgO	6	6	6	6	6	5	6	6	6	6
Chloride	–@	@	–	–	–	0.10*	0.10#	0.10#	0.10#	0.10
Alkalis $	0.6	0.6	0.6	0.6	0.6	–	0.6	0.6	0.6	–
C_3A	–	8	15	7	5	–	–	–	–	5
$2C_3A + C_4AF$	–	–	–	–	25	–	–	–	–	25
C_3S	–	–	–	35	–	–	–	–	–	–
C_2S (min)	–	–	–	40	–	–	–	–	–	–

@ – denotes no value specified

* – for pre-stressing applications, a lower value may be prescribed

– 0.05% for prestressed concrete

$ – limits of alkali are optional, recommended in case of reactive aggregates.

Comparison of Physical properties of Portland Pozzolana Cements

Item	ASTM C-150, Type IP	EN 197-1, Strength Classes 32.5, 42.5, 52.5	IS: 1489-Part I
Fineness, m^2/kg	–@	All requirements are identical to OPC as in Table 3	300
IST, minutes	45 (Min.)		30 (Min.)
FST, minutes	420 (Max.)		600 (Max.)
Compressive Strength, Mpa (Minimum) at			
3 days	13		16
7 days	20		22
28 days	25		33

Comparison of Physical properties of Portland Slag Cements

Item	ASTM C-150, Type IP	EN 197-1, Strength Classes 32.5, 42.5, 52.5	IS: 455
Fineness, m^2/kg	–@	All requirements are identical to OPC as in Table 3	225
IST, minutes	45 (Min.)		30 (Min.)
FST, minutes	420 (Max.)		600 (Max.)
Compressive Strength, Mpa (Minimum) at			
3 days	13		16
7 days	20		22
28 days	25		33

@ - Denotes no value specified

Comparison of Specifications for Granulated Slag

S.No.	Item	EN 197-1	ASTM C-989	IS: 12089
1.	(C+M+1/3A)/(S+2/3A)	–@	–	1.0
	Or			
	(C + M + A)/S, min	–	–	1.0
2.	(C + M + S), % mi n	67	–	–
3.	(C + M)/S, min	1.0	–	–
4.	MgO, % max	–	–	17
5.	MnO, % max	–	–	5.5
6.	Sulphide Sulphur, % max	–	2.5	2
7.	Insoluble Residue, % max	–	–	5
8.	Glass Content, % min	67	–	85

@ - denotes not specified.

(C=CaO, M = MgO, A = Al_2O_3, S = SiO_2)

Specifications for Fly ash in Cement and Concrete

(values are %, unless other units are indicated)

Item	ASTM	European Specifications			IS : 3812	
	C-618	EN-450	EN-197-1	BS 3892-I	Existing 1981	Proposed
SiO_2, min					35	35
Reactive/soluble SiO_2, min.		25	25			25
S + A + F, min.	70				70	70
MgO, max.					5	5
LOI (1 hour) max.	6	5 - 7	5 - 7	7	12	5
Total Alkalis, max.	1.5				1.5	1.5
SO_3, max	5	3		2	2.75	2.75
Free CaO, max		1	1			
Total/reactive CaO max.		10	10	10		
Fineness, 45 micron, max.	34#	40@		12		34
Blaine's m^2/kg min.					320	320
Cement activity, 28 days	75*	75*		80**	80***	80***
Lime reactivity, N/mm^2					4	4.5
Soundness, Lechatelier, mm	10	10	10		10	10
Autoclave, %	0.8				0.8	0.8

Note

i) @ Permitted variation + 10 % of average

ii) # Permitted variation $\pm$ 5 % of average

iii) * 25 % fly ash

** 30 % fly ash

*** 20 % fly ash

iv) Drying shrinkage < 0.15 in IS 3812

REFERENCES

2.1. *Fast Setting Cement, Engineering News Records*, Jan. 1956.

2.2 Product Literature of Birla White.

2.3 Information Supplied by CAI letter no. MISCEL/ENG/244 dated 7th Sept. 78.

2.4 Della, M. Roy, *Advanced Cement System, including CBC, DSP, MDF*, 9th International Congress on the Chemistry of Cement, New Delhi - 1992.

2.5 Comparison of BIS, ASTM and EN Cement Standards Compiled by Grasim Industries Ltd. (Cement Business) Mumbai.

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