



Such a flow is the result of the use of Superplasticizer

# 5

## CHAPTER

# Admixtures and Construction Chemicals

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### General

**A**dmixture 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 is 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.

Until about 1930 additives and admixtures though used, were not considered an important part of concrete technology. Since then, there has been an increase in the use of admixtures. Though the use of admixtures and additives is being frowned upon or scorned by some technologists, there are many on the contrary, who highly commend and foster the use and development of admixtures as it

imparts many desirable characteristics and effect economy in concrete construction. It should be remembered, however, that admixtures are no substitute for good concreting practices.

The history of admixtures is as old as the history of concrete. It embraces a very vast field as shown in table 5.22. But a few type of admixtures called Water Reducers or High Range Water Reducers, generally referred as plasticizers and superplasticizers, are of recent interest. They are specifically developed in Japan and Germany around 1970. Later on they were made popular in USA and Europe even in Middle East and Far East. Unfortunately, the use of plasticizers and superplasticizers have not become popular in India till recently (1985). There are many reasons for non acceptance for wider use of plasticizers in India: Ninety per cent of concreting activities are in the hands of common builders or Government departments who do not generally accept something new. Plasticizers were not manufactured in India and they were to be imported, and hence costly. Lack of education and awareness of the benefits accrued by the use of plasticizers, and we were used to making generally low strength concrete of the type M15 to M30, which do not really need the use of plasticizers.

Now, since early 1980s, some internationally renowned companies collaborated with Indian companies and have started manufacturing chemical admixtures in India. As a part of marketing they started educating consultants, architects, structural engineers and builders about the benefits of using admixtures. We, in India have also started using higher strength concrete for high rise buildings and bridges. Use of Ready mix concrete has really promoted the use of admixtures in India, in recent times.

It will be slightly difficult to predict the effect and the results of using admixtures because, many a time, the change in the brand of cement, aggregate grading, mix proportions and richness of mix alter the properties of concrete. Sometimes many admixtures affect more than one property of concrete. At times, they affect the desirable properties adversely. Sometimes, more than one admixture is used in the same mix. The effect of more than one admixture is difficult to predict. Therefore, one must be cautious in the selection of admixtures and in predicting the effect of the same in concrete.

As per the report of the ACI Committee 212, admixtures have been classified into 15 groups according to type of materials constituting the admixtures, or characteristic affect of the use. When ACI Committee 212 submitted the report in 1954, plasticizers and superplasticizers, as we know them today, were not existing. Therefore, in this grouping of admixtures, plasticizers and superplasticizers and a few variations in them have now been included under admixtures.

Classification of admixtures as given by M.R. Rixom (slightly modified to include a few new materials) is given in table 5.22.

In this chapter, the following admixtures and construction chemicals are dealt with.

## Admixtures

- Plasticizers
- Superplasticizers
- Retarders and Retarding Plasticizers
- Accelerators and Accelerating Plasticizers
- Air-entraining Admixtures
- Pozzolanic or Mineral Admixtures
- Damp-proofing and Waterproofing Admixtures
- Gas forming Admixtures

- Air-detraining Admixtures
- Alkali-aggregate Expansion Inhibiting Admixtures
- Workability Admixtures
- Grouting Admixtures
- Corrosion Inhibiting Admixtures
- Bonding Admixtures
- Fungicidal, Germicidal, Insecticidal Admixtures
- Colouring Admixtures

### Construction Chemicals

- Concrete Curing Compounds
- Polymer Bonding Agents
- Polymer Modified Mortar for Repair and Maintenance
- Mould Releasing Agents
- Protective and Decorative Coatings
- Installation Aids
- Floor Hardeners and Dust-proofers
- Non-shrink High Strength Grout
- Surface Retarders
- Bond-aid for Plastering
- Ready to use Plaster
- Guniting Aid
- Construction Chemicals for Water-proofing
  1. Integral Water-proofing Compounds
  2. Membrane Forming Coatings
  3. Polymer Modified Mineral Slurry Coatings
  4. Protective and Decorative Coatings
  5. Chemical DPC
  6. Silicon Based Water-repellent Material
  7. Waterproofing Adhesive for Tiles, Marble and Granite
  8. Injection Grout for Cracks
  9. Joint Sealants

### Plasticizers (Water Reducers)

Requirement of right workability is the essence of good concrete. Concrete in different situations require different degree of workability. A high degree of workability is required in situations like deep beams, thin walls of water retaining structures with high percentage of steel reinforcement, column and beam junctions, tremie concreting, pumping of concrete, hot weather concreting, for concrete to be conveyed for considerable distance and in ready mixed concrete industries. The conventional methods followed for obtaining high workability is by improving the gradation, or by the use of relatively higher percentage of fine aggregate or by increasing the cement content. There are difficulties and limitations to obtain high workability in the field for a given set of conditions. The easy method generally followed at the site in most of the conditions is to use extra water unmindful of the harm it can do to the strength and durability of concrete. It has been stressed time and again in almost all the chapters of this

book to the harmful effect of using extra water than necessary. It is an abuse, a criminal act, and unengineering to use too much water than necessary in concrete. At the same time, one must admit that getting required workability for the job in hand with set conditions and available materials is essential and is often difficult. Therefore, engineers at the site are generally placed in conflicting situations. Often he follows the easiest path and that is adding extra water to fluidise the mix. This addition of extra water to satisfy the need for workable concrete is amounting to sowing the seed of cancer in concrete.

Today we have plasticizers and superplasticizers to help an engineer placed in intriguing situations. These plasticizers can help the difficult conditions for obtaining higher workability without using excess of water. One must remember that addition of excess water, will only improve the fluidity or the consistency but not the workability of concrete. The excess water will not improve the inherent good qualities such as homogeneity and cohesiveness of the mix which reduces the tendency for segregation and bleeding. Whereas the plasticized concrete will improve the desirable qualities demanded of plastic concrete. The practice all over the world now is to use plasticizer or superplasticizer for almost all the reinforced concrete and even for mass concrete to reduce the water requirement for making concrete of higher workability or flowing concrete. The use of superplasticizer has become

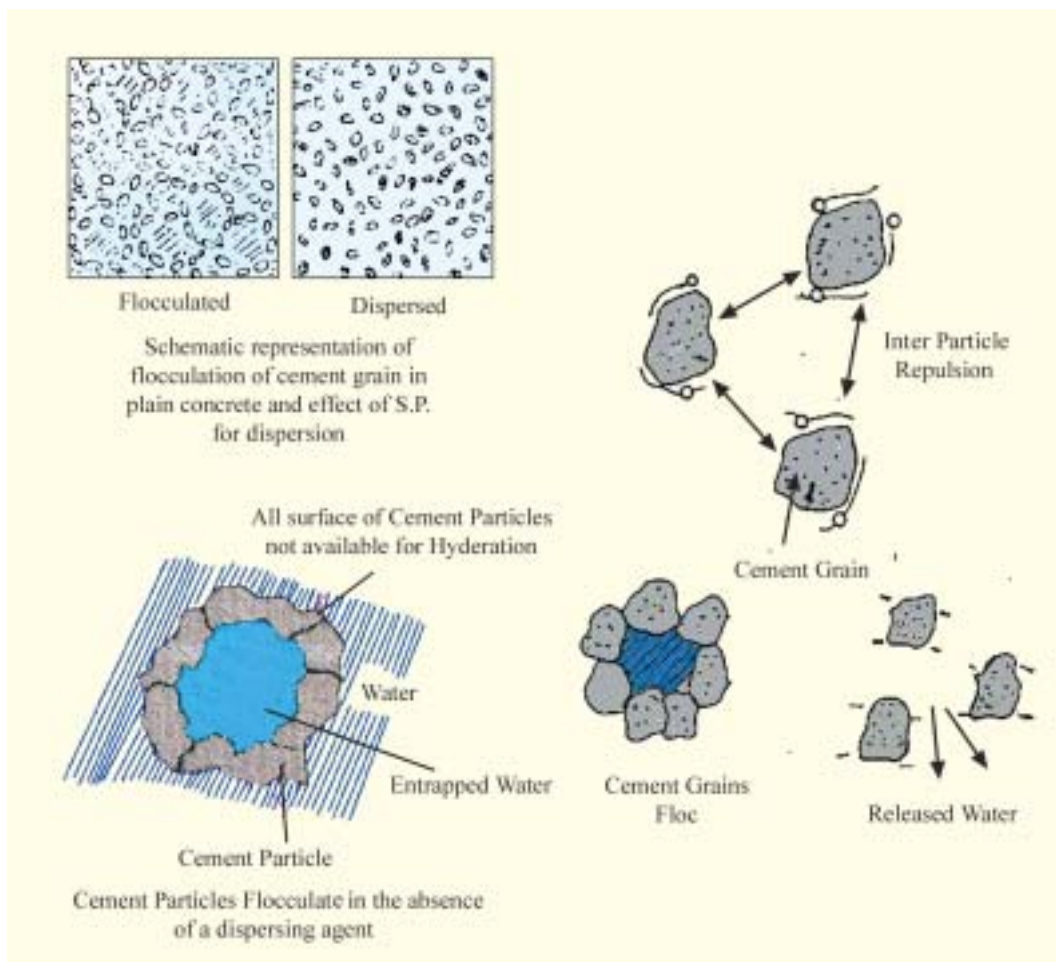


Fig. 5.1. Effect of surface-active agents on deflocculating of cement grains.

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. Sometimes the use of plasticizers is employed to reduce the cement content and heat of hydration in mass concrete.

The organic substances or combinations of organic and inorganic substances, which allow a reduction in water content for the given workability, or give a higher workability at the same water content, are termed as plasticizing admixtures. The advantages are considerable in both cases : in the former, concretes are stronger, and in the latter they are more workable.

The basic products constituting plasticizers are as follows:

- (i) Anionic surfactants such as lignosulphonates and their modifications and derivatives, salts of sulphonates hydrocarbons.
- (ii) Nonionic surfactants, such as polyglycol esters, acid of hydroxylated carboxylic acids and their modifications and derivatives.
- (iii) Other products, such as carbohydrates etc.

Among these, calcium, sodium and ammonium lignosulphonates are the most used. 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, depending on the dosage, initial slump of concrete, cement content and type.

A good plasticizer fluidizes the mortar or concrete in a different manner than that of the air-entraining agents. Some of the plasticizers, while improving the workability, entrains air also. As the entrainment of air reduces the mechanical strength, a good plasticizer is one which does not cause air-entrainment in concrete more than 1 or 2%.

One of the common chemicals generally used, as mentioned above is Lignosulphonic acid in the form of either its calcium or sodium salt. This material is a natural product derived from wood processing industries. Admixtures based on lignosulphonate are formulated from purified product from which the bulk of the sugars and other interfering impurities are removed to low levels. Such a product would allow adsorption into cement particles without any significant interferences with the hydration process or hydrated products. Normal water reducing admixtures may also be formulated from wholly synthetic raw materials. It is also observed that at a recommended dose, it does not affect the setting time significantly. However, at higher dosages than prescribed, it may cause excessive retardation. It must be noted that if unrefined and not properly processed lignosulphonate is used as raw material, the behaviour of plasticizer would be unpredictable. It is some times seen that this type of admixture has resulted in some increase in air-entrainment. It is advised that users should follow the instructions of well established standard manufacturers of plasticizers regarding dosage.

### Action of Plasticizers

The action of plasticizers is mainly to fluidify the mix and improve the workability of concrete, mortar or grout. The mechanisms that are involved could be explained in the following way:

*Dispersion.* Portland cement, being in fine state of division, will have a tendency to flocculate in wet concrete. These flocculation entraps certain amount of water used in the mix and thereby all the water is not freely available to fluidify the mix.

When plasticizers are used, they get adsorbed on the cement particles. The adsorption of charged polymer on the particles of cement creates particle-to-particle repulsive forces which overcome the attractive forces. This repulsive force is called Zeta Potential, which depends on the base, solid content, quantity of plasticizer used. The overall result is that the cement particles are deflocculated and dispersed. When cement particles are deflocculated, the water trapped inside the flocs gets released and now available to fluidify the mix. Fig. 5.1 explains the mechanism.

When cement particles get flocculated there will be interparticles friction between particle to particle and floc to floc. But in the dispersed condition there is water in between the cement particle and hence the interparticle friction is reduced.

*Retarding Effect.* It is mentioned earlier that plasticizer gets adsorbed on the surface of cement particles and form a thin sheath. This thin sheath inhibits the surface hydration reaction between water and cement as long as sufficient plasticizer molecules are available at the particle/solution interface. The quantity of available plasticizers will progressively decrease as the polymers become entrapped in hydration products.

Many research workers explained that one or more of the following mechanisms may take place simultaneously:

- Reduction in the surface tension of water.
- Induced electrostatic repulsion between particles of cement.
- Lubricating film between cement particles.
- Dispersion of cement grains, releasing water trapped within cement flocs.
- Inhibition of the surface hydration reaction of the cement particles, leaving more water to fluidify the mix.
- Change in the morphology of the hydration products.
- Induced steric hindrance preventing particle-to-particle contact.

It may be noted that all plasticizer are to some extent set retarders, depending upon the base of plasticizers, concentration and dosage used.

### **Superplasticizers (High Range Water Reducers)**

Superplasticizers constitute a relatively new category and improved version of plasticizer, the use of which was developed in Japan and Germany during 1960 and 1970 respectively. They are chemically different from normal plasticizers. Use of superplasticizers permit the reduction of water to the extent upto 30 per cent without reducing workability in contrast to the possible reduction up to 15 per cent in case of plasticizers.

The use of superplasticizer is practiced for production of flowing, self levelling, self compacting and for the production of high strength and high performance concrete.

The mechanism of action of superplasticizers are more or less same as explained earlier in case of ordinary plasticizer. Only thing is that the superplasticizers are more powerful as dispersing agents and they are high range water reducers. They are called High Range Water Reducers in American literature. It is the use of superplasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 Mpa or more. It is the use of superplasticizer which has made it possible to use fly ash, slag and particularly silica fume to make high performance concrete.

The use of superplasticizer in concrete is an important milestone in the advancement of concrete technology. Since their introduction in the early 1960 in Japan and in the early 1970 in Germany, it is widely used all over the world. India is catching up with the use of

superplasticizer in the construction of high rise buildings, long span bridges and the recently become popular Ready Mixed Concrete Industry. Common builders and Government departments are yet to take up the use of this useful material.

Superplasticizers can produce:

- at the same w/c ratio much more workable concrete than the plain ones,
- for the same workability, it permits the use of lower w/c ratio,
- as a consequence of increased strength with lower w/c ratio, it also permits a reduction of cement content.

The superplasticizers also produce a homogeneous, cohesive concrete generally without any tendency for segregation and bleeding.

**Classification of Superplasticizer.** Following are a few polymers which are commonly used as base for superplasticizers.

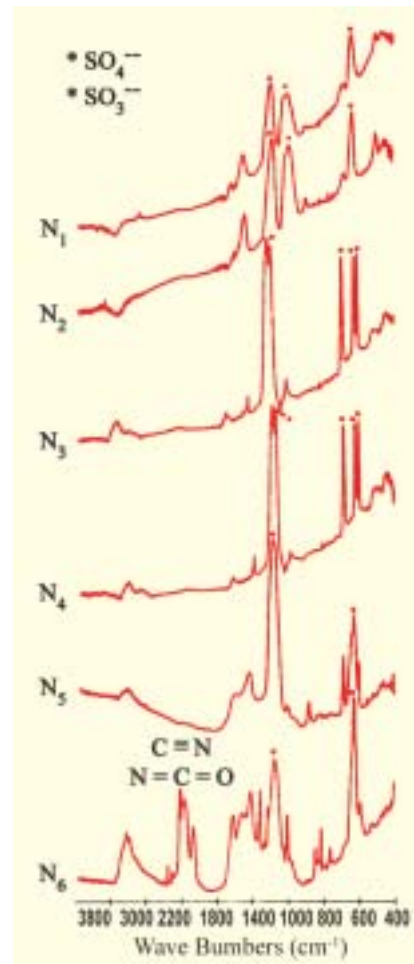
- Sulphonated malanie-formaldehyde condensates (SMF)
- Sulphonated naphthalene-formaldehyde condensates (SNF)
- Modified lignosulphonates (MLS)
- Other types

In addition to the above, in other countries the following new generation superplasticizers are also used.

- Acrylic polymer based (AP)
- Copolymer of carboxylic acrylic acid with acrylic ester (CAE)
- Cross linked acrylic polymer (CLAP)
- Polycarboxylate ester (PC)
- Multicarboxylatethers (MCE)
- Combinations of above.

Out of the above new generation superplasticizers based on carboxylic acrylic ester (CAE) and multicarboxylatether (MCE) are discussed later.

As far as our country is concerned, at present (2000 AD), we manufacture and use the first four types of superplasticizers. The new generation superplasticizers have been tried in recent projects, but it was not found feasible for general usage on account of high cost. The first four categories of products differ from one another because of the base component or on account of different molecular weight. As a consequence each commercial product will have different action on cements. Whilst the dosage of conventional plasticizers do not exceed 0.25% by weight of cement in case of lignosulphonates, or 0.1% in case of carboxylic acids, the products of type SMF or NSF are used considerably high dosages (0.5% to 3.00%), since they do not entrain air. The modified



N<sub>1</sub> to N<sub>5</sub>, infra-red spectrograph of a naphthalene superplasticizer; M<sub>6</sub>, lignosulfonate superplasticizer and a mixed superplasticizer.



lignosulphonate (LS) based admixtures, which have an effective fluidizing action, but at the relatively high dosages, they can produce undesirable effects, such as accelerations or delay in setting times. Moreover, they increase the air-entrainment in concrete.<sup>5.1</sup>

Plasticizers and superplasticizers are water based. The solid contents can vary to any extent in the products manufactured by different companies. Cost should be based on efficiencies and solid content, but not on volume or weight basis. Generally in projects cost of superplasticizers should be worked for one cubic meter of concrete. Consistency in the quality of superplasticizers supplied over a period of time can be tested and compared by "Infrared Spectrometry".

### Effects of Superplasticizers on Fresh Concrete

It is to be noted that dramatic improvement in workability is not showing up when plasticizers or superplasticizers are added to very stiff or what is called zero slump concrete at nominal dosages. A mix with an initial slump of about 2 to 3 cm can only be fluidised by plasticizers or superplasticizers at nominal dosages. A high dosage is required to fluidify no slump concrete. An improvement in slump value can be obtained to the extent of 25 cm or more depending upon the initial slump of the mix, the dosage and cement content. It is often noticed that slump increases with increase in dosage. But there is no appreciable increase in slump beyond certain limit of dosage. As a matter of fact, the overdosage may sometime harm the concrete. A typical curve, showing the slump and dosage is shown in Fig. 5.2.

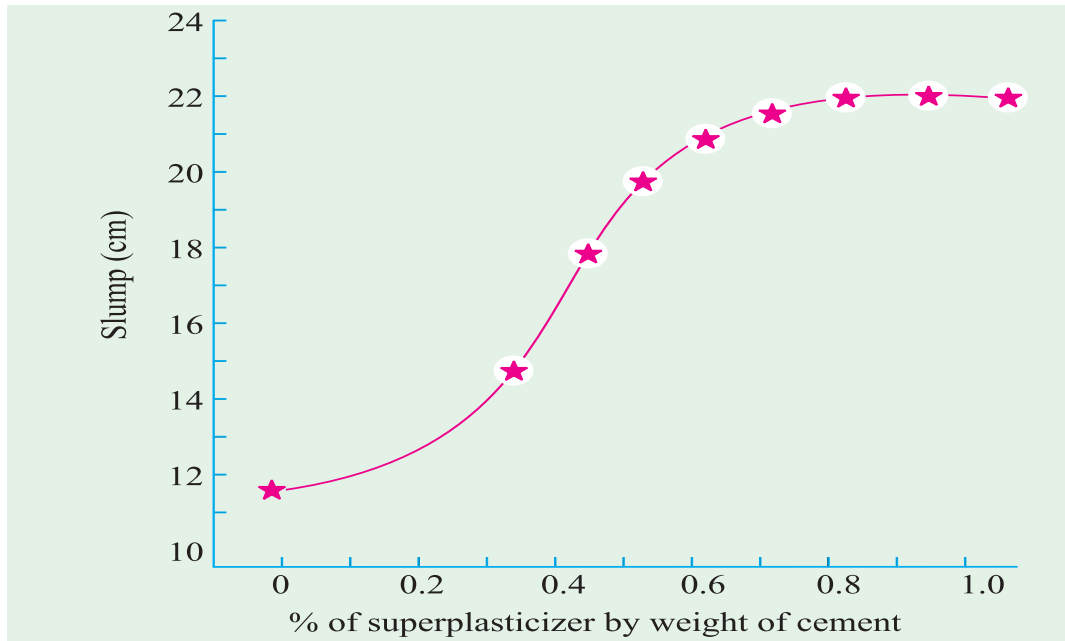
### Compatibility of Superplasticizers and Cement

It has been noticed that all superplasticizers are not showing the same extent of improvement in fluidity with all types of cements. Some superplasticizers may show higher fluidizing effect on some type of cement than other cement. There is nothing wrong with either the superplasticizer or that of cement. The fact is that they are just not compatible to show maximum fluidizing effect. Optimum fluidizing effect at lowest dosage is an economical consideration. Giving maximum fluidizing effect for a particular superplasticizer and a cement is very complex involving many factors like composition of cement, fineness of cement etc.

Although compatibility problem looks to be very complex, it could be more or less solved by simple rough and ready field method. Incidentally this simple field test shows also the optimum dose of the superplasticizer to the cement. Following methods could be adopted.

- Marsh cone test





- Mini slump test
- Flow table test.

Out of the above, Marsh cone test gives better results. In the Marsh cone test, cement slurry is made and its flowability is found out. In concrete, really come to think of it, it is the cement paste that influences flowability. Although, the quantity of aggregates, its shape and texture etc. will have some influence, it is the paste that will have greater influence. The presence of aggregate will make the test more complex and often erratic. Whereas the using of grout alone will make the test simple, consistent and indicative of the fluidifying effect of superplasticizer with a cement. The following procedure is adopted in Marsh cone test.

Marsh cone is a conical brass vessel, which has a smooth aperture at the bottom of diameter 5 mm. The profile of the apparatus is shown in Fig. 5.3.

Take 2 kg cement, proposed to be used at the project. Take one litre of water ( $w/c = 0.5$ ) and say 0.1% of plasticizer. Mix them thoroughly in a mechanical mixer (Hobart mixer is preferable) for two minutes. Hand mixing does not give consistent results because of unavoidable lump formation which blocks the



Fig. 5.3. Marsh Cone Test.

aperture. If hand mixing is done, the slurry should be sieved through 1.18 sieve to exclude lumps. Take one litre slurry and pour it into marsh cone duly closing the aperture with a finger. Start a stop watch and simultaneously remove the finger. Find out the time taken in seconds, for complete flow out of the slurry. The time in seconds is called the "Marsh Cone Time". Repeat the test with different dosages of plasticizer. Plot a graph connecting Marsh cone time in seconds and dosages of plasticizer or superplasticizer. A typical graph is shown in Fig. 5.4. The dose at which the Marsh cone time is lowest is called the saturation point. The dose is the optimum dose for that brand of cement and plasticizer or superplasticizer for that w/c ratio.

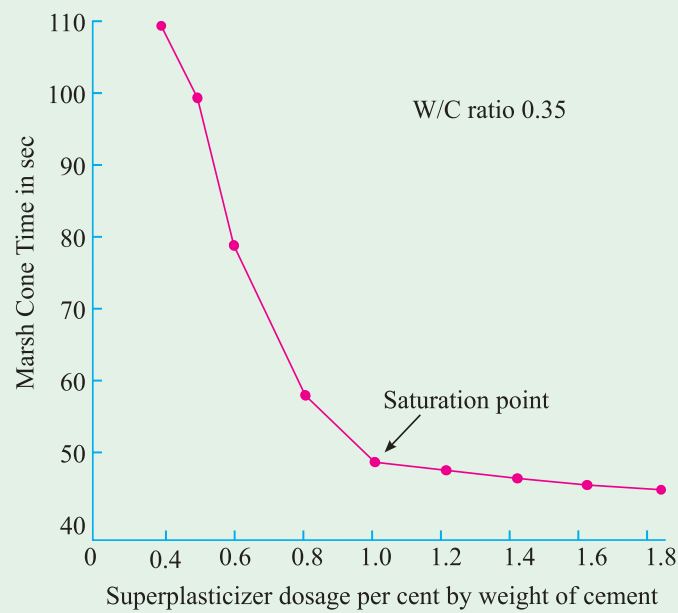


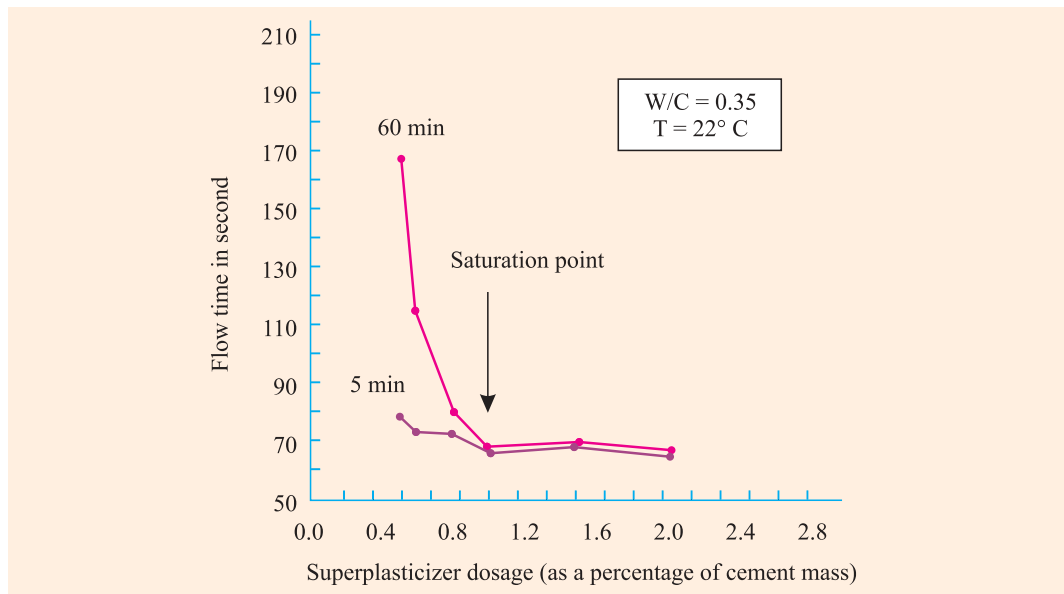
Fig. 5.5. Marsh cone viscometer with attachments, 6 mm, 8 mm and 11 mm.



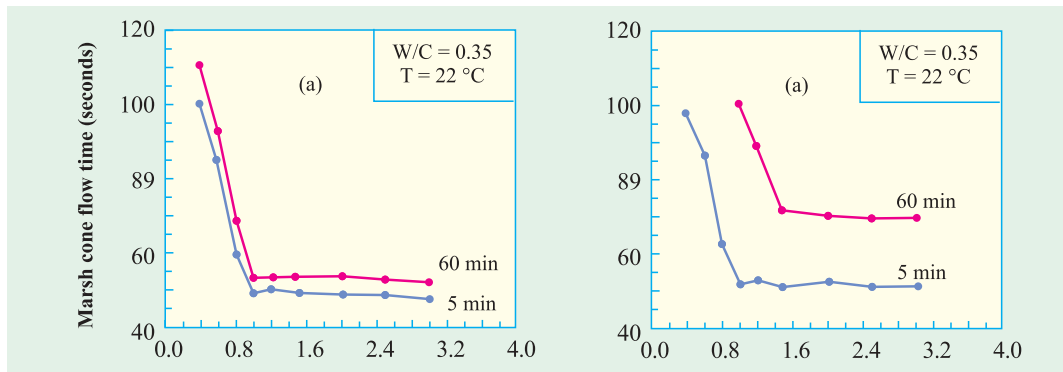
Mixing by mechanical mixer is important for consistent results.

The test could be carried out for various brands of cement and various brands of superplasticizer at different w/c ratio. Alternatively w/c ratio could be taken as fixed by Concrete Mix Design and this could be a fixed parameter and other two namely the brand of cement and type of superplasticizer could be varied to find out the optimum result. Lot of useful data could be collected from simple Marsh cone test. Each test takes hardly 15 minutes. The typical test results as obtained at Mc Bauchemie laboratory is shown in Table 5.1. It is noted that the result of the test is consistent. It is experienced that Marsh cone with aperture of 5 mm is not useful for finding the Marsh cone time of thick slurry or finding retarding effect of superplasticizer or the fluidizing effect of mortar sample. For this purpose, there are other attachments having bigger aperture of diameter 6 mm, 8 mm and 11 mm available which could be used. Fig. 5.5 shows some forms of other attachments.

Viscosity of cement paste or mortar with superplasticizer can also be measured by Brookfield Viscometer, or Roton Viscometer.



Flow time as a function of the supeplasticizer dosage



Represents the case of a fully compatible combination of cement and superplasticizer

Represents the case of incompatibility

**Table 5.1. Compatibility Study of Plasticizers and Superplasticizers with Different Cements**

Cement = 2 kg. W/C = 0.45

Sr. No.	Dosage % by wt of cement	Dosage Quantity in ml.	Type of Plasticizer	Marsh Cone Time for Cement Slurry in Seconds		
				Cement Brand I	Cement Brand II	Cement Brand III
1	0.1	2	Plasticizer A	105	110	120
2	0.1	2	Plasticizer B	72	75	103
3	0.1	2	Plasticizer C	86	88	105
4	0.5	10	Superplasticizer A	69	72	72
5	0.5	10	Superplasticizer B	59	62	65
6	0.5	10	Superplasticizer C	165	170	202
1	0.2	4	Plasticizer A	75	80	82
2	0.2	4	Plasticizer B	64	69	70
3	0.2	4	Plasticizer C	69	75	76
4	0.7	14	Superplasticizer A	63	68	66
5	0.7	14	Superplasticizer B	57	60	62
6	0.7	14	Superplasticizer C	152	156	176
1	0.3	6	Plasticizer A	75	69	70
2	0.3	6	Plasticizer B	64	65	62
3	0.3	6	Plasticizer C	69	68	65
4	0.9	18	Superplasticizer A	63	65	62
5	0.9	18	Superplasticizer B	57	55	60
6	0.9	18	Superplasticizer C	127	132	134
1	1.1	22	Superplasticizer A	58	60	60
2	1.1	22	Superplasticizer B	45	50	46
3	1.1	22	Superplasticizer C	75	83	90

From the above table it can be seen that cement brand I is showing good compatibility than the other two brands of cements with all the plasticizers and superplasticizers. If one is to choose the plasticizer and superplasticizers, one should go for plasticizer B or superplasticizer B. You also notice that superplasticizer B consistently gives very good plasticising effect.

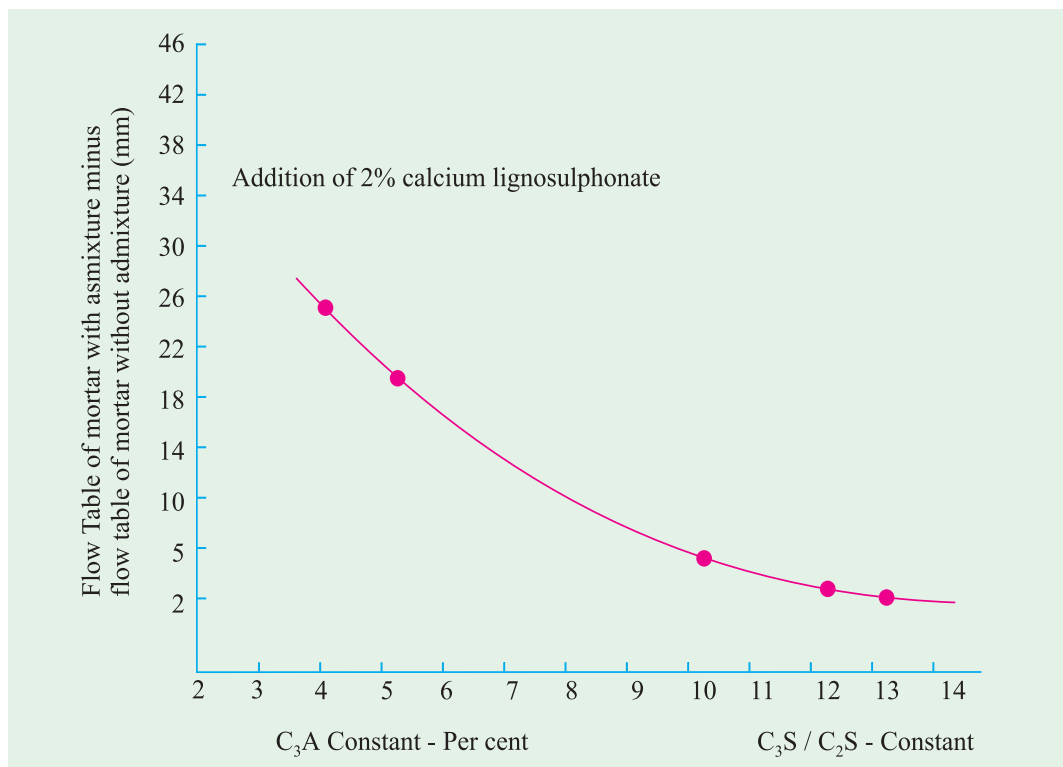
### Factors Effecting the Workability

- Type of superplasticizers
- Dosage
- Mix composition
- Variability in cement composition and properties
- Mixing procedure
- Equipments
- Others

### Type of Superplasticizers

It is a well established fact that the average molecular weight of the plasticizer is of primary importance for its efficiency as plasticizer in concrete. The higher the molecular weight, the higher is the efficiency. However, it should be noted that there is a maximum value of molecular weight beyond which efficiency is expected to decrease. It may be further noted that several intrinsic properties of the superplasticizers may influence the performance. Therefore, it is difficult to compare the efficiency of one plasticizer from the other in the absence of number of related properties of superplasticizers.

**Dosage.** It has been already explained while describing the Marsh cone test that the dosage of superplasticizer influences the viscosity of grout and hence the workability of



concrete. The optimum dosage can be ascertained from Marsh cone test if brand of cement, plasticizer and w/c ratio is already fixed. Simple Marsh cone test can give realistic dosage than manufacturers instructions which is general in nature. In our country generally low dosage is adopted for normal concreting operations. A dosage more than 2.5% by weight of cement is rarely used. But in other countries much higher dosages up to 4 to 5% are used in special situations. It has been reported in literatures that upto a dosage of about 3% there are no harmful effect on the hardening properties of concrete. Higher dosage is said to have affected the shrinkage and creep properties.

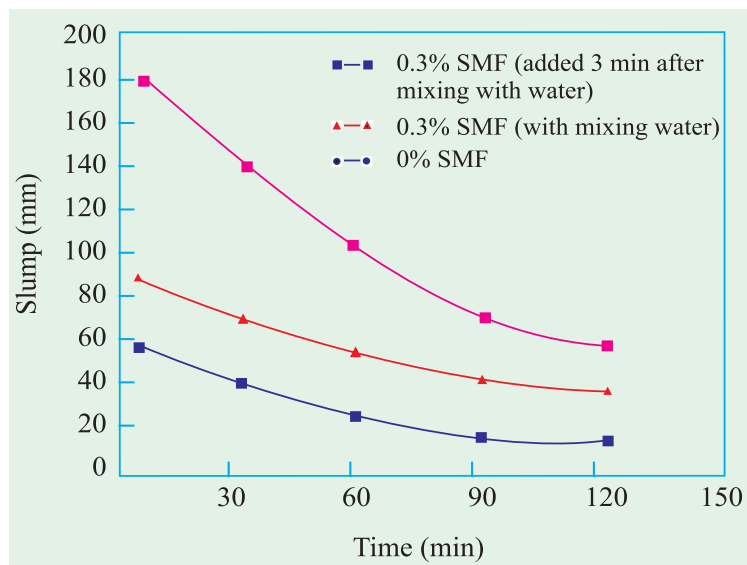
**Mix Composition.** The mix composition particularly the aggregate/cement ratio or richness of the mix, w/c ratio, and use of other supplementary cementing materials like fly ash or silica fume affects the workability. Wetter the mix better is the dispersion of cement grains and hence better workability. The size and shape of aggregate, sand grading will also have influence on the fluidifying effect.

**Variability in Cement Composition.** The variability in cement with respect to compound composition, in particular  $C_3A$  content,  $C_3S/C_2S$  ratio, fineness of cement, alkali content and gypsum content are responsible for the lack of compatibility with a particular type of superplasticizer and their performance in concrete. Out of the above  $C_3A$  content will have over-riding influence on the performance of superplasticizer. Fig. 5.6 shows the effect of  $C_3A$  content.

### Mixing Procedure

Plasticizer must be properly and intimately mixed in concrete to bring about proper dispersion with cement particles. Therefore, hand mixing is out of question. When you use concrete mixer, generally about 80% of the total water is added to the empty drum and then materials are loaded into the drum by hopper. When you use superplasticizer, it is better to add all the water to the drum keeping about one litre of water in spare. The exact quantity of superplasticizer is diluted with that one litre of water and thrown into the drum in two or three installments over the well mixed concrete so that proper dispersion of plasticizer actually takes place in the drum. Having added the plasticizer, the concrete must be mixed for about one more minute before discharging. The practice of adding superplasticizer along with the bulk mixing water is not giving good results. Experimental result showed that adding plasticizer after three minutes of mixing has yielded better results. Fig. 5.7 shows the effect of addition of water three minutes after mixing with the water.

It has been found that all over India, electrically operated small laboratory mixer is used for conducting laboratory trials. These laboratory



mixers are inefficient and they do not mix the concrete ingredients thoroughly, leave apart the efficient mixing of superplasticizers. The results obtained from the trials, using laboratory mixer, is far from realistic. In such situations the following procedure gives better consistent results.

Add all the calculated quantity of water into the drum. Then add all the quantity of cement and sand. Mix these ingredients very well. When they are well mixed, add the calculated quantity of plasticizer and thoroughly mix them together. You will notice the full action of plasticizer in fluidifying the mix. Then you add the coarse aggregates and mix them for another one minutes. When the mixer is not efficient as in the case of laboratory mixer, the above procedure of mixing will give good results.

**Equipment.** It has been discussed above that inefficient spot mixer at site or laboratory that is small mixer does not exploit the action of superplasticizer fully, often they do not even mix the concrete uniformly and properly. The fabrication of concrete mixer is not a simple job. The shape of the drum, its bottom diameter and shape, number of blades, the angle of blades, length and depth of blades, the space between drum and blade and space between the blades will have lot to do with the mixing efficiency. The manufacturers often neglect these details. Generally pan mixer show better efficiency particularly in case of small scale laboratory mixers. Such small capacity pan mixers are not generally available for trial. Some manufacturers of concrete mixers have now started fabrication and supply of pan mixers.

The mixers in the batching plant are of capacity half a cubic meter and above. They are generally of pan type. They are well designed and fabricated and as such every efficient. The mixing time is around 20 seconds. Within this short spell of 20 seconds, very intimate mixing is done. It is observed that for identical parameters concrete mixed in the batching plant gives about 20 to 30 mm more slump than trial mix carried out in laboratory using small, inefficient mixers.

**Others.** The slump value of a superplasticized concrete may also be affected on account of other admixtures used concurrently in concrete such as air-entraining agent, fly ash, slag or silica fume. The temperature and relative humidity also affect the result.

### Site Problems in the use of Superplasticizers

Some of the practical site problems in the use of superplasticizers are listed below:

- Slump of reference mix. (*i.e.*, concrete without plasticizer)
- Inefficient laboratory mixer for trial.
- Sequence of addition of plasticizer.
- Problem with crusher dust.
- Problem with crushed sand.
- Importance of shape and grading of coarse aggregate.
- Compatibility with cement.
- Selection of plasticizer and superplasticizer.
- Determination of dosage.
- Slump loss.
- How to reduce slump loss.
- Casting of cubes.
- Compaction at site.
- Segregation and bleeding.
- Finishing.
- Removal of form work.

It is not intended to discuss each of the above points separately as some of the problems are self explanatory. The points mentioned above are discussed in general and where applicable, solution to the problems are also indicated, for general guidance.

It is mentioned earlier that very stiff zero slump concrete can not be perceptibly improved at nominal dosage. Although there is improvement in rheology of matrix with the use of superplasticizers, it does not become perceptible and measurable by slump test. If the initial concrete mix is designed in such a way as to have about 2 to 3 cm slump, then only the slump could be enhanced to a high level. High dosage of plasticizer may give good slump in case of a stiff mix. But it is uneconomical. Initial slump in the reference concrete is an important consideration.

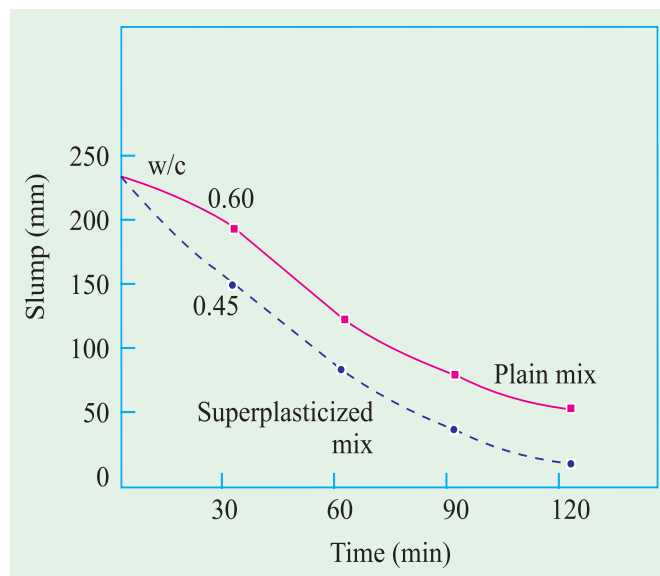
Generally available laboratory mixers are inefficient especially when small quantity of plasticizers are used for trial mix. Use of pan mixer will give better results.

The sequence and method of addition of superplasticizer is described earlier for good results.

In the years to come for large projects one will have to go for crushed sand. In spite of the modern well designed crushers, higher quantity of dust is generally present. This dust interferes with plasticizing properties of mix and hence anticipated results are not obtainable. For the construction of Mumbai-Pune express highway, they specified only the crushed sand. The initial trials presented lot of problems with the presence of excess of crusher dust when reasonable doses of superplasticizer were used. In some sectors, some contractors had to go for combination of natural sand and crushed sand. Whereas some other contracting firm managed to use only crushed sand. Whatever it is, the dust in crushed sand affects the performance of plasticizers. Incidentally, excess of crusher dust increases drying shrinkage.

For normal strength concrete upto 30 or 40 MPa, the shape of aggregate is not of primary importance. For production of high strength concrete of the order of 50 MPa or 60 MPa, the w/c ratio become so low that shape of aggregates becomes very important and also the use of superplasticizers becomes essential for the requirement of workability, particularly when concrete is to be transported over long distance and pumped. In one situation in the construction of high rise building at Mumbai where 60 MPa concrete was used, well graded, cubical shaped aggregate, specially manufactured, could solve the problem. In one of the project sites at Delhi, where aggregates flakiness index was very high, particularly in 10 mm aggregate, the achievement of high slump was found to be difficult in spite of using high dosage of superplasticizers.

In many sites, compatibility problem with cement and plasticizer becomes primary considerations. This can be solved by simple Marsh cone test. Marsh cone test also indicates the economical dosage.





Superplasticisers are costly and they operate at higher dosages. If the slump value at a point of batching and the slump value at a point of placing is known, by conducting a few field trials, it is possible to arrive at a decision whether plasticizer would be sufficient or one should go for superplasticizer. Site trials are also required to find out the dosage, the slump value and probable slump loss.

**Slump Loss.** One of the most important nagging site problem is the loss of slump. Slump at mixing point is not of much importance, but the slump at placing point is of primary importance. Often there is delay between mixing and placing. Achieving high slump at the mixer, only to be lost with time, before placing is a bad economy. Loss of slump is natural even with unplasticized concrete, but rate of loss slump is little more in case of superplasticized concrete. Fig. 5.8 indicates the slump loss with time.

Many users demand the slump value at mixing or batching plant and also specify the slump value after a delay of 1 or 2 or 3 hours period at placing point. It is not a correct specification. User should only specify the slump value at placing point after a delay of 1 or 2 or 3 hours. It should be left to the superplasticizer manufacturers or concrete supplier to supply concrete of slump value as demanded by user at the time of placing of concrete.

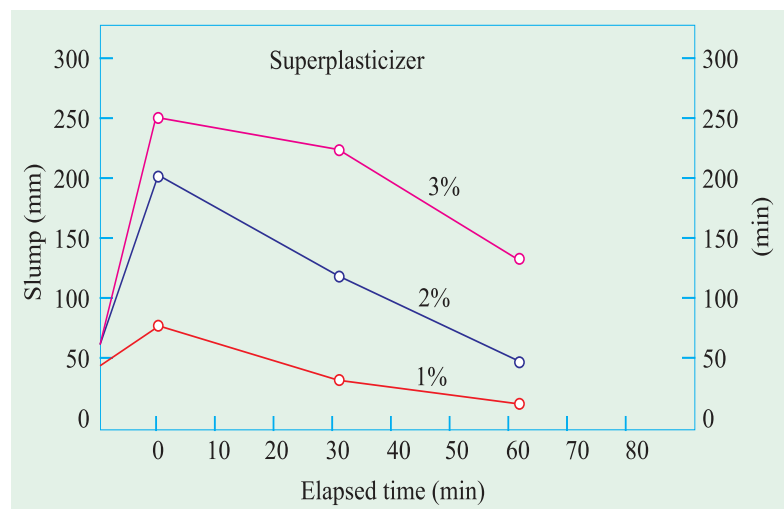
### Steps for Reducing Slump Loss

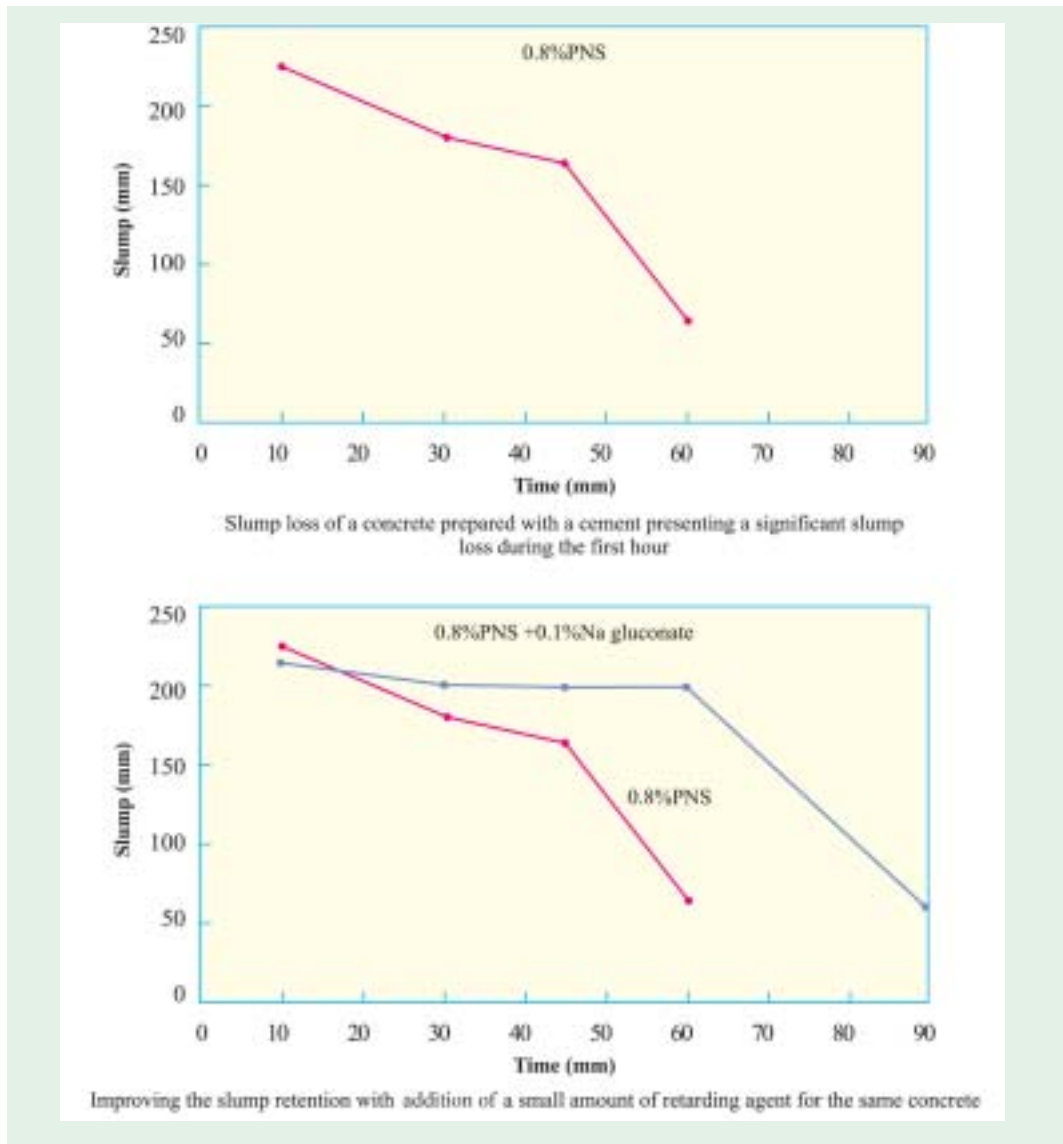
The slump loss can be managed by taking any one or more of the following actions:

- Initial high slump.
- Using retarders.
- Using retarding plasticizer or superplasticizer.
- By repetitive dose.
- By dosing at final point.
- By keeping temperature low.
- By using compatible superplasticizer with cement.

When very high slump is managed at the mixing point, even if loss of slump takes place, still the residual slump will be good enough for satisfactory placing of concrete. Although this method is not a good and economical method some time this method is adopted. Fig. 5.9.

Pure retarders are used at the time of mixing. This will keep the concrete in a plastic condition over a long time. Just before adding an appropriate dose of plasticizer or superplasticizer which will give desirable slump value for placing requirements. This is possible only when concrete is conveyed by transit mixers. Some time instead of using pure retarders and plasticizer separately, a retarding plasticizer, or retarding superplasticizer is used in an appropriate dose in the initial stage itself. The retarding





plasticizer or superplasticizers retains the slump for longer periods which may be sufficient for placing.

One of the common methods to combat the slump loss is to give repetitive doses at intervals and thereby boosting the slump so that required slump is maintained for long time. Figure 5.10 shows the typical repetitive method of using plasticizer. The time interval should be chosen in such a way that the concrete will have such a residual slump value which can be boosted up.

Sometimes a small dose of superplasticizer is added at the beginning and the slump is boosted up. When the concrete arrives at the pouring point, it will still have some residual slump but not good enough for placing by pump or by tremie. For pumping concrete you need a slump of around 100 mm and tremie placing the desirable slump is 150 mm. At this point an appropriate dose of superplasticizer is added to boost up the slump to required level.

It is a common knowledge that hydration process can be retarded by keeping the temperature of the concrete low. At low temperature the slump loss is also slow. Use of ice flakes instead of water is resorted to reduce the slump loss. Often the use of ice flakes is an additional step to reduce the slump loss.

Use of highly compatible admixture with the given cement or *vice-versa* will also reduce the problem of slump loss. A cement with low  $C_3A$  content will be of use in

this regard. In one of the limited trial conducted, 43 grade cement has shown better compatibility and performance than 33 or 53 grade cement.

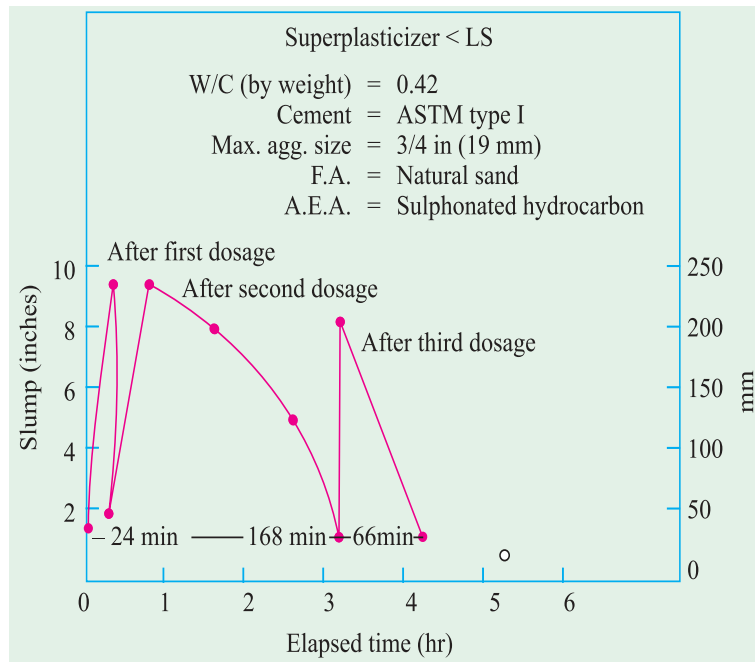
It will be shown later that the new generation superplasticizers are an effective answer for this severe problem of slump loss. Refer Fig. 5.14.

### Other Potential Problems

Sometimes, it is possible that a strong retardation and excessive air-entrainment may take place when lignosulphonates are used in large dose, particularly when the undesirable components in commercial lignosulphonates are not removed. In some superplasticizers, problems like low fluidification, rapid slump loss, severe segregation, have been reported. The problem of incompatibility seems to be one of the common problems generally met with in the field. The practical approach to solve these problems is to cross test with other plasticizers or other cement samples, and practical solutions arrived. In a overdosed mix, cement paste may become too fluid and no longer retain the coarse or even fine aggregates in suspension, causing severe segregation. In such cases either the dose could be reduced or aggregate content, particularly the sand content may be increased.

When concrete pump and placer boom are used for placing concrete, the slump requirement is around 100 mm. Suppose 100 mm slump concrete is used for a roof slab casting, such a high slump which is undesirable for roof casting, causes problems by way of segregation and bleeding particularly in the hands of inexperienced workers. Such concrete will have to be handled with care and understanding.

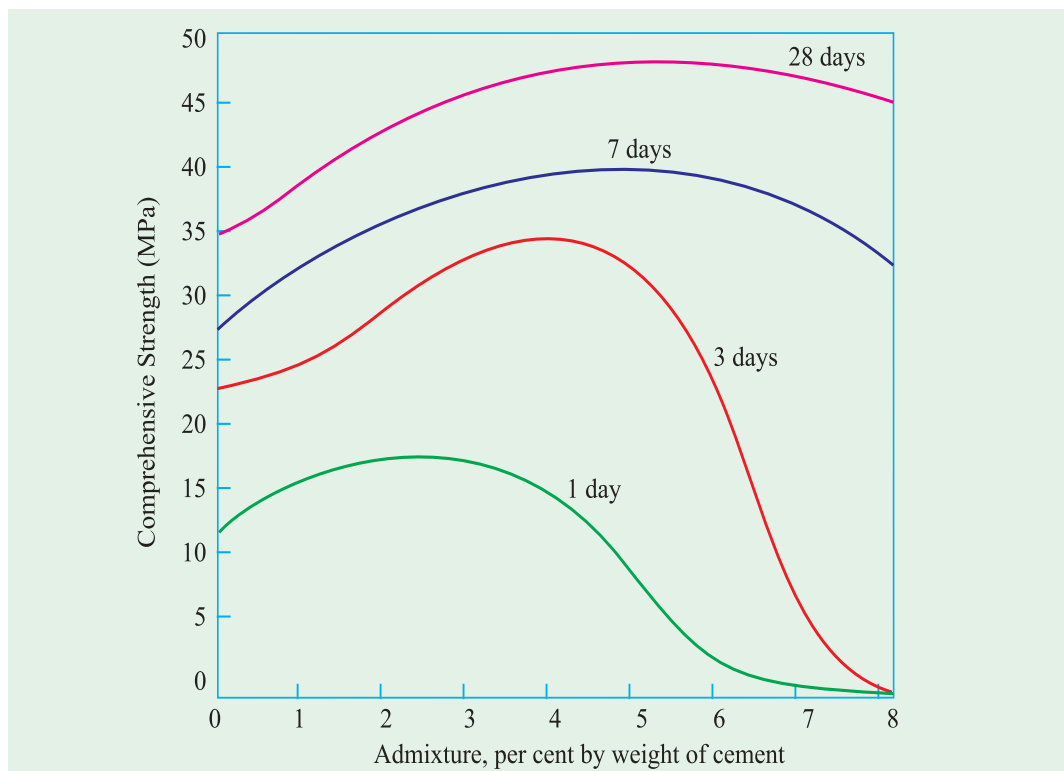
Similarly, while casting cubes using highly plasticized concrete, special care and understanding of concrete is required. Compaction of cubes can not be done in the usual method of vibrating or even tamping. If the casting of the cube is done blindly without understanding the behaviour of such plastic concrete, serious segregation occurs in the cube mould. Top half of the cube mould consists only of mortar and is devoid of coarse aggregates, with the result, that such segregated concrete cubes show very low strength.



They blame the plasticizers or cement for such low strength. Often such anomalous situations have come to the notice even with major contractors.

### Effect of Superplasticizers on the Properties of Hardened Concrete

Plasticizers or superplasticizers do not participate in any chemical reactions with cement or blending material used in concrete. Their actions are only physical in fluidizing the mix, made even with low water content. Their fluidifying action lasts only as long as the mix is in plastic condition. Once the effect of adsorbed layer is lost, the hydration process continues normally. It can be categorically said that the use of right quality of plasticizers or superplasticizers when used in usual small dose (say up to 3% by weight of cement) there is no bad effect on the properties of hardened concrete. Only in case of bad quality lignosulphonate based plasticizer is used, it may result in air-entrainment, which reduces the strength of concrete. Since plasticizers and superplasticizers improve the workability, compactability and facilitate reduction in w/c ratio, and thereby increase the strength of concrete, it contributes to the around improvement in the properties of hardened concrete. As a matter of fact, it is the use of superplasticizers, which is a pragmatic step to improve around properties of hardened concrete. The use of superplasticizer has become an unavoidable material in the modern High Performance Concrete (HPC).



It has been mentioned earlier that all plasticizers and superplasticizers exhibit certain retarding properties. These retarding properties do not make significant difference when the dosage is normal (say upto 3%). The strength parameter is not reduced beyond one day. But when plasticizers are used in higher dose, the strength development will be greatly affected in respect of one day and even three days strength. However, seven day strength and beyond,

there will not be any reduction in strength. The typical strength development of lignosulphonate type water reducing admixture is shown in Fig. 5.11.

At the same w/c ratio, naphthalene based or melamine based superplasticizers do not considerably modify the drying shrinkage of concrete. At the same consistency, they sometime reduce drying shrinkage appreciably.

The total creep is higher when concrete contains naphthalene sulphonates, at high w/c ratio (0.64). On the contrary, when w/c ratio is low, the difference in creep between samples with and without plasticizers are insignificant.

Impermeability plays a primary role on the durability of concrete and since this depends on w/c ratio, superplasticizers should exert a favourable effect. Superplasticizers, owing to the reduction in w/c ratio, reduce the penetration of chlorides and sulphate into the concrete and, therefore, improve their resistance to the de-icing effect of salt or sea water. For the same reason, the resistance to sulphate attack is also improved.

Suffice it to say that the use of plasticizer or superplasticizer, could lead to the reduction in w/c ratio, without affecting the workability and thereby concrete becomes stronger. Therefore, it will contribute to the alround improvement of hardened properties of concrete.

### New Generation Superplasticizers

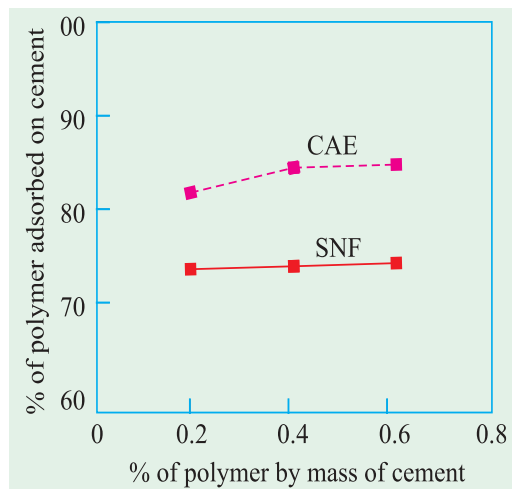
It has been amply brought out that superplasticizers are used, (a) to increase the workability without changing the mixture composition, (b) to reduce the amount of mixing water, in order to reduce the w/c ratio which results in increase of strength and durability, and (c) to reduce both water and cement in order to cut cost and incidentally to reduce creep, shrinkage, and heat of hydration.

One of the most important drawbacks of traditional superplasticizers such as SMF or SNF or MLS, is the slump loss. Slump loss with time presents a serious limitation on the advantages of superplasticizers. More recently in Europe and Japan, new generation superplasticizers – all based on family of acrylic polymers (AP) have been investigated. The new generation plasticizers have been listed on page 109 under classification

### Carboxylated Acrylic Ester (CAE)

Out of these, two types namely carboxylated acrylic ester (CAE) copolymer and multicarboxylatether (MCE) are of particular interest.

The carboxylated Acrylic Ester contains carboxylic (COO<sup>-</sup>) instead of sulphonic (SO<sub>3</sub><sup>-</sup>) groups present in the SMF or SNF. It was thought, as explained earlier, that the dispersion of cement grain is caused by the electrostatic repulsion, in case of SMF and SNF. But the recent experiments conducted by M. Collpardi *et al* and Y.O. Tanaka *et al* did not confirm the above mechanism for the plasticizing action of the acrylic polymers. Table 5.2 indicates that AP based superplasticizers produce negligible Zeta potential change (0.3 to 5.0 mV), in contrast to SNF – based superplasticizers (23–28 mV), in aqueous suspensions of cement particles.<sup>5.4</sup>



**Table 5.2. Zeta potential of cement particles in suspension with superplasticizers<sup>5.4</sup>**

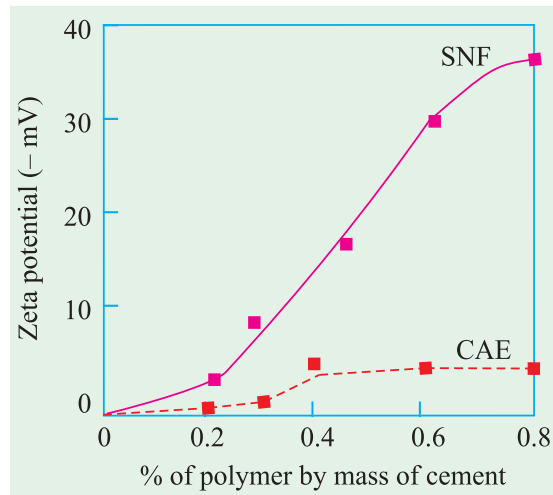
Superplasticizers	Main component	Zeta-potential (-mV)
A	AP*	5.0
B	AP	0.3
C	AP	1.0
D	AP	4.0
E	AP	4.0
F	AP	2.0
G	SNF	23.0
H	SNF	28.0

\*AP = Polycarboxylate type

Figure 5.12 and Fig. 5.13 show the adsorption on cement particles and Zeta-potential measurements of CAE in comparison with SNF. In particular it is seen that adsorption of CAE is about 85% when compared to adsorption of 75% in case of SNF. Fig. 5.13 indicate that the Zeta potential of cement particle mixed with CAE appeared to be much lower than that of SNF.

It could be inferred that in case of AP-based admixtures, the increase in fluidity is not because of electrostatic repulsion associated with Zeta potential but would seem to be the higher polymer adsorption and steric hindrance effect. The new family of superplasticizers based on acrylic polymers, show the following characteristics:

- Flowing concrete can be produced at lower w/c ratio.
- The effectiveness does not depend on the addition procedure (immediate or delayed).
- The slump loss is much reduced than the traditional sulphonated superplasticizers.

**Table 5.3. Effect of method of addition of NSF or CAE superplasticizer on the slump of concrete mix<sup>5.5</sup>**

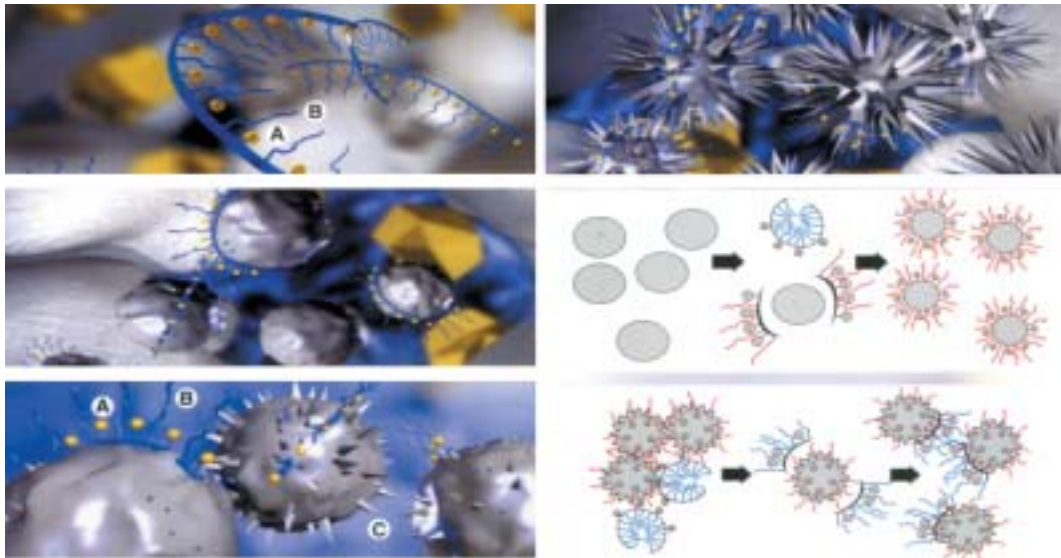
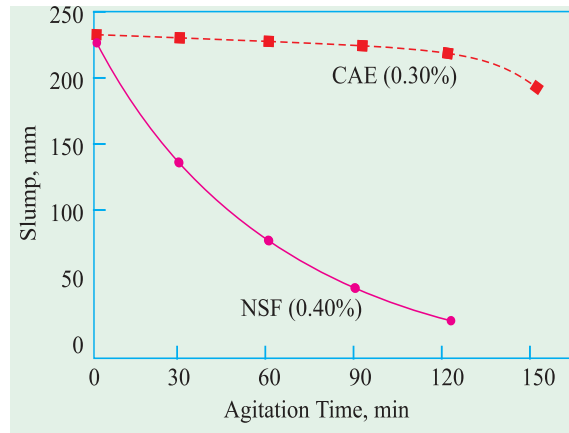
Type	Admixture		W/C Ratio	Slump (mm)
	Dosage* (%)	Method of Addition**		
NSF	0.48	immediate	0.40	100
NSF	0.48	delayed	0.40	230
CAE	0.30	immediate	0.39	230
CAE	0.30	delayed	0.39	235

\*As dry polymer by weight of cement.

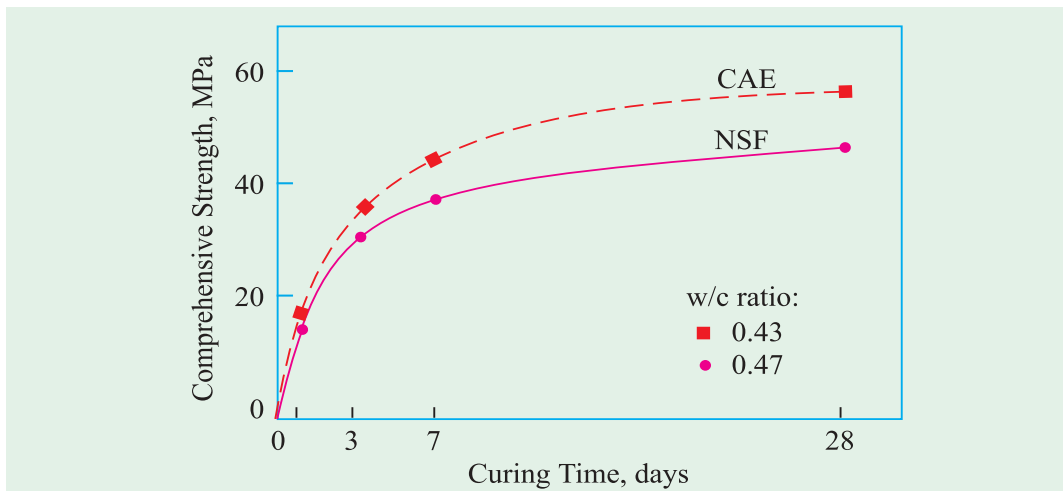
\*\* Immediate: admixture with mixing water. Delayed: admixture after 1 min of mixing.

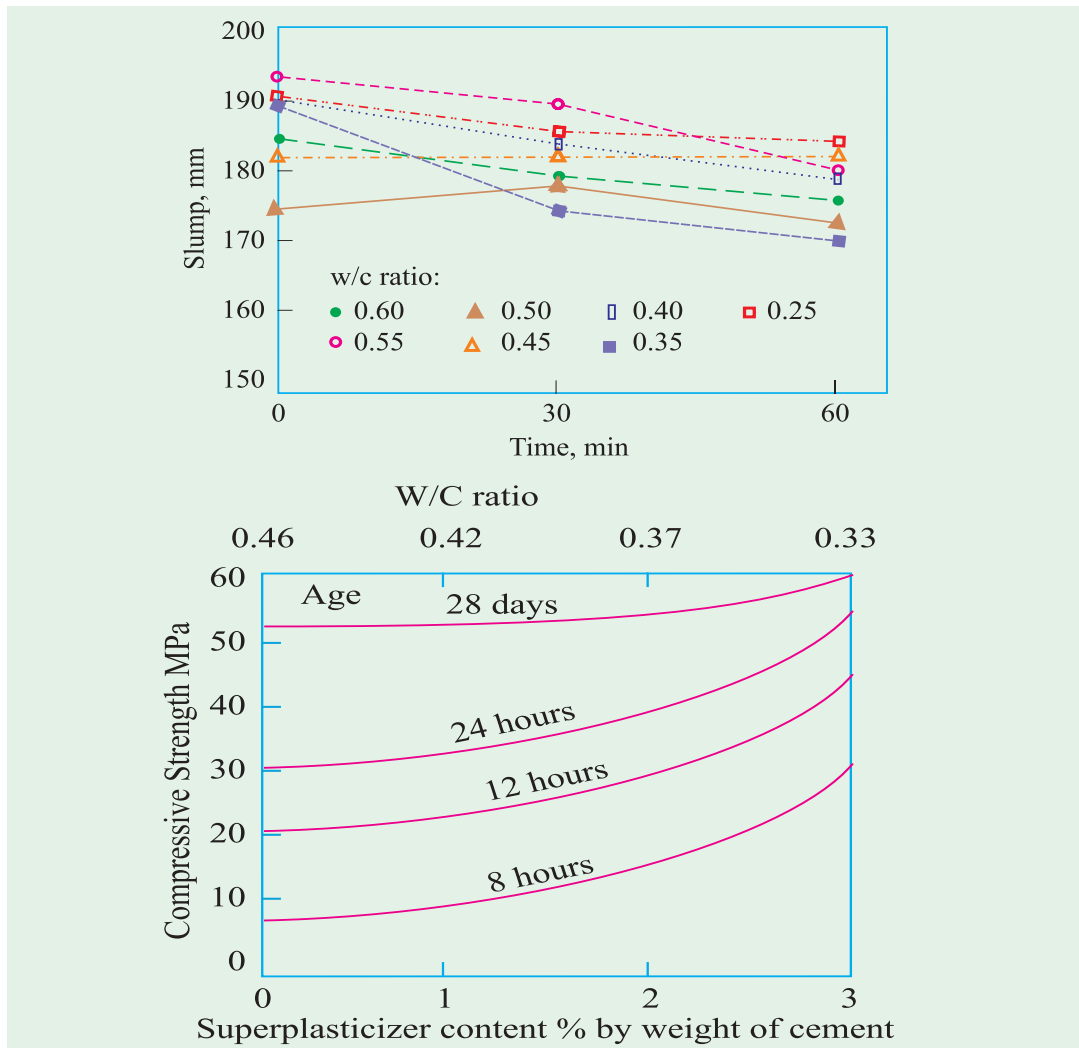
The properties of CAE is shown in Table 5.3 and in Fig. 5.14 and Fig. 5.15 which are self explanatory about the superiority of CAE with respect to fluidifying effect, loss of slump and compressive strength. Fig. 5.16 shows the typical slump loss for various w/c ratio.

It is pointed again that increase in compressive strength is on account of the ability of CAE to reduce a higher water content for the same workability.



Mechanism of action of acrylic based new generation superplasticizers works on both electrostatic repulsion and steric hindrance (Courtesy : MBT)





Superplasticizers are sometime used for high early strength. The high early strength is generally obtained because of its ability to reduce the water content and, therefore w/c which develops high early strength and secondly such superplasticizers will have such a base that will not cause much retarding effect on the concrete. Fig. 5.17 shows the influence of superplasticizers on the early strength of concrete.

### Multicarboxylatether

The new generation of superplasticizers which are based on poly-carboxylatether with the generic name of multicarboxylatether (MCE) is found more suitable for production of High Performance Concrete. The properties of these superplasticizers are:

- Excellent flowability at low w/c ratio
- High reduction of water
- Lower slump loss with time
- Shorter retardation time
- Very high early strength
- It works at low dosages



## 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. Retarders are used to overcome the accelerating effect of high temperature on setting properties of concrete in hot weather concreting. The retarders are used in casting and consolidating large number of pours without the formation of cold joints. They are also used in grouting oil wells. Oil wells are sometimes taken upto a depth of about 6000 meter deep where the temperature may be about 200°C. The annular spacing between the steel tube and the wall of the well will have to be sealed with cement grout. Sometimes at that depth stratified or porous rockstrata may also require to be grouted to prevent the entry of gas or oil into some other strata. For all these works cement grout is required to be in mobile condition for about 3 to 4 hours, even at that high temperature without getting set. Use of retarding agent is often used for such requirements.

Sometimes concrete may have to be placed in difficult conditions and delay may occur in transporting and placing. In ready mixed concrete practices, concrete is manufactured in central batching plant and transported over a long distance to the job sites which may take considerable time. In the above cases the setting of concrete will have to be retarded, so that concrete when finally placed and compacted is in perfect plastic state.

Retarding admixtures are sometimes used to obtain exposed aggregate look in concrete. The retarder sprayed to the surface of the formwork, prevents the hardening of matrix at the interface of concrete and formwork, whereas the rest of the concrete gets hardened. On removing the formwork after one day or so, the unhardened matrix can be just washed off by a jet of water which will expose the aggregates. The above are some of the instances where a retarding agent is used.

Perhaps the most commonly known retarder is calcium sulphate. It is interground to retard the setting of cement. The appropriate amount of gypsum to be used must be determined carefully for the given job. Use of gypsum for the purpose of retarding setting time is only recommended when adequate inspection and control is available, otherwise, addition of excess amount may cause undesirable expansion and indefinite delay in the setting of concrete.

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. These chemicals may have variable action on different types of cement when used in different quantities. Unless experience has been had with a retarder, its use as an admixture should not be attempted without technical advice. Any mistake made in this respect may have disastrous consequences.

Common sugar is one of the most effective retarding agents used as an admixture for delaying the setting time of concrete without detrimental effect on the ultimate strength. Addition of excessive amounts will cause indefinite delay in setting. At normal temperatures addition of sugar 0.05 to 0.10 per cent have little effect on the rate of hydration, but if the quantity is increased to 0.2 per cent, hydration can be retarded to such an extent that final set may not take place for 72 hours or more. Skimmed milk powder (casein) has a retarding effect mainly due to sugar content.

Other admixtures which have been successfully used as retarding agents are Ligno sulphonic 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. This also increases 28 days compressive strength by 10 to 20 per cent. Materials like mucic

acid, calcium acetate and a commercial products by name "Ray lig binder" are used for set retarding purposes. These days admixtures are manufactured to combine set retarding and water reducing properties. They are usually mixtures of conventional water reducing agents plus sugars or hydroxylated carboxylic acids or their salts. Both the setting time and the rate of strength build up are effected by these materials. This is shown in Table 5.4.

**Table. 5.4. Effect of retarding/water-reducing admixtures on setting time and strength build up**

Admixture addition litres/50 kgs.	Setting time hrs.		W : C ratio	Compressive Strength MPa		
	Initial	Final		3 days	7 days	28 days
0	4.5	9	0.68	20	28	37
0.14	8.0	13	0.61	28	36	47
0.21	11.5	16	0.58	30	40	50
0.28	16.0	21	0.58	30	42	54

### Retarding Plasticizers

It is mentioned earlier that all the plasticizers and superplasticizers by themselves show certain extent of retardation. Many a time this extent of retardation of setting time offered by admixtures will not be sufficient. Instead of adding retarders separately, retarders are mixed with plasticizers or superplasticizers at the time of commercial production. Such commercial brand is known as retarding plasticizers or retarding superplasticizers. ASTM type D is retarding plasticizers and ASTM type G is retarding superplasticizer. In the commercial formulation we have also retarding and slump retaining version.

Retarding plasticizers or superplasticizers are important category of admixtures often used in the Ready mixed concrete industry for the purposes of retaining the slump loss, during high temperature, long transportation, to avoid construction or cold joints, slip form construction and regulation of heat of hydration.

One must be careful in the selection of such ready made retarding admixtures. On account of heterogeneous nature and different molecular weight of retarders used with plasticizers, they tend to separate out. It happens when sugar solution is used as cheap retarders. When retarders like gluconate is used such separation or settlement of retarders do not happen. It is cautioned that such retarding plasticizers should always be shaken thoroughly or well stirred before use. There are cases that settlement of retarders from rest of the ingredients causing excessive retardation and failure of structures.

### Accelerators

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

- permit earlier removal of formwork;
- reduce the required period of curing;
- advance the time that a structure can be placed in service;
- partially compensate for the retarding effect of low temperature during cold weather concreting;
- in the emergency repair work.

Table 5.5. Physical Requirements According to IS 9103 : 1999

Sl No.	Requirements	(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)	(9)
								Accelerating Admixture	Retarding Admixture		
i.	Water content, percent of control sample, Max	—	—	—	—	95	—	—	80	80	7.2.5
ii.	Slump	—	—	—	—	—	—	—	Not more than 15 mm below that of the control mix concrete	—	7.2.1
iii.	Time of setting, allowable deviation from control sample hours:										7.2.3
	Initial										
	Max	-3	+3	±1	—	—	—	—	—	+4	
	Min	-1	+1	—	—	—	—	—	+1.5	+1	
	Final										
	Max	-2	+3	±1	—	—	—	—	±1.5	±3	
	Min	-1	+1	—	—	—	—	—	—	—	
iv.	Compressive strength, percent of control sample, Min										8.2.1
	1 day	—	—	—	—	—	—	—	140	—	
	3 days	125	90	110	90	110	90	125	125	125	
	7 days	100	90	110	90	110	90	125	125	125	
	28 days	100	90	110	90	110	90	115	115	115	
	6 months	90	90	100	90	100	90	100	100	100	
	1 year	90	90	100	90	100	90	100	100	100	

Table 5.5 (Continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
v.	Flexural strength, percent of control sample, <i>Min</i>							8.2.2
	3 days	110	90	100	90	110	110	
	7 days	100	90	100	90	100	100	
	28 days	90	90	100	90	100	100	
vi.	Length change, percent increase over control sample, <i>Max</i>							8.2.3
	28 days	0.010	0.010	0.010	0.010	0.010	0.010	
	6 months	0.010	0.010	0.010	0.010	0.010	0.010	
	1 year	0.010	0.010	0.010	0.010	0.010	0.010	
vii.	Bleeding, percent increase over control sample, <i>Max</i>	5	5	5	5	5	5	7.2.4
viii.	Loss of workability	—	—	—	—	At 45 min the slump shall be not less than that of control mix concrete at 15 min	At 2 h, the slump shall be not less than that of control mix concrete at 15 min	7.2.1.2
ix.	Air content (%) <i>Max, over control</i>	—	—	—	—	1.5	1.5	

Table 5.6. Specification for various types of admixtures according to ASTM 494-82

Property	Type A, water reducing and retarding	Type B retarding	Type C, accelerating	Type D, water reducing and retarding	Type E, water reducing and accelerating	Type F, water reducing, high range	Type G, water reducing high range and retarding
Water content, max percent of control	95	—	—	95	95	88	88
Time of setting, allowable deviation from control, min initial: at least not more than	— 60 earlier nor 90 later	60 later 210 later	60 earlier 210 earlier	60 later 210 later	60 earlier 210 earlier	— 60 earlier nor 90 later	60 later 210 later
Final: at least not more than	— 60 earlier nor 90 later	— 210 later	60 earlier —	— 210 later	60 earlier —	— 60 earlier nor 90 later	— 210 later
Compressive strength, min percent of control <sup>a</sup>							
1 day	—	—	—	—	—	140	125
3 days	110	90	125	110	125	125	125
7 days	110	90	100	110	110	115	115
28 days	110	90	100	110	110	110	110
6 months	100	90	90	100	100	100	100
1 year	100	90	90	100	100	100	100
Flexural strength, min percent control <sup>a</sup>							
3 days	100	90	110	100	110	110	110
7 days	100	90	100	100	100	100	100
28 days	100	90	90	100	100	100	100

Table 5.6 (Continued)

Length Change, max shrinkage (alternative requirements) <sup>b</sup>	135	135	135	135	135	135	135	135	135
Percent of control	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Increase over control									
Relative durability factor, min <sup>c</sup>	80	80	80	80	80	80	80	80	80

<sup>a</sup> The compressive and flexural strength of the concrete containing the admixture under test at any test age shall be not less than 90 per cent of that attained at any previous test age. The objective of this limit is to require that the compressive and flexural strength of the concrete containing the admixture under test shall not decrease with age.

<sup>b</sup> Alternative requirements, percent of control limit applies when length change of control is 0.030 percent or greater; increase over control limit applies when length change of control is less than 0.030 percent.

<sup>c</sup> This requirement is applicable only when the admixture is to be used in air-entrained concrete which may be exposed to freezing and thawing while wet.

Table 5.7. Specification for various types of admixtures according to BS 5075: Part 1:1982.

Type of Admixture	Water reduction percent	Compaction factor	STIFFENING TIME		COMPRESSIVE STRENGTH	
			Time from completion of mixing to reach a resistance to penetrate* of: 0.5 MPa (70 psi) 3.5 MPa (500 psi)	Time from completion of mixing to reach a resistance to penetrate* of: 0.5 MPa (70 psi) 3.5 MPa (500 psi)	percent of control mix (minimum)	Age
Accelerating	—	Not more than 0.02 below control mix	More than 1 hr.	At least 1 hr less than control mix	125	24 hr
	8	—	—	—	95	28 days
Retarding	—	Not more than 0.02 below control mix	At least 1 hr longer than control mix	—	90	7 days
	8	—	—	—	95	28 days
Normal-reducing	—	At least 0.03 above control mix	—	—	90	7 days
	8	Not more than 0.02 below control mix	Within 1 hr of control mix	Within 1 hr of control mix	110	28 days
Accelerating water-reducing	—	At least 0.03 above control mix	—	—	125	24 hrs
	8	Not more than 0.02 below control mix	More than 1 hr.	At least 1 hr less than control mix	90	28 days
Retarding water-reducing	—	At least 0.03 above control mix	—	—	90	7 days
	8	Not more than 0.02 below control mix	At least 1 hr longer than control mix	—	90	28 days

\* The penetration is determined by a special brass rod of 6.175 mm in diameter.

The air content with no water reduction shall not be more than 2 per cent higher than that of the control mix, and not more than total of 3 per cent.

Table 5.8. Specification for superplasticizing admixture according to BS 5075: Part 3:1985.

Type of Admixture	Water reduction per cent	Workability	Loss of slump	STIFFENING TIME		COMPRESSIVE STRENGTH	
				Time from completion of mixing to reach a resistance to penetrate* of: 0.5 MPa (70 psi)	Time from completion of mixing to reach a resistance to penetrate* of: 3.5 MPa (500 psi)	Percentage of control mix (minimum)	Age
Superplasticizing	—	Flow table: 510 to 620 mm	At 45 min not less than that of control mix at 10 to 15 min. At 4 h not more than that of control mix at 10 to 15 min.	—	—	90	7 days
				—	—	90	28 days
Superplasticizing	16	Slump: not more than 15 mm below that of control mix	—	Within 1 hour of control mix	Within 1 hour of control mix	140	24 h
				—	—	125	7 days
Retarding superplasticizing	—	Flow table: 510 to 620 mm	At 4 h not less than that of control mix at 10 to 15 min.	—	—	90	7 days
				—	—	90	28 days
Retarding superplasticizing	16	Slump: not more than 15 mm below that of control mix	—	1 to 4 hour longer than control mix	—	125	7 days
				—	—	115	28 days

\* The penetration is determined by a special brass rod of 6.175 mm in diameter. The air content with no water reduction shall not be more than 2 per cent higher than that of the control mix, and not more than total of 3 per cent.



Table 5.9. List of some of the commercial plasticizers and superplasticizers manufactured in India.

Sl.No.	Name and Address	Brand Name	Description	Function
1.	Mc-Bauchemie (Ind.) Pvt. Ltd. 201, Vardhaman Chambers Sector-17, Vashi Navi Mumbai-400703	(a) Emce Plast BV	Water reducing plasticizer	Increases workability at low dosage
		(b) Emce Plast 4 BV	Water reducing and retarding plasticizer	-do-
		(c) Emce Plast RP	Superplasticizer	Produces flowing pumpable concrete
		(d) Zentrament Super BV	Superplasticizer	Produces high early strength—makes the mix flowable and pumpable
		(e) Zentrament F BV	Superplasticizer	Excellent compatibility with all cements
		(f) Centriplast FF 90	Superplasticizer based on melamine formaldehyde	High performance retarding superplasticizer—it maintains slump for longer time
		(g) Zentrament T5 BV	Retarding superplasticizer	Good plasticizing effect
		(h) Muraplast FK 61	Superplasticizer	Universal retarding plasticizer
		(i) MC-Erstarrungsbremse K T3	-do-	
		2.	Fosroc Chemicals (Ind) Ltd. Hafeeza Chamber, 2nd Floor 111/74, K.H. Road Bangalore-560027	(a) Conplast 211
(b) Conplast P 509	- do -			High performance plasticizer
(c) Conplast 337	Superplasticizer			Gives high workability
(d) Conplast 430	- do -			- do -
(e) Conplast RP 264	Plasticizer			Retards setting time
(f) Conplast NC	- do -			Accelerates initial setting time

Table 5.9. (Continued)

3.	Sika Qualcrete Pvt. Ltd. 24 B, Park Street Calcutta-16	(a) Plastiment BV 40	Plasticizer	Water reducing plasticizer
		(b) Sikament 300, 350, 400	- do -	- do -
		(c) Sikament FF	Superplasticizer	High range water reducer
		(d) Sikament 600	- do -	Sett retarding agents
4.	Roffe Constrn. Chemicals Pvt. Ltd., 12 C, Vikas Centre S.V. Road, Santacruz (W) Mumbai-54	(a) Roff Plast 330	Plasticizer	Water reducer
		(b) Roff Super Plast 321	Superplasticizer	Gives higher early strength
		(c) Roff Super Plast 820	- do -	- do -
		(d) Roff Super Plast 840	- do -	High performance retarder

In the past one of the commonly used materials as an accelerator was calcium chloride. But, now a days it is not used. Instead, some of the soluble carbonates, silicates fluosilicates and some of the organic compounds such as triethenolamine are used. Accelerators such as fluosilicates and triethenolamine are comparatively expensive.

The recent studies have shown that calcium chloride is harmful for reinforced concrete and prestressed concrete. It may be used for plain cement concrete in comparatively high dose. The limits of chloride content in concrete is given in chapter on Durability of Concrete.

Some of the accelerators produced these days are so powerful that it is possible to make the cement set into stone hard in a matter of five minutes or less. With the availability of such powerful accelerator, the under water concreting has become easy. Similarly, the repair work that would be carried out to the waterfront structures in the region of tidal variations has become easy. The use of such powerful accelerators have facilitated, the basement waterproofing operations. In the field of prefabrication also it has become an invaluable material. As these materials could be used up to 10°C, they find an unquestionable use in cold weather concreting.

Some of the modern commercial accelerating materials are Mc-Schnell OC, Mc-Schnell SDS, Mc-Torkrethilfe BE, manufactured by Mc-Bauchemic (Ind) Pvt. Ltd. MC-Torkrethilfe BE is a material specially formulated to meet the demand for efficient and multifold properties desired for sprayed concrete and shotcreting operations. A field trial is essential to determine the dose for a given job and temperature conditions when the above materials are used.

### Accelerating Plasticizers

Certain ingredients are added to accelerate the strength development of concrete to plasticizers or superplasticizers. Such accelerating superplasticizers, when added to concrete result in faster development of strength. The accelerating materials added to plasticizers or superplasticizers are triethenolamine chlorides, calcium nitrite, nitrates and fluosilicates etc. The accelerating plasticizers or accelerating superplasticizers manufactured by well known companies are chloride free.

Table 5.5, Table 5.6, Table 5.7 and 5.8 shows the specification limits of IS 9103 of 1999, ASTM 494 of 1982, BS 5075 part I of 1982 and BS part 3 of 1985 respectively. Table 5.9 gives the list of some of the commercial plasticizers and superplasticizers manufactured in India.

### Air-entraining Admixture

Perhaps one of the important advancements made in concrete technology was the discovery of air entrained concrete. Since 1930 there has been an ever increasing use of air entrained concrete all over the world especially, in the United States and Canada. Due to the recognition of the merits of air entrained concrete, about 85 per cent of concrete manufactured in America contains one or the other type of air entraining agent. So much so that air entraining agents have almost come to be considered a necessary 'fifth ingredient' in concrete making.

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 air voids present in concrete can be brought under two groups:

- (a) Entrained air
- (b) Entrapped air.

Entrained air is intentionally incorporated, minute spherical bubbles of size ranging from 5 microns to 80 microns distributed evenly in the entire mass of concrete. The entrapped air is the voids present in the concrete due to insufficient compaction. These entrapped air voids may be of any shape and size normally embracing the contour of aggregate surfaces. Their size may range from 10 to 1000 microns or more and they are not uniformly distributed throughout the concrete mass.

### **Air entraining agents**

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.
- ( d ) Water soluble soaps of resin acids, and animal and vegetable fatty acids.
- ( e ) Miscellaneous materials such as the sodium salts of petroleum sulphonic acids, hydrogen peroxide and aluminium powder, etc.

There are a number of air entraining agents available in the market. The common air entraining agents in United States are Vinsol resin, Darex, N Tair, Airalon, Orvus, Teepol, Petrosan and Cheecol. Out of these the most important air entraining agents which at one time enjoyed world-wide market are Vinsol resin and Darex.

In India, large scale use of air entrained concrete is not being practised, primarily due to the fact that frost scaling of concrete is not a serious problem in our country so far. However, the advantages of the use of air entrained concrete have been realised for the construction of multi-purpose dams. Air entrained concrete has been used in the construction of Hirakud dam, Koyna dam, Rihand dam etc. In these dams, to start with, American air entraining agents such as Vinsol resin, Darex etc. were used. Later on in 1950s certain indigenous air entraining agents were developed. They are Aerosin—HRS., Rihand A.E.A., Koyna, Ritha powder, Hico, etc. Now modern admixture manufacturing companies are manufacturing a number of commercial air entraining agents. MC-Mischoel LP, MC-Mischoel AEA, Complast AE 215, Roff AEA 330 are some of the commercial brands available in India.

### **Factors affecting amount of air entrainment**

The manufacture of air entrained concrete is complicated by the fact that the amount of air entrainment in a mix is affected by many factors; the important ones are:

- (a) The type and quantity of air entraining agent used.
- (b) Water/cement ratio of the mix.
- (c) Type and grading of aggregate.
- (d) Mixing time.
- (e) The temperature.
- (f) Type of cement.
- (g) Influence of compaction.
- (h) Admixtures other than air entraining agent used..

Different air entraining agents produce different amounts of air entrainment, depending upon the elasticity of the film of the bubble produced, and the extent to which the surface tension is reduced. Similarly, different quantities of air entraining agents will result in different

amounts of air entrainment. Water/cement ratio is one of the important factors affecting the quantity of air. At very low water/cement ratio, water films on the cement will be insufficient to produce adequate foaming action. At intermediate water/cement ratio (*viz.* 0.4 to 0.6) abundant air bubbles will be produced. But at a higher water/cement ratio although to start with, a large amount of air entrainment is produced, a large proportion of the bubbles will be lost progressively with time. The grading of aggregate has shown good influence on the quantity of air entrainment. It was established that the quantity of air increased from the lowest fineness modulus of sand to a peak at about F.M. of 2.5, and, thereafter, decreased sharply. The sand fraction of 300 and 150 microns showed a significant effect on the quantity of air entrainment. The higher quantity of these fractions resulted in more air entrainment.

The amount of air entrainment is found to increase with the mixing time upto a certain time and thereafter with prolonged mixing the air entrainment gets reduced. The temperature of concrete at the time of mixing was found to have a significant effect on the amount of air entrainment. The amount of air entrainment decreases as the temperature of concrete increases. The constituents of the cement especially the alkali content plays an important part in the entrainment of air in concrete. Similarly, the fineness of cement is also a factor.

Air content is also reduced by the process of compaction, on account of the movement of air bubbles to the surface and destruction. It is estimated that as much as 50 per cent of the entrained air may be lost after vibration for 2 1/2 minutes and as much as 80 per cent may be lost by vibration for 9 minutes. The experiments conducted at Hirakud dam indicated that an air content of 10.5 per cent after 30 sec of vibration came down to 6 per cent after 180 sec of vibration. The other admixtures used in conjunction with air entraining agents will also significantly affect the amount of air entrained. The use of fly ash in concrete will reduce the amount of air entrained. Similarly, the use of calcium chloride also has the tendency to reduce and limit air entrainment.

### **The Effect of Air Entrainment on the Properties of Concrete**

Air entrainment will effect directly the following three properties of concrete:

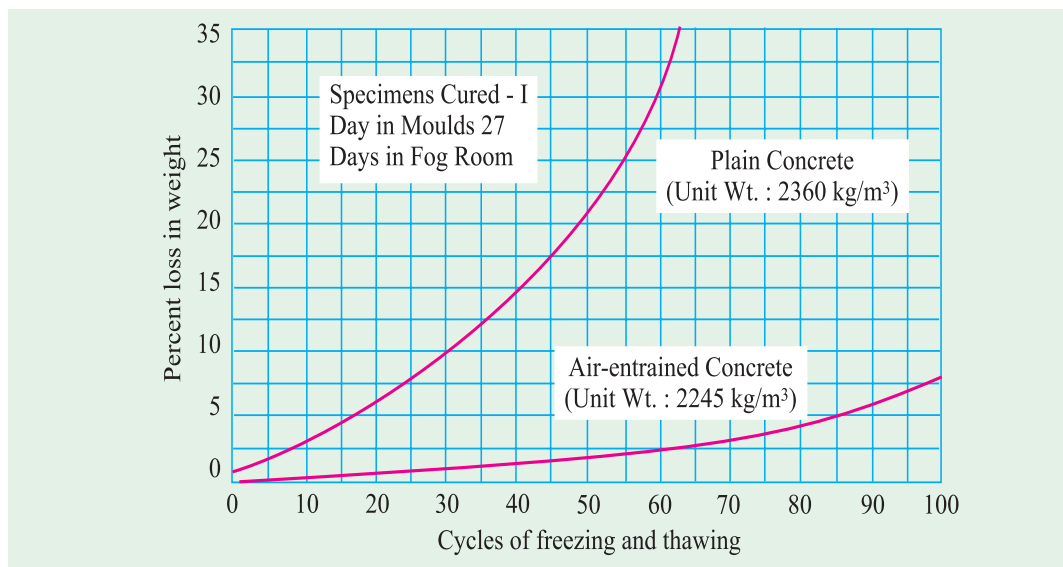
- (a) Increased resistance to freezing and thawing.
- (b) Improvement in workability.
- (c) Reduction in strength.

Incidentally air entrainment will also effect the properties of concrete in the following ways:

- (a) Reduces the tendencies of segregation.
- (b) Reduces the bleeding and laitance.
- (c) Decreases the permeability.
- (d) Increases the resistance to chemical attack.
- (e) Permits reduction in sand content.
- (f) Improves placeability, and early finishing.
- (g) Reduces the cement content, cost, and heat of hydration.
- (h) Reduces the unit weight.
- (i) Permits reduction in water content.
- (j) Reduces the alkali-aggregate reaction.
- (k) Reduces the modulus of elasticity.

### Resistance to Freezing and Thawing

The greatest advantage derived from the use of air entrained concrete is the high resistance of hardened concrete to scaling due to freezing and thawing. It is found that when ordinary concrete is subjected to a temperature below freezing point, the water contained in the pore of the concrete freezes. It is well known that the volume of ice is about 10 per cent higher than the corresponding volume of water. Hence, the ice formed in the pores of hardened concrete exerts pressure. The cumulative effect of this pressure becomes considerable, with the result that surface scaling and disruption of concrete at the weaker section takes place. Similarly, surface scaling and disruption also takes place in plain concrete when subjected to the action of salt used for deicing purpose. Similar pattern of failure of plain concrete is also noticed in concrete structures at the tidal zone and spray zone. It has been

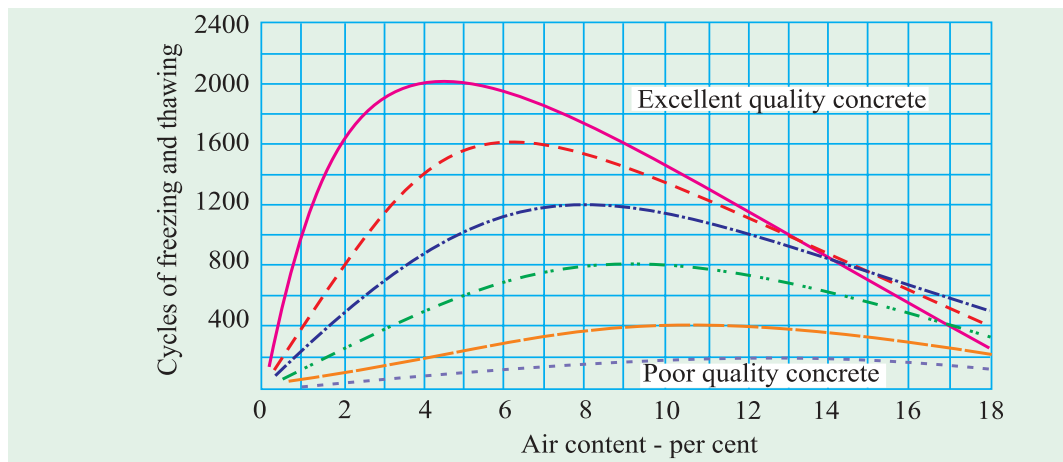


firmly established that air entrainment in concrete increases the resistance by about three to seven times in such situations.

Modification of pore structure is believed to be responsible for the marked improvement in resistance to frost attack. In ordinary concrete, there may exist bigger voids inter-connected by capillaries, latter being largely formed by the bleeding. But in the air entrained concrete though the total air voids are more, the voids are in the form of minute, discrete bubbles of comparatively uniform size and regular spherical shape. This air void system reduces the tendency for the formation of large crystals of ice in the concrete. Secondly, the inter-connected air voids system acts as buffer space to relieve the



Air Entrainment increases the durability of concrete in snowbound region.



internal pressure. Fig. 5.18 shows the relative durability of plain and air entrained concrete.

The resistance of concrete to freezing and thawing was measured by Blanks by means of durability factor which he defined as the number of cycles of freezing and thawing to produce failure divided by 100. The curves given by Blanks are reproduced in Fig. 5.19 to show the relationships between the durability and the air content for good quality concrete and poor quality concrete. It can be seen that excellent quality concrete with 4 per cent air entrainment withstood upto 2000 cycles of freezing and thawing before disintegration, whereas, poor quality concrete needed about 14 per cent air content and it disintegrated at about 200 cycles.

In India, concrete is very rarely subjected to extreme freezing temperature. However, with the development of communication in the Northern Regions, more and more concrete likely to be subjected to freezing action is used. The knowledge of air entrainment of concrete is required to improve the durability of concrete structures used in marine conditions. Hitherto the use of air entrainment has been practised only in the case of multi-purpose dams for the purpose of workability. And, therefore, it is necessary that Indian engineers must be educated regarding the use of air entraining agents for air entrained concrete. The use of air-entraining agent, for improvement in workability in general concrete construction is also required to be practised more and more. Air entrained mortar gives much better performance for plastering works.

### Effect on workability

The entrainment of air in fresh concrete by means of air entraining agent improves workability. It was seen that the placeability of air entrained concrete having 7.5 cm slump is superior to that of non-air entrained concrete having 12.5 cm slump. This easier placeability of a lower slump should be recognised by the people concerned with concrete construction in difficult situations. Better placeability of air entrained concrete results in more homogeneous concrete with less segregation, bleeding and honeycombing. The concrete containing entrained air is more plastic and 'fatty' and can be more easily handled than ordinary concrete. The pumpability of the mix also increases enormously.

In fact, all the above qualities mentioned are closely related to workability and as such let us consider the aspect of workability.

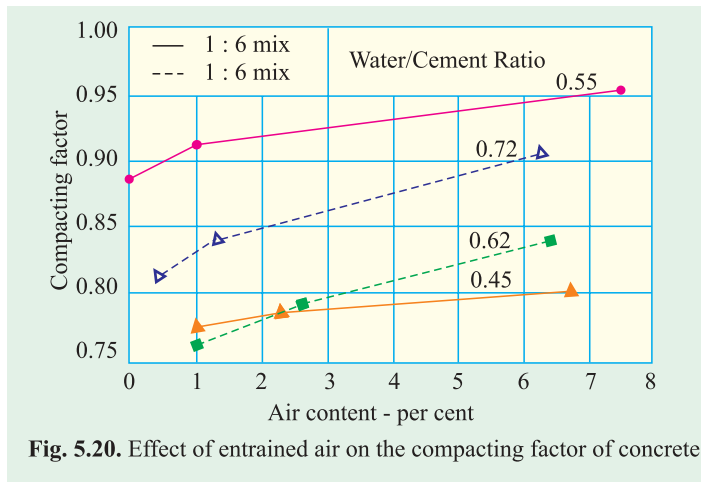


Fig. 5.20. Effect of entrained air on the compacting factor of concrete.

For adequate workability of concrete, aggregate particles must be spaced so that they can move past one another with comparative ease during mixing and placing. In non-air entrained concrete, workability can be achieved by including sufficient fine sand, cement and water to separate the particles of coarser aggregate and supply of matrix, in which movement can occur with minimum

interference. By such means, spacing of the solids is increased and the dilatancy necessary for the manipulation of fresh concrete is reduced, with consequent reduction of work required.

An improvement in workability caused by air entrainment can be viewed from another angle as follows:

Proportioning of concrete mixes involves compromise between requirements for workability and requirements for strength, durability, volume stability and other properties of hardened concrete. Workability requires that the inter particle voids in the aggregates be more than filled by cement paste, whereas good quality of hardened concrete requires that these voids be just filled. It is the role of entrained air to solve this conflict. Firstly, entrained air increases the effect volume of cement paste during mixing and placing, thereby eliminating the need for extra paste to induce the workability.

Having fulfilled the requirements of workability for placing and compaction the extra air will escape or may be made to escape to achieve the desired density in the hardened concrete. As a result of compaction 1/2 to 2/3 of the air content of the fresh concrete may be driven out depending upon the duration of vibration and water/cement ratio.

The marked improvement in the workability of air entrained concrete can also be attributed to the lubricating effect of the microscopic bubbles between the fine aggregates and providing a cushioning effect between the grains of sand, thereby reducing particle interference to a minimum. In fact, they seem to introduce ball bearing upon which the particles may slide.

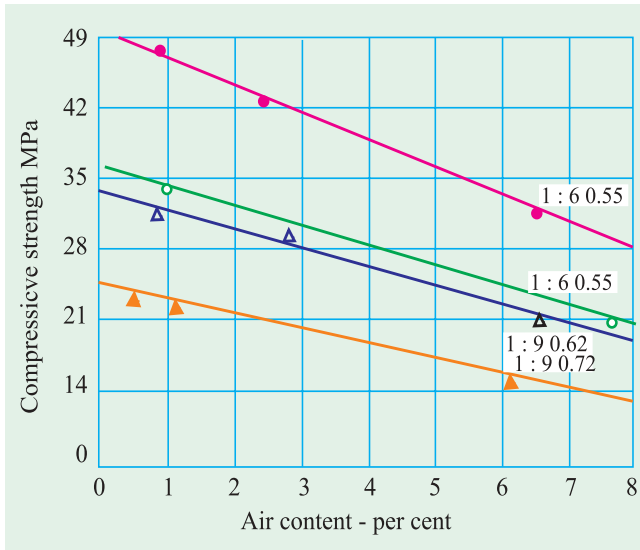
The effect of the percentage of air entrainment on the compacting factor for different mixes and water/cement ratios is illustrated in Fig. 5.20 which is prepared from information given by Wright. It is seen that 5 per cent air may increase the compacting factor by 0.07. A corresponding increase of the slump would be from 12 mm to 50 mm.

The increase in the workability is rather greater for wetter mixes than for drier ones, and for the leaner mixes than for the richer ones, and further it has been shown that the increase is greater for angular aggregates than for rounded ones.

### Effect on strength

It can be generally stated that air entrainment in concrete reduces the compressive strength of concrete. But when the process is applied properly, taking advantage of the

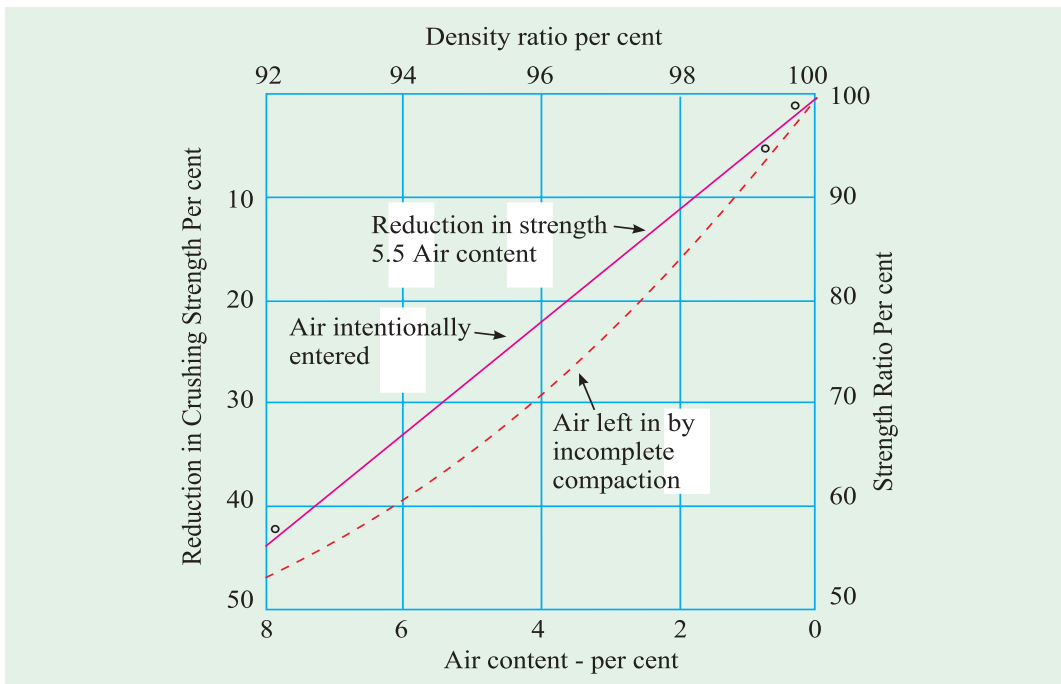


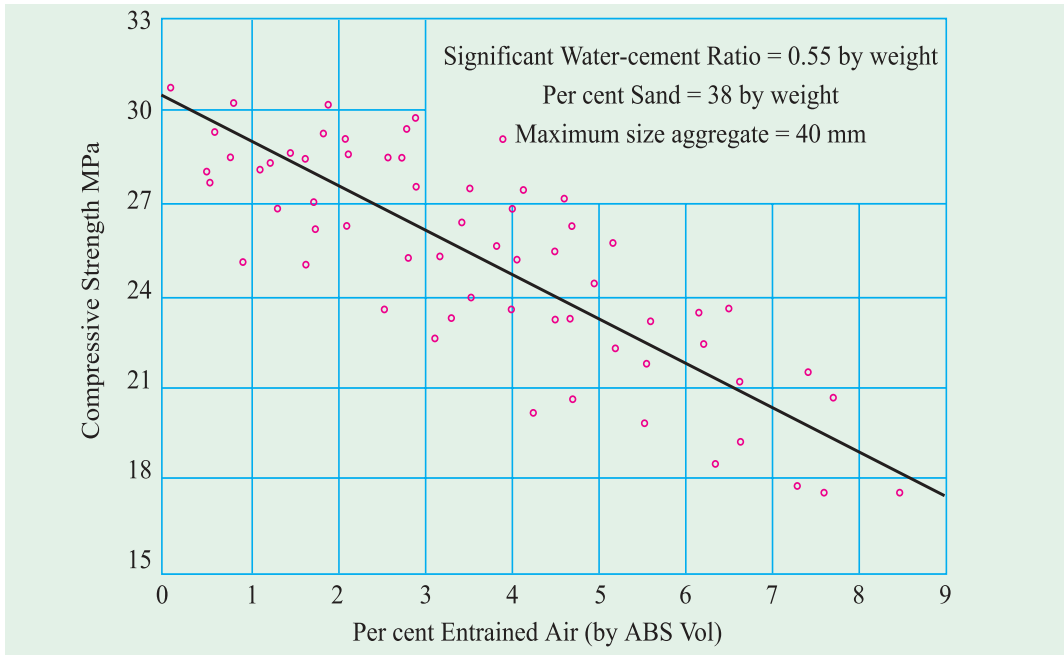


benefits accrued on account of air-entrainment, little or no loss of strength should take place and it is even possible that under certain circumstances a gain of strength may be possible. It is true that at a given water/cement ratio, an increase in air content results in loss of strength, but the air entrainment enables reduction of water/cement ratio and sand content, for the given workability, thereby regaining most if not all the lost strength.

The result of test on the compressive strength of air entrained concrete carried out at

the Road Research Laboratory, U.K. as reported by Wright<sup>5.7</sup> is shown in Fig. 5.21 and in Fig. 5.22. In these tests four mixes were investigated and the air content was increased without making any other adjustments to the mix proportions. Fig. 5.21 shows the actual strength obtained. It will be seen that the strength decreases in proportion to the amount of air. In Fig. 5.22 the same results are shown expressed as a percentage of the strengths of concretes containing no air. It will be seen that a single straight line is obtained. This represents a decrease in strength of 5.5 per cent for each per cent of air entrained. A curve is also plotted showing the strength of concrete containing air voids resulting from incomplete compaction *i.e.*, entrapped air. The graph shows that the entrapped air effects

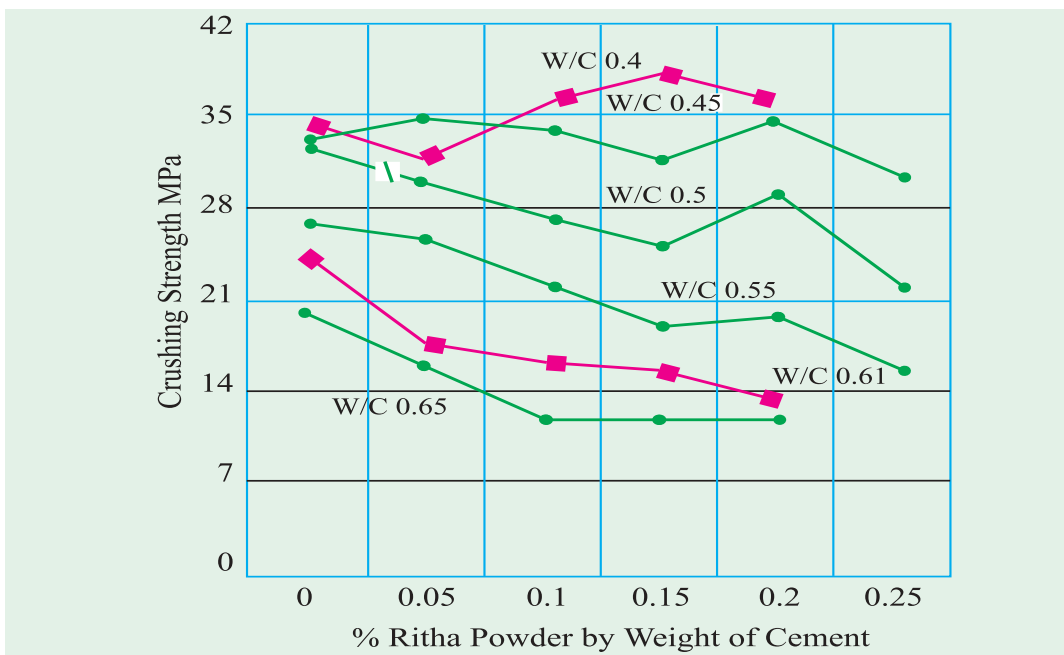




the strength slightly more than the entrained air. But it must be appreciated, however, that air voids caused by incomplete compaction do not provide the other advantages of entrained air such as increased durability and better workability etc.

The effect of air entrainment on strength is dependent on three factors *i.e.*, on the amount of air entrained, the richness of the mix, and on the type of air entraining agent used.

The first two factors on the strength of concrete both in compression and bending were investigated by Klieger<sup>5,8</sup> and the summary of the results is reproduced in Table 5.10. It can be



noticed that the water content was reduced to maintain the slump constant as the air content was increased and this reduction in the water content sometimes more than compensated for the reduction in strength due to the increase in air content. Thus, in cases when the reduction in water content was greatest such as the lean 21 MPa mixes with the smaller maximum sized aggregates, the entrainment of air actually increased the strength of concrete both in compression and in bending. On the other hand, in cases where greater reduction in water content could not be effected, when the mix is rich and the maximum aggregate size was large, there was reduction in both the flexural and the compressive strengths. Between these two extremities the strength varied from an increase of approximately 10 per cent in bending and approximately 17.5 per cent in compression to a reduction of approximately 24 per cent in bending and 46 per cent in compression<sup>5,8</sup>. The effect of air-entrainment on flexural strength is, therefore, not so great as the effect on compressive strength.

The above facts have also been confirmed by Blanks and Cordon. The Fig. 5.23 shows the result of the experiments conducted by Cordon to study the effect of air entrainment on the compressive strength of concrete. It can be seen that the strength of concrete decreases uniformly with the increase in air content of fresh concrete. At constant water/cement ratio, the air entrainment resulted in the decrease of strength of 1.4 MPa. (about 5 per cent average) for each per cent air entrained. On the contrary, the experiment carried out at the College of Military Engineering, Pune using Ritha Powder as an air entraining agent showed an average loss of strength of about 0.55 MPa. for each per cent air entrained. (Fig. 5.24)<sup>5,9</sup>

### Effect on Segregation, Bleeding and Laitance

Segregation and bleeding of concrete are different manifestations of loss of homogeneity. Segregation usually implies separation of coarser aggregate from mortar or separation of cement paste from aggregates. Bleeding is the autogenous flow of mixing water within, or its emergence to the surface from freshly placed concrete, usually, as a result of sedimentation of the solids due to compaction and self weight of the solids. Bleeding results in the formation of a series of water channels some of which will extend to the surface. A layer of water will emerge at the surface of the concrete, often bringing some quantity of cement with it. The formation of this layer of neat cement particles is called laitance.

Segregation, bleeding and consequent formation of laitance are reduced greatly by air entrainment. These actions probably result from physical phenomena due to the incorporation of a system of air bubbles. Firstly, the bubbles buoy up the aggregates and cement and hence reduce the rate at which sedimentation occurs in the freshly placed concrete. Secondly, the bubbles decrease the effective area through which the differential movement of water may occur. Thirdly, the bubbles increase the mutual adhesion between cement and aggregate. Lastly, the surface area of voids in the plastic concrete is sufficiently large to retard the rate at which water separates from the paste by drainage.

All research workers are unanimous in their opinion about the advantages of entrained air regarding reduction in bleeding but, opinions are divided regarding the role played by air entrainment in reducing segregation. Tests carried out at the Road Research Laboratory, U.K., using sloping chute have indicated that, in the case of a well designed mix having only a slight tendency to segregate, the entrainment of air yielded no improvement, but a mix which segregates considerably was improved by air entrainment.

The large reduction in bleeding developed by the concrete containing air entraining admixtures is evident from the Table 5.11 which is reproduced from Charles E Wuerpel's articles on laboratory studies of concrete containing air entraining admixtures.

**Table 5.10.** Effect of Entrained air on Concrete Strengths<sup>5,8</sup>  
Age at test, 28 days of moist curing, slump 50 to 75 mm

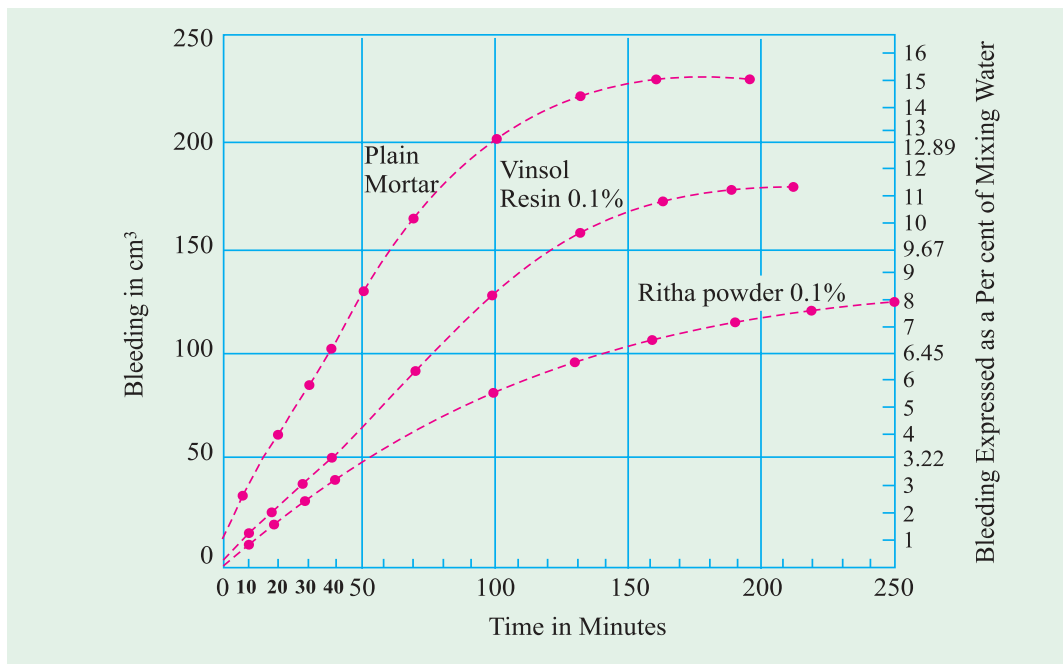
Cement content in kg/cu.m	Maximum size of aggregate mm	Average percentage change in strength for each 1 per cent of entrained air for total amounts of entrained air shown in per cent.											
		In bending						In compression					
		1	2	3	4	5	6	1	2	3	4	5	6
210	72	-1.0	-1.0	-1.3	-1.6	-1.9	-2.1	0	-1.2	-1.9	-2.6	-3.2	-3.8
	40	0	-0.5	-1.0	-1.2	-1.7	-2.1	+3.7	+1.5	-0.4	-1.8	-3.2	-4.1
	20	+2.2	+1.7	+1.5	+1.1	+0.4	0	+5.0	+3.4	+2.2	+1.7	+1.0	0
	10	+4.3	+3.6	+3.4	+2.6	+2.0	+1.7	+9.6	+7.5	+5.9	+4.4	+3.5	+2.1
	4.75	0	0	0	0	0	0	0	0	0	0	0	0
290	72	-3.8	-3.4	-3.6	-3.6	-3.7	-3.8	-7.5	-7.5	-7.5	-7.5	-7.6	-7.7
	40	-3.8	-3.8	-4.0	-4.0	-4.0	-4.0	-5.0	-5.0	-5.3	-5.5	-5.8	-6.0
	20	-2.9	-2.6	-2.7	-2.6	-2.6	-2.7	-3.3	-3.3	-3.6	-3.8	-3.8	-3.9
	10	-0.9	-0.9	-1.1	-1.3	-1.5	-1.7	0	0	-0.4	-0.8	-1.3	-2.0
	4.75	+1.0	+1.0	+0.3	-0.1	-0.4	-0.9	+3.6	+3.6	+2.4	+1.8	+1.1	+0.3
370	72	-8.6	-7.2	-6.0	-5.0	-4.1	-	-4.0	-4.3	-4.9	-5.3	-5.7	-
	40	-3.5	-3.2	-3.5	-3.7	-	-	-1.4	-2.8	-4.1	-5.0	-	-
	20	-1.4	-1.6	-1.9	-2.1	-2.2	-2.4	-2.8	-3.4	-3.3	-3.9	-4.2	-4.5
	10	-1.5	-1.5	-1.5	-1.7	-1.9	-1.9	-3.0	-2.8	-2.7	-2.6	-2.8	2.7
	4.75	-1.6	-1.6	-1.6	-1.5	-	-	-5.1	-3.7	-2.7	-1.8	-	-

Table 5.11. Effect of Admixtures on Bleeding

Air entraining admixtures	Cement factor = 240 kg/cu. m		Cement factor = 320 kg/cu. m	
	Cement A Bleeding %	Cement C Bleeding %	Cement A Bleeding %	Cement C Bleeding %
Plain Concrete	100	100	100	100
Q	52	49	42	34
R	59	56	49	49
U	25	25	19	15
V	42	33	36	30
Z	55	57	25	20

It was found that the Ritha powder proved to be an efficient air entraining agent in reducing the bleeding in cement mortar or concrete. The results of tests conducted at College of Military Engineering, Pune using Ritha powder and Vinsol resin are shown in Fig. 5.25. It can be seen that while the plain mortar bled 15 per cent of the mixing water in about 3 hours times, the mortar containing Ritha powder bled only 7 1/2 per cent of the mixing water and the mortar containing Vinsol resin bled 11 per cent of the mixing water.

Since bleeding and formation of laitance are inter-related, considerable reduction in bleeding will also automatically reduce the formation of laitance which is of considerable importance. In concrete the reduced bleeding permits early finishing of the surface reducing the waiting period for the commencement of trowelling. Reduction in bleeding also improves the wearing quality of concrete.



### Effect on Permeability

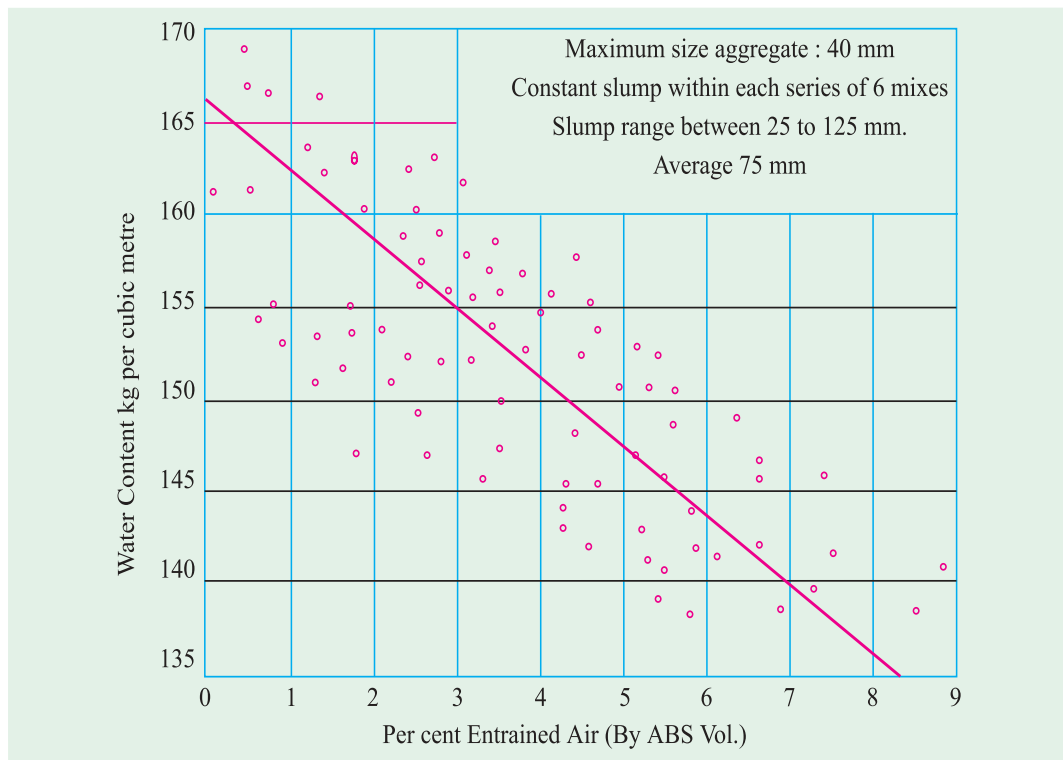
The entrainment of air does appear to have much effect on the permeability of concrete. Greater uniformity of concrete with entrained air due to its increased workability, modified pore-structure of the air entrained concrete, reduction of water channel due to reduction in bleeding, are some of the reasons for improving the permeability characteristics of air entrained concrete. Cement stored in silos built of air entrained concrete, has been found to show no caking of cement, whereas, cement stored in silos made of ordinary concrete revealed caking along the periphery of the silo. The minute disconnected air bubbles offer a better barrier to the passage of water. The reduced water/cement ratio also is one of the factors for reduced permeability.

### Effect on Chemical Resistance

In view of lower permeability and absorption, the air entrained concrete will have greater resistance for chemical attack than that of normal concrete. In the Road Research Laboratory, U.K., specimens of comparable mix of ordinary and air entrained concrete have been immersed in 5 per cent solution of magnesium sulphate and the deterioration in quality has been assessed by measuring the decrease in the velocity of a ultrasonic wave through the specimen. It was found that air entrained concrete showed less deterioration than ordinary concrete.

### Effect on sand, water and cement content

The minute spheroidal air bubbles act as fine aggregates and enable the reduction of fine aggregates. The reduction of fine aggregate further enables the reduction of water requirement without impairing the workability and slump. This will have to be considered in



designing an air entrained mix. On the basis of a large number of experiments it is reported that sand content by weight of total aggregate may be reduced by one per cent for each per cent increase in air entrainment upto about 8 per cent, without any appreciable change in workability or slump.

The water requirement of an average concrete mix is reduced approximately 3.5 kg/cu.m with rounded aggregate and 4.8 kg/cu.m with angular aggregates for each per cent air entraining. Fig. 5.26 shows the reduction of water for natural aggregates as given by Cordon.<sup>5,10</sup>

The reduction in water/cement ratio naturally effects the basic increase in strength and durability due to the non-availability of excess water for the formation of bleeding channels through the matrix of concrete. Table 5.12 shows the advantages accrued by air entrainment in concrete regarding the reduction of sand and reduction of water requirements.

Entrainment of air is particularly useful in the case of lean concrete, even from the point of view of strength. Many a time increases the strength of lean mixes. In such cases it will be possible for reducing the cement content for the given strength. Blanks and Cordon found that concrete made with 160 mm maximum size aggregate gave satisfactory strength for mass concrete work with only 106 kg cement content per cu.m. provided air was entrained. The reduction in cement content results in a lower heat of hydration in mass concrete and lower temperature rise. The decrease in temperature rise results in reduced cracking or undesirable internal stresses.

### **Unit Weight**

The useful factor which should not be overlooked, is the reduction in density of the air entrained concrete. Comparing two mixes, one ordinary concrete and the other air entrained, which have the same workability and strength, the air entrained concrete will contain 5 per cent less of solid material, and hence will be lower in weight. Incidentally, this will result in an economy of about 5 per cent in the cost of cement and aggregate, less the cost of air entraining agent and cost of extra supervision.

### **Alkali-Aggregate Reaction**

There are evidences that air entrainment reduces the alkali-aggregate reaction. Use of air entraining agent has frequently been recommended as a means for controlling expansion due to alkali-aggregate reaction in mortar and concrete.

### **Modulus of Elasticity**

Available data indicate that the modulus of elasticity of concrete mix having the same water/cement ratio and the same aggregate is reduced by 2 to 3 per cent for each per cent of air entrainment.

### **Abrasion Resistance**

Concrete containing less than 6 per cent air entrainment has about the same resistance to abrasion as normal concrete, when cement contents of the comparable concrete are constant. However, there is a progressive decrease in abrasion resistance with further increase in air content. When the air entrainment is of the order of about 10 per cent, abrasion resistance is markedly low. Since concrete used in pavements is generally specified to have not more than 3 to 6 per cent of entrained air, the abrasion resistance should be satisfactory.

### Optimum Air Content in Concrete

The recommended air content in a given concrete is a function of (a) the purpose for which the concrete is used and its location and climatic condition (b) the maximum size of aggregate (c) the richness of the mix. Usually, the desirable air content is ranging from 3 to 6 per cent.

Lower air content is normally specified for concrete floors, in a building even in cold countries, because they are not subjected to severe weather conditions. An air content of about 4 per cent may probably be sufficient for the required workability and reduced bleeding.

For reinforced concrete of relatively high cement content, a limit of probably 3 to 4 per cent is adequate from the workability and bleeding point of view. The strength will be unduly lowered if the air content is increased.

Again, the larger the aggregate, the less is the amount of air sufficient to give desired results. For mass concrete with 160 mm maximum size aggregate, an air entrainment of about 2.5 to 3 per cent would be sufficient. But in the mass concrete if the maximum size of aggregate is smaller, a higher percentage of air entrainment is desirable.

Despite the variations, the overall limits are from 3 to 6 per cent. This range constitutes reasonable specification limits covering all conditions. There is no advantage in increasing the air content above 6 per cent even from the durability point of view. The optimum durability as measured from the resistance to freezing and thawing for good quality concrete, good resistance is achieved within 6 per cent of entrained air as can be seen from Fig. 5.19. On the other hand, air entrainment below about 3 per cent may not extend envisaged advantages of an air entrained concrete.

### Measurement of Air Content in Air Entrained Concrete

The exact air content in concrete is extremely important as it affects the various properties of concrete as explained earlier. If the amount of air entrained in a mix differs widely from the design value, the properties of the concrete may be seriously affected. Too little air results in insufficient workability and too much air will result in low strength. It is, therefore, necessary that the air content should be maintained at the stipulated value. In view of the many factors affecting the air content, measurements must be done frequently throughout the progress of the work. If the air content is found to be varying beyond the specified limit, adjustment is made by altering the amount of air entraining agent.

There are mainly three methods for measuring air content of fresh concrete:

- (a) Gravimetric Method;      (b) Volumetric Method;      (c) Pressure Method.

#### Gravimetric Method

Gravimetric method was the first to be used and it did not require any special equipment. The procedure is principally one of determining the density of fresh concrete compacted in a standard manner. This is then compared with the theoretical density of air-free concrete, calculated from the mix proportions and specific gravities of the constituent materials making the concrete. Thus if the air-free density is 2380 kg/cu.m. and the measured density is 2220 kg/cu.m., then one cu.m. of concrete will contain 2220/2380 cu.m. of solid and liquid matter

and the rest being air. Therefore, the air content then is  $1 - \frac{2220}{2380} = 0.07$  or 7%.

The gravimetric method is satisfactory for use in the laboratory but it is not well-suited for field use. It necessitates a skilled operator and an accurate balance. It also requires the



**Table 5.12.** Approximate sand and water content per cubic metre of plain and air-entrained concrete<sup>5.10</sup>

**A. Natural or Rounded Coarse Aggregate**

Max. size of coarse aggregate (mm)	Plain concrete		Air entrained concrete		
	Sand % of total aggregate (absolute volume)	Net water content per cu.m (kg.)	Recommended air content (%)	Sand % of total aggregate (absolute vol.)	Net water content per cu.m (kg)
12.5	51	152	6 ± 1	47	132
20	46	141	5 ± 1	42	122
25	41	136	4.5 ± 1	37	118
40	37	127	4 ± 1	34	112
50	34	120	4 ± 1	31	107
80	31	114	3.5 ± 1	28	100
160	26	100	3 ± 1	24	89
<b>B. Manufactured Angular Coarse Aggregate</b>					
12.5	55	164	6 ± 1	51	141
20	50	152	5 ± 1	46	132
25	45	147	4.5 ± 1	42	127
40	41	139	4 ± 1	38	120
50	38	132	4 ± 1	35	118
80	35	125	3.5 ± 1	32	110
160	30	112	3 ± 1	27	98

knowledge of mix proportions of concrete. Even if weigh batching is done, loss of materials, segregation and other factors may cause a sample of concrete taken in the cylinder for experiment to be different from the ideal mix. The accurate specific gravity of the materials also must be known. Without these the result will not be correct.

### Volumetric Method

The volumetric method or displacement method aims at measuring directly the volume of air in the sample of fresh concrete. There are a number of modifications, but the principle is to take a sample of concrete of known volume, remove all the air and then determine the amount of water required to restore the original volume.

A vessel is partly filled with concrete, the amount of concrete being determined by weighing, or by using a vessel made in two parts, the lower one being filled completely and struck off level so that a fixed volume of concrete is obtained. Water is added to make up a given volume as indicated by a mark on the narrow neck of the second part. The air is then removed by agitation of the mixture, either by rolling or by stirring. When the removal of the air is complete, the water level is restored to its original position, by a further addition of water. The additional water required to make up the original level indicate the air content in the concrete. The air content can also be calculated by the weight of extra water.

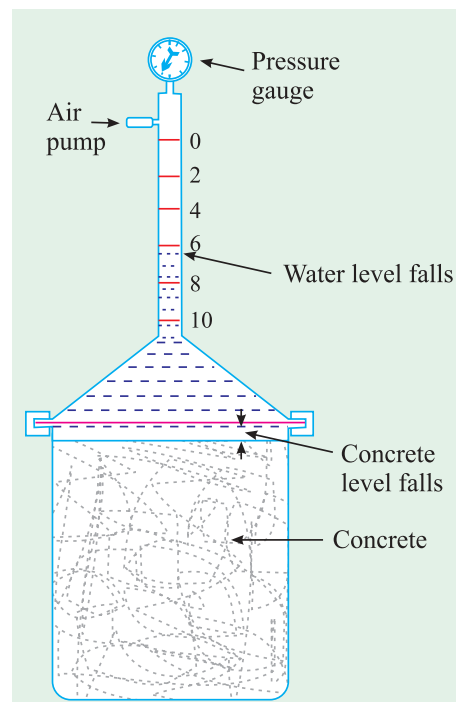
In some variations of this method, weighing is eliminated entirely. This method requires great care and skilled operation. It is a tedious job to remove all the air, and it is difficult to know when the removal of the air is complete. The trouble caused by the formation of foam on the surface is often reduced by using some alcohol. Considerable time is consumed in rolling and stirring the sample of concrete, and generally the process must be repeated to make sure that all the air has been removed. The chief advantage of the rolling method is that it can be used with all types of aggregates and it is specially recommended for concrete containing light weight aggregate.

### Pressure Method

This is perhaps the best method for finding the air content of fresh concrete because of its superiority and ease of operation. There are two different methods of measuring air by the pressure. One utilises a pressure meter that is known as the water type. The other is the Washington air meter. Both operate on the principle of Boyle's law, namely that the volume of gas at a given temperature is inversely proportional to the pressure to which it is subjected.

#### The Water Type Meter

The vessel is filled with concrete, compacted in a standard manner and struck off level. A cover is then clamped in position. Water is added until the level reaches "0" mark on the tube of the cover and then pressure is applied by means of a bicycle pump. The pressure is transmitted to the air entrained in the concrete, which contracts accordingly. Then the water level falls. The pressure



is increased to a predetermined value as indicated by a small pressure gauge mounted on the cover. The glass gauge tube is so calibrated that the percentage of air by volume is indicated directly. The instruments are generally designed to employ a working pressure of the order of 1 kg /sq. cm. The correction may be made for the air contained in the aggregate. The apparatus is shown in Figure 5.27.

### Pozzolanic or Mineral Admixtures

The use of pozzolanic materials is as old as that of the art of concrete construction. It was recognised long time ago, that the suitable pozzolans used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes. Ancient Greeks and Romans used certain finely divided siliceous materials which when mixed with lime produced strong cementing material having hydraulic properties and such cementing materials were employed in the construction of aqueducts, arch, bridges etc. One such material was consolidated volcanic ash or tuff found near Pozzuoli (Italy) near Vesuvius. This came to be designated as Pozzuolana, a general term covering similar materials of volcanic origin found in other deposits in Italy, France and Spain. Later, the term pozzolan was employed throughout Europe to designate any materials irrespective of its origin which possessed similar properties.

Specimens of concrete made by lime and volcanic ash from Mount Vesuvius were used in the construction of Caligula Wharf built in the time of Julius Caesar nearly 2000 years ago is now existing in a fairly good condition. A number of structures stand today as evidence of the superiority of pozzolanic cement over lime. They also attest the fact that Greeks and Romans made real advance in the development of cementitious materials.

After the development of natural cement during the latter part of the 18th century, the Portland cement in the early 19th century, the practice of using pozzolans declined, but in more recent times, Pozzolans have been extensively used in Europe, USA and Japan, as an ingredient of Portland cement concrete particularly for marine and hydraulic structures.

It has been amply demonstrated that the 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.

In addition to these advantages, contrary to the general opinion, good pozzolans will not unduly increase water requirement or drying shrinkage.



Another Model of Air Entrainment Meter.

### Pozzolanic Materials

Pozzolanic 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.

It has been shown in Chapter I that on hydration of tri-calcium silicate and di-calcium silicate, calcium hydroxide is formed as one of the products of hydration. This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. The siliceous or aluminous compound in a finely divided form react with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. Generally, amorphous silicate reacts much more rapidly than the crystalline form. It is pointed out that calcium hydroxide, otherwise, a water soluble material is converted into insoluble cementitious material by the reaction of pozzolanic materials.

The reaction can be shown as



This reaction is called pozzolanic reaction. The characteristic feature of pozzolanic reaction is firstly slow, with the result that heat of hydration and strength development will be accordingly slow. The reaction involves the consumption of  $\text{Ca(OH)}_2$  and not production of  $\text{Ca(OH)}_2$ . The reduction of  $\text{Ca(OH)}_2$  improves the durability of cement paste by making the paste dense and impervious.

Pozzolanic materials can be divided into two groups: natural pozzolana and artificial pozzolana.

#### Natural Pozzolans

- Clay and Shales
- Opalinc Cherts
- Diatomaceous Earth
- Volcanic Tuffs and Pumicites.

#### Artificial Pozzolans

- Fly ash
- Blast Furnace Slag
- Silica Fume
- Rice Husk ash
- Metakaoline
- Surkhi.

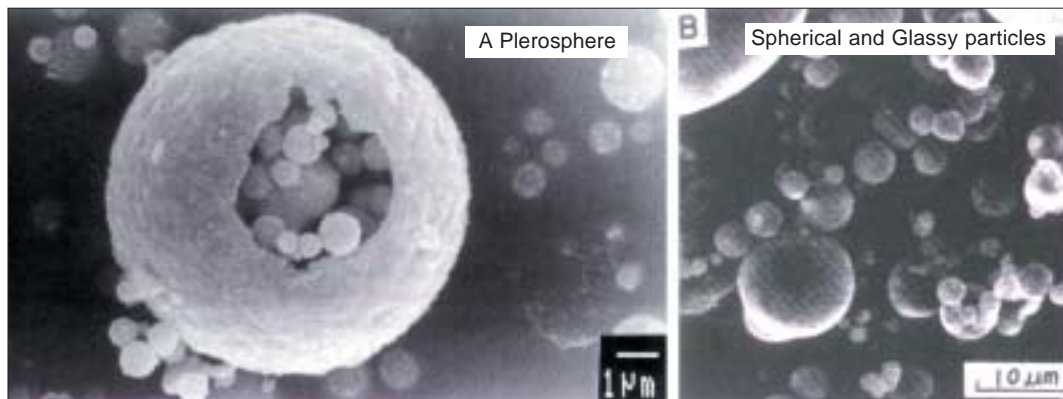
Other mineral admixtures, like finely ground marble, quartz, granite powder are also used. They neither exhibit the pozzolanic property nor the cementitious properties. They just act as inert filler.

Natural pozzolans such as diatomaceous earth, clay and shale, pumicites, opaline cherts etc., needs further grinding and sometimes needs calcining to activate them to show pozzolanic activities. In Hirakud dam construction in Orissa, naturally occurring clay known as Talabara clay has been used as pozzolanic materials. The natural pozzolans have lost their popularity in view of the availability of more active artificial pozzolans.

### Artificial Pozzolans

**Fly Ash:** Fly ash is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator. In U.K. it is referred as pulverised fuel ash (PFA). Fly ash is the most widely used pozzolanic material all over the world.

Fly ash was first used in large scale in the construction of Hungry Horse dam in America in the approximate amount of 30 per cent by weight of cement. Later on it was used in Canyon and Ferry dams etc. In India, Fly ash was used in Rihand dam construction replacing cement upto about 15 per cent.



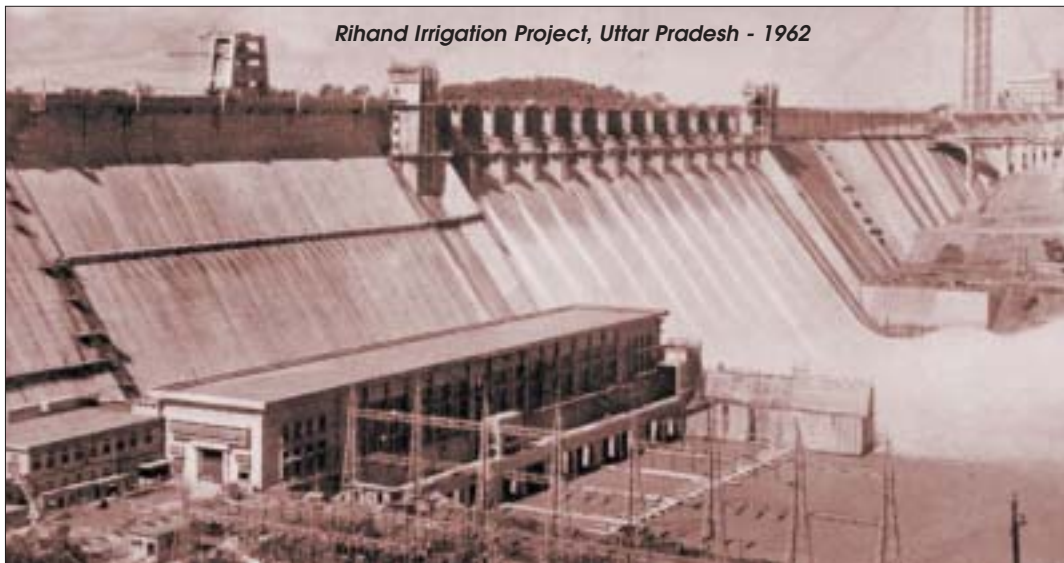
Scanning electron micrograph of Class F, Fly Ash.

In the recent time, the importance and use of fly ash in concrete has grown so much that it has almost become a common ingredient in concrete, particularly for making high strength and high performance concrete. Extensive research has been done all over the world on the benefits that could be accrued in the utilisation of fly ash as a supplementary cementitious material. High volume fly ash concrete is a subject of current interest all over the world.

The use of fly ash as concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control. In India alone, we produce about 75 million tons of fly ash per year, the disposal of which has become a serious environmental problem. The effective utilisation of fly ash in concrete making is, therefore, attracting serious considerations of concrete technologists and government departments.

Secondly, cement is the backbone for global infrastructural development. It was estimated that global production of cement is about 1.3 billion tons in 1996. Production of every tone of cement emits carbon dioxide to the tune of about 0.87 ton. Expressing it in another way, it can be said that 7% of the world's carbon dioxide emission is attributable to Portland cement industry. Because of the significant contribution to the environmental pollution and to the high consumption of natural resources like limestone etc., we can not go on producing more and more cement. There is a need to economise the use of cement. One of the practical solutions to economise cement is to replace cement with supplementary cementitious materials like fly ash and slag.

In India, the total production of fly ash is nearly as much as that of cement (75 million tons). But our utilisation of fly ash is only about 5% of the production. Therefore, the use of fly ash must be popularised for more than one reasons.



In India, fly ash was used for the first time in the construction of Rihand Irrigation Project, Uttar Pradesh in 1962, replacing cement upto about 15 per cent.

There are two ways that the fly ash can be used: one way is to intergrind certain percentage of fly ash with cement clinker at the factory to produce Portland pozzolana cement (PPC) and the second way is to use the fly ash as an admixture at the time of making concrete at the site of work. The latter method gives freedom and flexibility to the user regarding the percentage addition of fly ash.

There are about 75 thermal power plants in India. The quality of fly ash generated in different plants vary from one another to a large extent and hence they are not in a ready to use condition. To make fly ash of consistent quality, make it suitable for use in concrete, the fly ash is required to be further processed. Such processing arrangements are not available in India.

The Table 5.13 indicates the variability of Indian fly ash from different sources.<sup>5,11</sup>

The quality of fly ash is governed by IS 3812 - part I - 2003. The BIS specification limit for chemical requirement and physical requirement are given in Tables 5.14 and 5.15 (IS 3812–2003). High fineness, low carbon content, good reactivity are the essence of good fly ash. Since fly ash is produced by rapid cooling and solidification of molten ash, a large portion of components comprising fly ash particles are in amorphous state. The amorphous characteristics greatly contribute to the pozzolanic reaction between cement and fly ash. One of the important characteristics of fly ash is the spherical form of the particles. This shape of particle improves the flowability and reduces the water demand. The suitability of fly ash could be decided by finding the dry density of fully compacted sample.

ASTM broadly classify fly ash into two classes.

**Class F:** Fly ash normally produced by burning anthracite or bituminous coal, usually has less than 5% CaO. Class F fly ash has pozzolanic properties only.

**Class C:** Fly ash normally produced by burning lignite or sub-bituminous coal. Some class C fly ash may have CaO content in excess of 10%. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

Fly ash, when tested in accordance with the methods of test specified in IS: 1727–1967\*, shall conform to the chemical requirements given in Table 5.14.

Table 5.13. Illustrative Properties of Fly Ash from Different Sources<sup>5.11</sup>

Property/Source	A	B	C	D	E*
Specific gravity	1.91	2.12	2.10	2.25	2.146 to 2.429
Wet sieve analysis (Percentage retained on No. 325 BS sieve)	16.07	54.65	15.60	5.00	51.00 (Dry)
Specific surface (cm <sup>2</sup> /g Blaines)	2759	1325	2175	4016	2800 to 3250
Lime reactivity (kg/sq.cm)	86.8	56.0	40.3	79.3	56.25 to 70.31
<b>Chemical Analysis</b>					
Loss on ignition percentage	5.02	11.33	1.54	4.90	1–2
SiO <sub>2</sub>	50.41	50.03	63.75	60.10	45–59
SO <sub>3</sub>	1.71	–	–	–	Traces to 2.5
P <sub>2</sub> O <sub>5</sub>	0.31	–	–	–	–
Fe <sub>2</sub> O <sub>3</sub>	3.34	10.20	30.92	6.40	0.6–4.0
Al <sub>2</sub> O <sub>3</sub>	30.66	18.20	–	18.60	23.33
Ti <sub>2</sub>	0.84	–	–	–	0.5–1.5
Mn <sub>2</sub> O <sub>3</sub>	0.31	–	–	–	–
CaO	3.04	6.43	2.35	6.3	5–16
MgO	0.93	3.20	0.95	3.60	1.5–5
Na <sub>2</sub> O	3.07	–	–	–	–

Glass content: Highly variable within and between the samples but generally below 35%.

**\*Lignite-based**

Table 5.14. Chemical Requirements (IS : 3812 – Part -1 : 2003)

Sl. No.	Characteristic	Requirement
( 1 )	( 2 )	( 3 )
(i)	Silicon dioxide (SiO <sub>2</sub> ) plus aluminium oxide (Al <sub>2</sub> O <sub>3</sub> ) plus iron oxide (Fe <sub>2</sub> O <sub>3</sub> ) per cent by mass, <i>Min</i>	70.0
( i i )	Silicon dioxide (SiO <sub>2</sub> ), per cent by mass, <i>Min</i>	35.0
( i i i )	Reactive silica in percent by mass, <i>Min</i>	20.0
( i v )	Magnesium oxide (MgO), per cent by mass, <i>Max</i>	5.0
( v )	Total sulphur as sulphur trioxide (SO <sub>3</sub> ), per cent by mass, <i>Max</i>	3.0
( v i )	Available alkalis, as sodium oxide (Na <sub>2</sub> O), per cent by mass, <i>Max</i>	1.5
( v i i )	Total chloride in present by mass, <i>Max</i>	0.05
( v i i i )	Loss on ignition, per cent by mass, <i>Max</i>	5.0

**Note 1.** Applicable only when reactive aggregates are used in concrete and are specially requested by the purchaser.

**Note 2.** For determination of available alkalis, IS: 4032–1968 ‘Method of chemical analysis of hydraulic cement’ shall be referred to.

Limits regarding moisture content of fly ash shall be as agreed to between the purchaser and the supplier. All tests for the properties specified shall, however, be carried out on oven dry samples.

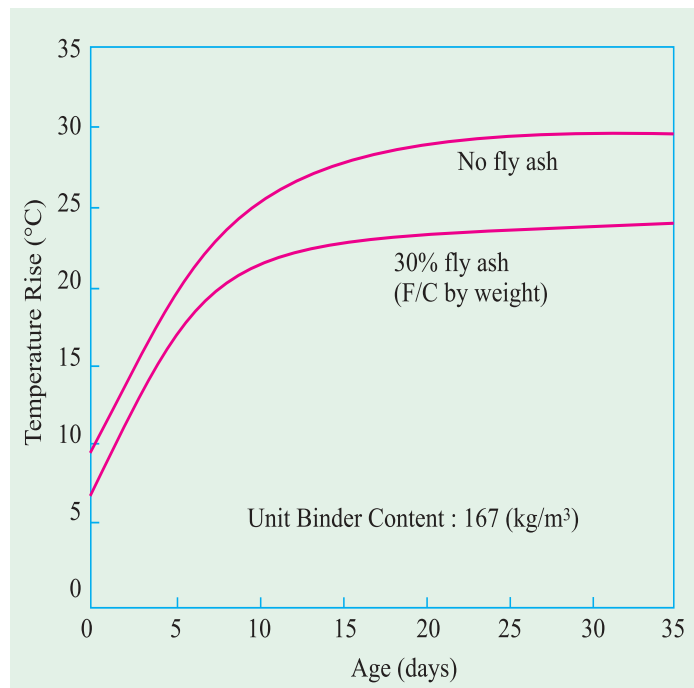
**Table 5.15. Physical Requirements (IS : 3812 – Part -1 : 2003)**

Sl. No.	Characteristic	Requirement Grade of Fly ash	
		I	II
(1)	(2)	(3)	(4)
( i )	Fineness — Specific surface in $\text{m}^2/\text{kg}$ by Blaine's permeability method, <i>Min</i>	320	250
( i i )	Lime reactivity — Average compressive strength in $\text{N}/\text{mm}^2$ , <i>Min</i>	4.5	3.0
( i i i )	Compressive strength at 28 days in $\text{N}/\text{mm}^2$ , <i>Min</i>	Not less than 80 per cent of the strength of corresponding plain cement mortar cubes	
( i v )	Soundness by autoclave test expansion of specimens, <i>Max</i>	0.8	0.8

### Effect of Fly Ash on Fresh Concrete

Good fly ash with high fineness, low carbon content, highly reactive forms only a small fraction of total fly ash collected. The ESP fly ash collected in chambers I and II are generally very coarse, non spherical particles showing large ignition loss. They can be called coal ash rather than fly ash. Such fly ash (coal ash) are not suitable for use as pozzolan and they do not reduce the water demand.

Use of right quality fly ash, results in reduction of water demand for desired slump. With the reduction of unit water content, bleeding and drying shrinkage will also be reduced. Since fly ash is





not highly reactive, the heat of hydration can be reduced through replacement of part of the cement with fly ash. Fig. 5.28 shows the reduction of temperature rise for 30% substitution of fly ash.<sup>5,12</sup>

### Effects of Fly Ash on Hardened Concrete

Fly ash, when used in concrete, contributes to the strength of concrete due to its pozzolanic reactivity. However, since the pozzolanic reaction proceeds slowly, the initial strength of fly ash concrete tends to be lower than that of concrete without fly ash. Due to continued pozzolanic reactivity concrete develops greater strength at later age, which may exceed that of the concrete without fly ash. The pozzolanic reaction also contributes to making the texture of concrete dense, resulting in decrease of water permeability and gas permeability. It should be noted that since pozzolanic reaction can only proceed in the presence of water enough moisture should be available for long time. Therefore, fly ash concrete should be cured for longer period. In this sense, fly ash concrete used in under water structures such as dams will derive full benefits of attaining improved long term strength and water-tightness.

### Durability of Concrete

Sufficiently cured concrete containing good quality fly ash shows dense structure which offers high resistivity to the infiltration of deleterious substances.

A point for consideration is that the pozzolanic reactivity reduces the calcium hydroxide content, which results in reduction of passivity to the steel reinforcement and at the same time the additional secondary cementitious material formed makes the paste structure dense, and thereby gives more resistance to the corrosion of reinforcement. Which one will have an overriding effect on the corrosion of reinforcement will be a point in question. Published data reports that concrete with fly ash shows similar depth of carbonation as that of concrete without fly ash, as long as the compressive strength level is same.

It is also recognised that the addition of fly ash contributes to the reduction of the expansion due to alkali-aggregate reaction. The dilution effect of alkali and reduction of the water permeability due to dense texture may be one of the factors for reduction of alkali-aggregate reaction.

In conclusion it may be said that although fly ash is an industrial waste, its use in concrete significantly improve the long term strength and durability and reduce heat of hydration. In other words good fly ash will be an indispensable mineral admixture for high performance concrete.

### High Volume Fly Ash Concrete (HVFA)

In India, the generation of fly ash is going to have a quantum jump in the coming decade. It is tentatively estimated that currently (2000 AD), we



High volume Fly Ash has been used in the Barker Hall Project, University of California at Berkeley for the construction of shearwalls.

produce about 100 million tons of fly ash and out of which only about 5% is utilised, in making blended cements and in a few cases as mineral admixture. The disposal of remaining fly ash has become a serious problem. There will also be greater need to economise and to conserve the cement for more than one reasons.

One of the practical methods for conserving and economising cement and also to reduce the disposal problem of fly ash is to popularise the high volume fly ash concrete system.

High volume fly ash concrete is a concrete where in 50 to 60% fly ash is incorporated. It was first developed for mass concrete application where low heat of hydration was of primary consideration. Subsequent work has demonstrated that this type of concrete showed excellent mechanical and durability properties required for structural applications and pavement constructions. Some investigations have also shown the potential use of the high volume fly ash system for shotcreting, light weight concrete and roller compacted concrete.

In Canada, considerable work is going on the development of blended cement incorporating high volume fly ash. The use of this type of cement permits to overcome the problem of additional quality control and storage facilities at the ready-mixed concrete batching plants.

Due to very low water content of high volume fly ash concrete, the use of superplasticizer becomes necessary for obtaining workable concrete. Use of air-entraining admixtures is also concurrently used.

Most investigations on high-volume fly ash concrete were carried out at Canada Center for Mineral and Energy Technology (CANMET). The typical mix proportion used and optimised on the basis of investigations are shown below<sup>5,13</sup>

**Table 5.16. Typical (HVFA) Mix Proportions<sup>5,13</sup>**

	<i>Low strength</i>	<i>Medium strength</i>	<i>High strength</i>
Water	115 kg/m <sup>3</sup>	120 kg/m <sup>3</sup>	110 kg/m <sup>3</sup>
ASTM Type I cement	125 kg/m <sup>3</sup>	155 kg/m <sup>3</sup>	180 kg/m <sup>3</sup>
Class F fly ash	165 kg/m <sup>3</sup>	215 kg/m <sup>3</sup>	220 kg/m <sup>3</sup>
C.A.	1170 kg/m <sup>3</sup>	1195 kg/m <sup>3</sup>	1110 kg/m <sup>3</sup>
F.A.	800 kg/m <sup>3</sup>	645 kg/m <sup>3</sup>	760 kg/m <sup>3</sup>
Air-entraining Admixture	200 ml/m <sup>3</sup>	200 ml/m <sup>3</sup>	280 ml/m <sup>3</sup>
Superplasticizer	3.0 l/m <sup>3</sup>	4.5 l/m <sup>3</sup>	5.5 l/m <sup>3</sup>

**Properties of (HVFA) Fresh Concrete.** Most of the investigations at CANMET have been performed with flowing concrete, *i.e.*, concrete with a slump of about 180 to 220 mm. Dosage of superplasticizer may vary considerably. They have also used zero slump concrete without superplasticizer for roller-compacted concrete applications.

**Bleeding and Setting Time.** As the water content is low in high volume fly ash, the bleeding is very low and often negligible. Setting time is little longer than that of conventional concrete. This is because of low cement content, low rate of reaction and high content of superplasticizer. One will have to be careful in cold weather concreting in stripping the formwork.

**Heat of Hydration.** On account of low cement content, the heat of hydration generated is rather low. CANMET investigations have shown that the heat of hydration of HVFA was about 15 to 25°C less than that of reference concrete without fly ash. In one of the experiments, in case of a concrete block of size 3.05 x 3.05 x 3.05 meter, the maximum temperature reached was 54°C (increase of 35°C) as against a heat of hydration of 83°C (increase of 65°C) in a block of same size made out of concrete using ASTM Type I Cement only. In both the cases the weight of cementitious materials used is same.

### Curing of (HVFA) Concrete

High Volume fly ash concrete is to be cured effectively and for longer duration than ordinary concrete and also normal fly ash concrete to obtain continued pozzolanic reaction so that HVFA develops desirable mechanical properties. HVFA concrete should be properly protected from premature drying by properly covering the surface.

### Mechanical Properties of (HVFA) Concrete

The properties of HVFA concrete are largely dependent on characteristics of cement and fly ash. Generally the mechanical properties are good in view of low water content, lower water to cementitious ratio and dense microstructure. The typical mechanical properties of high-volume fly ash concrete as per CANMET investigation is given below in Table 5.17.

**Table 5.17. Typical Mechanical Properties of Hardened High Volume Fly Ash Concrete (Medium Strength) Made at CANMET with ASTM Type I Cement.**<sup>5.13</sup>

<b>Compressive Strength</b>	
1 day	8 ± 2 MPa
7 days	20 ± 4 MPa
28 days	35 ± 5 MPa
91 days	43 ± 5 MPa
365 days	55 ± 5 MPa
<b>Flexural Strength</b>	
14 days	4.5 ± 0.5 MPa
91 days	6.0 ± 0.5 MPa
<b>Splitting Tensile Strength</b>	
28 days	3.5 ± 0.5 MPa
<b>Young's Modulus of Elasticity</b>	
28 days	35 ± 2 GPa
91 days	38 ± 2 GPa
Drying shrinkage strain at 448 days	500 ± 50 x 10 <sup>-6</sup>
Specific creep strain at 365 days per MPa of stress	28 ± 4 x 10 <sup>-6</sup>

### Durability of (HVFA) Concrete

Several laboratory and field investigation conducted in Canada and U.S.A. have demonstrated excellent durability of high volume fly ash concrete. It was tested for water permeability, resistance to freezing and thawing, resistance to the penetration of chloride ions,

corrosion to steel reinforcement, resistance to sulphate attack, controlling alkali-aggregate expansion, carbonation and durability in marine environment. The results have shown superior quality of high volume fly ash concrete 5.13.

### Use of High Volume Fly Ash

All along conventional fly ash concrete has been in use in many parts of the world for several decades. Various standards and codes have generally limited the addition of class F fly ash to 10 to 25 per cent. Laboratory and field demonstration projects during last 10–12 years have shown that concrete containing 55 to 60 per cent fly ash has excellent structural and durability characteristics, when mixed with low water to cementitious ratio and superplasticizer. Since 1985 yet another new economical, useful construction material HVFA has appeared on the construction scenario. Since then this high volume fly ash has been used in many high-rise buildings, industrial structures, water front structures, concrete roads and Roller compacted concrete dams. There is high potential for this material on account of sound economy and usefulness to absorb large quantity of under utilised otherwise harmful waste material.

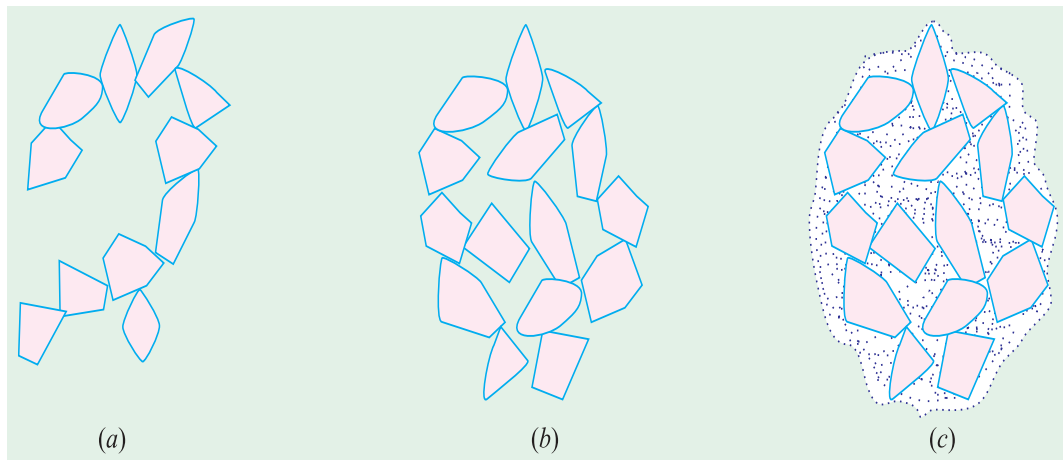
### Silica Fume

Silica fume, also referred to as microsilica or condensed silica fume, is another material that is used as an artificial pozzolanic admixture. It is a product resulting from reduction of high purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as an oxidised vapour. It cools, condenses and is collected in cloth bags. It is further processed to remove impurities and to control particle size. Condensed silica fume is essentially silicon dioxide (more than 90%) in noncrystalline form. Since it is an airborne material like fly ash, it has spherical shape. It is extremely fine with particle size less than 1 micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 20,000 m<sup>2</sup>/kg, as against 230 to 300 m<sup>2</sup>/kg.

Silica fume as an admixture in concrete has opened up one more chapter on the advancement in concrete technology. The use of silica fume in conjunction with superplasticizer has been the backbone of modern High performance concrete. In one article published in 1998 issue of 'Concrete International' by Michael Shydrowski, President, Master Builder, Inc states "Twenty five years ago no one in the concrete construction industry could even imagine creating and placing concrete mixes that would achieve in place compressive strengths as high as 120 MPa . . . . The structures such as Key Tower in Cleaveland with a design strength of 85 MPa, and Wacker Tower in Chicago with specified concrete strength of 85 MPa, and two Union Square in Seattle with concrete that achieved 130 MPa strength – are testaments to the benefits of silica fume technology in concrete construction".

It should be realised that silica fume by itself, do not contribute to the strength dramatically, although it does contribute to the strength property by being very fine pozzolanic material and also creating dense packing and pore filler of cement paste. Refer Fig. 5.29. Really speaking, the high strengths of high performance concrete containing silica fume are attributable, to a large degree, to the reduction in water content which becomes possible in the presence of high dose of superplasticizer and dense packing of cement paste.

Pierre-Claude Aitcin and Adam Neville in one their papers "High-Performance Concrete Demystified" states "Strengths in the range of 60 to 80 MPa were obtained without use of silica fume. Even higher strengths up to 100 MPa have been achieved, but only rarely. In our opinion there is no virtue in avoiding silica fume if it is available and economical, as its use



simplifies the production of high performance concrete and makes it easier to achieve compressive strengths in the range of 60 to about 90 MPa. For higher strengths, the use of silica fume is essential.”

### Indian Scenario

Silica fume has become one of the necessary ingredients for making high strength and high performance concrete. In India, silica fume has been used very rarely. Nuclear Power Corporation was one of the first to use silica fume concrete in their Kaiga and Kota nuclear power projects.

Silica fume was also used for one of the flyovers at Mumbai where, for the first time in India 75 MPa concrete was used (1999). Silica fume is also now specified for the construction of proposed Bandra-Worli sea link project at Mumbai.

At present, India is not producing silica fume of right quality. Recently, Steel Authority of India has provided necessary facilities to produce annually about 3000 tons of silica fume at their Bhadravathi Complex. It appears that the quality of silica fume produced by them needs upgradation.

In India, however, the silica fume of international quality is marketed by Elkem Metallurgy (P) Ltd., 66/67, Mahavir Centre, Sector 17, Vashi, Navi Mumbai-400 703.

Since silica fume or microsilica is an important new material, let us see this material in some detail.

- microsilica is initially produced as an ultrafine undensified powder
- at least 85% SiO<sub>2</sub> content
- mean particle size between 0.1 and 0.2 micron
- minimum specific surface area is 15,000 m<sup>2</sup>/kg
- spherical particle shape.

### Available forms

Microsilica is available in the following forms:

- Undensified forms with bulk density of 200–300 kg/m<sup>3</sup>
- Densified forms with bulk density of 500–600 kg/m<sup>3</sup>
- Micro-pelletised forms with bulk density of 600–800 kg/m<sup>3</sup>
- Slurry forms with density 1400 kg/m<sup>3</sup>.

- Slurry is produced by mixing undensified microsilica powder and water in equal proportions by weight. Slurry is the easiest and most practical way to introduce microsilica into the concrete mix
- Surface area 15–20 m<sup>2</sup>/g
- Standard grade slurry pH value 4.7, specific gravity 1.3 to 1.4, dry content of microsilica 48 to 52%.

### Pozzolanic Action

Microsilica is much more reactive than fly ash or any other natural pozzolana. The reactivity of a pozzolana can be quantified by measuring the amount of Ca(OH)<sub>2</sub> in the cement paste at different times. In one case, 15% of microsilica reduced the Ca(OH)<sub>2</sub> of two samples of cement from 24% to 12% at 90 days and from 25% to 11% in 180 days. Most research workers agree that the C – S – H formed by the reaction between microsilica and Ca(OH)<sub>2</sub> appears dense and amorphous.<sup>5,14</sup>

### Influence on Fresh Concrete

Water demand increases in proportion to the amount of microsilica added. The increase in water demand of concrete containing microsilica will be about 1% for every 1% of cement substituted. Therefore, 20 mm maximum size aggregate concrete, containing 10% microsilica, will have an increased water content of about 20 litres/m<sup>3</sup>. Measures can be taken to avoid this increase by adjusting the aggregate grading and using superplasticizers. The addition of microsilica will lead to lower slump but more cohesive mix. The microsilica make the fresh concrete sticky in nature and hard to handle. It was also found that there was large reduction in bleeding and concrete with microsilica could be handled and transported without segregation.

It is reported that concrete containing microsilica is vulnerable to plastic shrinkage cracking and, therefore, sheet or mat curing should be considered. Microsilica concrete

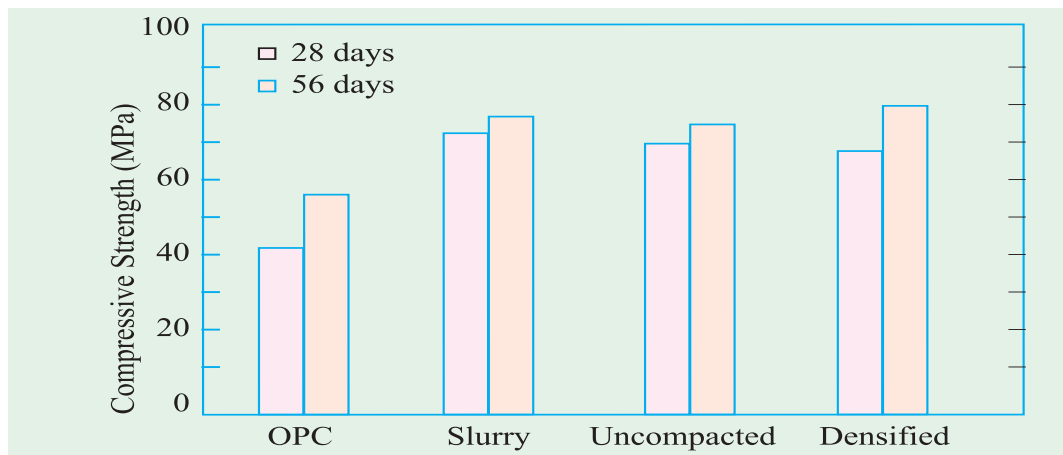


Microsilica slurry



Microfiller effect

Courtesy : MC Bauchemie (India) Pvt. Ltd.



produces more heat of hydration at the initial stage of hydration. However, the total generation of heat will be less than that of reference concrete.

### Influence on Hardened Concrete

Concrete containing microsilica showed outstanding characteristics in the development of strength. Fig. 5.30 shows that 60 to 80 MPa can be obtained relatively easily. It has been also found out that modulus of elasticity of microsilica concrete is less than that of concrete without microsilica at the same level of compressive strength.

As regards, the improvement in durability aspects many published reports, of this investigation carried out, indicate improvement in durability of concrete with microsilica. There are some investigations indicating contradiction, particularly with reference to resistance against frost damage.

With regard to whether or not, silica fume is effective for alkali-aggregate reaction, some research workers report that it is effective, others conclude that while it is effective, addition of silica fume in small quantities actually increases the expansion.

### Mixing

By far the most popular application of microsilica is in the 50 : 50 slurry form; as it is easy to store and dispense. There are conflicting views on whether microsilica is best added in powder or slurry form. The work by Hooton among others showed that, for equivalent microsilica additions, slurry produced significantly higher compressive and tensile strengths.<sup>5,15</sup>

The slurry needs to be kept agitated for a few hours in a day to avoid gelling and sedimentation. Presently in India, Mc-Bauchemie (Ind) Pvt. Ltd., supply the silica fume slurry under the trade name "Centrilit Fumes".

### Curing

Curing is probably the most important aspect of microsilica concrete as the material undergoes virtually zero bleeding. If the rate of evaporation from the surface is faster than the rate of migration of water from interior to the surface, plastic shrinkage takes place. In the absence of bleeding and slow movement of water from interior to the surface, early curing by way of membrane curing is essential.

### Rice Husk Ash

Rice husk ash, is obtained by burning rice husk in a controlled manner without causing

environmental pollution. When properly burnt it has high  $\text{SiO}_2$  content and can be used as a concrete admixture. Rice husk ash exhibits high pozzolanic characteristics and contributes to high strength and high impermeability of concrete.

Rice husk ash (RHA) essentially consist of amorphous silica (90%  $\text{SiO}_2$ ), 5% carbon, and 2%  $\text{K}_2\text{O}$ . The specific surface of RHA is between 40 – 100  $\text{m}^2/\text{g}$ .

India produces about 122 million ton of paddy every year. Each ton of paddy producers about 40 kg of RHA. There is a good potential to make use of RHA as a valuable pozzolanic material to give almost the same properties as that of microsilica.

In U.S.A., highly pozzolanic rice husk ash is patented under trade name Agrosilica and is marketed. Agrosilica exhibit superpozzolanic property when used in small quantity *i.e.*, 10% by weight of cement and it greatly enhances the workability and impermeability of concrete. It is a material of future as concrete admixtures.

### Surkhi

Surkhi, was the commonest pozzolanic materials used in India. It has been used along with lime in many of our old structures, before modern Portland cement has taken its roots in India. Even after Portland cement made its appearance in the field of construction, surkhi was used as an admixture to remedy some of the shortcomings of cement concrete. Surkhi was one of the main constituents in waterproofing treatments in conjunction with lime and sometimes even with cement for extending valuable pozzolanic action to make the treatment impervious.

Surkhi is an artificial pozzolana made by powdering bricks or burnt clay balls. In some major works, for large scale production of surkhi, clay balls are specially burnt for this purpose and then powdered. By its nature, it is a very complex material differing widely in its qualities and performances. Being derived from soil, its characteristics are greatly influenced by the

#### BHAKRA NANGAL DAM



In Bhakra Nangal Dam scientifically made surkhi (burnt clay Pozzolana) was used about 100 tons per day at the rate of 20% Cement replacement.



constituent mineral composition of soil, degree of burning and fineness of grinding. Because of the complexity of problem there has been much confusion on account of contradictory results obtained by various research workers.

In the past, the term surkhi was used for a widely varying material with respect to composition, temperature of burning, fineness of grinding etc. Now the terminology "calcined clay Pozzolana" is used instead of the word surkhi, giving specific property and composition to this construction material. IS 1344 of 1981 covers the specification for calcined clay pozzolana for use in mortar or concrete. IS 1727 of 1967 covers the methods of test for pozzolanic materials.

Surkhi has been used as an admixture in the construction of Vanivilas Sagar dam, Krishnaraja Sagar dam, Hira Bhaskar Sagar dam, Nizamsagar, Mettur, Low Bhavani, Tungabhadra, Chambal, Kakrapara, Bhakra, and in Rana Pratap Sagar dam.

In Bhakra Nangal Project, illitic argillaceous clay was calcined in an oil fired rotary kiln and the grinding operation was carried out through multichamber ball mill. Such a scientifically made surkhi was used 100 tons per day at the rate of 20% cement replacement.

In India, there are a large number of pozzolanic clay deposits of strained and impure kaolins, ferruginous or ochreous earths, altered laterites, bauxites and shales etc., available in different parts of the country, which will yield highly reactive pozzolanic materials. Central Road Research Institute, New Delhi, have conducted an all India survey of pozzolanic clay deposits.

During late 1970s and early 80s, when there was an acute shortage of cement in the country, the cement manufacturers used all kinds of calcined clay pozzolanic materials, that are not strictly conforming to the specification limits in the manufacture of PPC. This has led to the bad impression about the quality of PPC in the minds of common builders in the country. The qualities of PPC as manufactured in India today, specially by those companies who generate and use fly ash in their own plant, is of high quality. Often PPC could be considered better than OPC. In spite of this, the users at large, as saying goes, "once bitten, twice shy", have not yet overcome their bad experience of 1980s in respect of qualities of PPC.

Presently, in view of the large scale availability of fly ash and blended cement the old practice of using surkhi and the modern calcined clay pozzolana has lost its importance.

## Metakaolin

Considerable research has been done on natural pozzolans, namely on thermally activated ordinary clay and kaolinitic clay. These unpurified materials have often been called "Metakaolin". Although it showed certain amount of pozzolanic properties, they are not highly reactive. Highly reactive metakaolin is made by water processing to remove unreactive impurities to make 100% reactive pozzolan. Such a product, white or cream in colour, purified, thermally activated is called High Reactive Metakaolin (HRM).

High reactive metakaolin shows high pozzolanic reactivity and reduction in  $\text{Ca(OH)}_2$  even as early as one day. It is also observed that the cement paste undergoes distinct densification. The improvement offered by this densification includes an increase in strength and decrease in permeability.

The high reactive metakaolin is having the potential to compete with silica fume.

High reactive metakaolin by trade name "Metacem" is being manufactured and marketed in India by speciality Minerals Division, Head office at Arundeeep Complex, Race Course, South Baroda 390 007.

## Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast-furnace slag is a nonmetallic product consisting essentially of silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form a glassy sand like granulated material. The granulated material when further ground to less than 45 micron will have specific surface of about 400 to 600 m<sup>2</sup>/kg (Blaine).

The chemical composition of Blast Furnace Slag (BFS) is similar to that of cement clinker. Table 5.18 shows the approximate chemical composition of cement clinker, blast-furnace slag (BFS) and fly ash.

**Table 5.18. Approximate Oxide Composition of Cement Clinker, BFS and Fly Ash**

Sl. No.	Constituents	Percentage contents		
		<i>Cement clinker</i>	<i>Blast furnace slag</i>	<i>Fly ash</i>
1	CaO	60–67	30–45	1.0–3.0
2	SiO <sub>2</sub>	17–25	30–38	35–60
3	Al <sub>2</sub> O <sub>3</sub>	3.0– 8.0	15–25	10–30
4	Fe <sub>2</sub> O <sub>3</sub>	0.5– 6.0	0.5–2.0	4–10
5	MgO	0.1– 4.0	4.0–17.0	0.2–5.0
6	MnO <sub>2</sub>		1.0–5.0	
7	Glass		85–98	20–30
8	Specific gravity	3.15	2.9	2.1–2.6

The performance of slag largely depends on the chemical composition, glass content and fineness of grinding. The quality of slag is governed by IS 12089 of 1987. The following table shows some of the important specification limits.

**Table 5.19. Specifications of BFS as per IS 12089 of 1987**

(1)	Manganese oxide %	◆	5.5 Max
(2)	Magnesium oxide %		17.0 Max
(3)	Sulphide sulphur %		2.0 Max
(4)	Glass content %		85.0 Min
(5)	$\frac{\text{CaO} + \text{MgO} + 1/3 \text{Al}_2\text{O}_3}{\text{SiO}_2 + 2/3 \text{Al}_2\text{O}_3}$	≥	1.0
	OR		
(6)	$\frac{\text{CaO} + \text{MgO} + \text{Al}_2\text{O}_3}{\text{SiO}_2}$	≥	1.0
	where MnO in slag is more than 2.5%		
(7)	$\frac{\text{CaO} + \text{C}_2\text{S} + 1/2 \text{MgO} + \text{Al}_2\text{O}_3}{\text{SiO}_2 + \text{MnO}}$	≥	1.5

Table 5.20. Compositions of some of the Indian Blast Furnace Slags<sup>5,16</sup>

	<i>Tisco 78</i>	<i>Tisco 90</i>	<i>Durgapur</i>	<i>Rourkela</i>	<i>Bokaro</i>	<i>Bhilai</i>
SiO <sub>2</sub>	31.66	31.50	33.00	33.50	30.50	32.50
CaO	32.25	31.50	36.00	28.50	29.50	33.50
Al <sub>2</sub> O <sub>3</sub>	24.00	22.50	24.00	24.50	25.00	22.50
MgO	5.92	10.00	4.00	8.00	8.50	8.00
MnO	1.25	1.25	1.40	3.00	1.00	1.00
FeO	0.80	0.85	1.00	1.00	1.00	0.80
S	0.80	0.85	0.60	0.70	0.90	0.80
Liquid Temperature	1430°C	1482°C	1457°C	1431°C	1489°C	1430°C
<i>Hydraulic Indices</i>	<i>Tisco 78</i>	<i>Tisco 90</i>	<i>Durgapur</i>	<i>Rourkela</i>	<i>Bokaro</i>	<i>Bhilai</i>
P	1.02	1.00	1.09	0.85	0.97	1.03
B	0.68	0.77	0.70	0.65	0.68	0.75
H	1.96	2.03	1.94	1.82	2.06	1.97
IH	1.70	1.84	1.67	1.59	1.82	1.76
I	15.89	16.00	16.00	10.00	17.75	15.00
F	1.81	1.82	1.87	1.57	1.88	1.80

**Note:**

P = CaO/SiO<sub>2</sub>  
 B = (CaO + MgO)/(SiO<sub>2</sub> + Al<sub>2</sub>O<sub>3</sub>)  
 H = (CaO + MgO + Al<sub>2</sub>O<sub>3</sub>)/SiO<sub>2</sub>  
 IH = (CaO + 0.56 Al<sub>2</sub>O<sub>3</sub> + 1.40 MgO) SiO<sub>2</sub>  
 I = 20 + CaO + Al<sub>2</sub>O<sub>3</sub> + 0.5 MgO - 2 SiO<sub>2</sub>  
 F = (CaO + 0.5S + Al<sub>2</sub>O<sub>3</sub> + 0.5 MgO)/(SiO<sub>2</sub> + MnO)

In India, we produce about 7.8 million tons of blast furnace slag. All the blast furnace slags are granulated by quenching the molten slag by high power water jet, making 100% glassy slag granules of 0.4 mm size. Indian blast furnace slag has been recently evaluated by Banerjee A.K. and the summary of the same has been reproduced in Table 5.20.

The blast furnace slag is mainly used in India for manufacturing slag cement. There are two methods for making Blast Furnace Slag Cement. In the first method blast furnace slag is interground with cement clinker alongwith gypsum. In the second method blast furnace slag is separately ground and then mixed with the cement.

Clinker is hydraulically more active than slag. It follows then that slag should be ground finer than clinker, in order to fully develop its hydraulic potential. However, since slag is much harder and difficult to grind compared to clinker, it is ground relatively coarser during the process of inter-grinding. This leads to waste of hydraulic potential of slag. Not only that the inter-grinding seriously restricts the flexibility to optimise slag level for different uses.

The hydraulic potential of both the constituents – clinker and slag can be fully exploited if they are ground separately. The level of fineness can be controlled with respect to activity, which will result in energy saving. The present trend is towards separate grinding of slag and clinker to different levels. The clinker and gypsum are generally ground to the fineness of less than 3000 cm<sup>2</sup>/g (Blaine) and slag is ground to the level of 3000–4000 cm<sup>2</sup>/g (Blaine) and stored separately. They are blended after weigh batching, using paddle wheel blenders, or pneumatic blenders. Pneumatic blenders give better homogeneity when compared to mechanical blenders.

Just as fly ash is used as an admixture in making concrete Ground Granulated Blast-furnace Slag popularly called GGBS is used as an admixture in making concrete. In other countries its use as an admixture is more common than its use as slag cement. Now in India, since it is available separately as ground granulated blast-furnace slag (GGBS), its use as admixture should become more common. Recently for marine outfall work at Bandra, Mumbai, GGBS has been used as an admixture to replace cement to the tune of 70%. Presently in India, with the growing popularity of RMC, the scope for using GGBS for customer's tailor made requirements should also become popular.

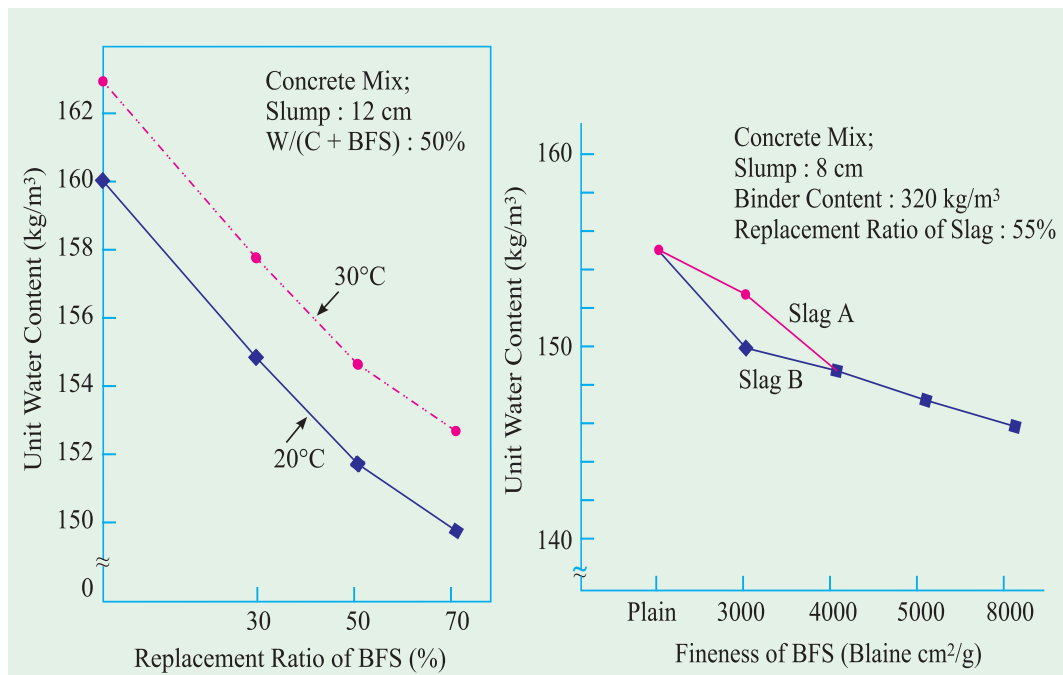
### Performance of GGBS in Concrete

**Fresh Concrete:** The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump. This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag. This is because of the surface configuration and particle shape of slag being different than cement particle. In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement. Fig. 5.31 and Fig. 5.32 shows the reduction in unit water content.

Reduction of bleeding is not significant with slag of 4000  $\text{cm}^2/\text{g}$  fineness. But significant beneficial effect is observed with slag fineness of 6000  $\text{cm}^2/\text{g}$  and above.

**Hardened Concrete:** Exclusive research works have shown that the use of slag leads to the enhancement of intrinsic properties of concrete in both fresh and hardened conditions. The major advantages recognised are

- Reduced heat of hydration
- Refinement of pore structures
- Reduced permeabilities to the external agencies
- Increased resistance to chemical attack.



**Table 5.21** Effect of Fineness and Replacement (per cent) of BSF on various Properties of Concrete<sup>5,19</sup>

Fineness (cm <sup>2</sup> /g)	2750 – 5500			5500 – 7500			7500 –		
	30	50	70	30	50	70	30	50	70
Replacement (%)									
Workability	B	B	B	A	A	A	A	A	A
Bleeding	B	B	C	A	A	A	A	A	A
Hydration control	A	A	A	A	A	A	A	A	A
Adiabatic temp. rise	–	–	A	–	–	A	–	–	A
Hydration-heat control	B	A	A	B	B	A	B	B	A
Early age strength	B	C	C	B	C	C	B	B	C
28 days strength	B	C	C	A	B	C	A	A	A
Long term strength	B	A	A	B	A	A	A	A	B
High strength B	C	C	A	B	B	A	A	B	
Drying shrinkage	B	B	B	B	B	B	B	B	B
Freeze-thaw resistance	B	B	B	B	B	B	B	B	B
Carbonation control	–	–	C	–	–	C	–	–	C
Watertightness	B	A	A	A	A	A	A	A	A
Chloride ion resistance	B	A	A	A	A	A	A	A	A
Ability of seawater	B	A	A	B	A	A	B	A	A
Chemical resistance	B	B	A	B	B	A	B	B	A
Heat resistance	B	B	B	B	B	B	B	B	B
Availability of accelerate curing	B	B	B	B	B	B	B	B	B
Control for AAR expansion	B	A	A	B	A	A	B	A	A

**Notes:** A = superior to OPC (ordinary portland cement)  
 B = slightly better than or as well as OPC  
 C = inferior to OPC  
 – = unknown

The above beneficial effect of slag will contribute to the many facets of desirable properties of concrete. Instead of dealing separately the improvement of various properties of concrete, it is given in a consolidated manner as per the report on concrete using GGBS by the Architectural Institute of Japan (1992).<sup>5,19</sup>

Table 5.21 shows the effect of Fineness and replacement (per cent) of BFS on various properties of concrete.

Blast furnace slag, although is an industrial by-product, exhibits good cementitious properties with little further processing. It permits very high replacement of cement and extends many advantages over conventional cement concrete. At present in India, it is used for blended cement, rather than as cement admixture. In large projects with central batching plant and in RMC this cement substitute material could be used as useful mineral admixture and save cement to the extent of 60 to 80 per cent.

### Damp-proofing and Waterproofing Admixture

In practice one of the most important requirements of concrete is that it must be impervious to water under two conditions, firstly, when subjected to pressure of water on one side, secondly, to the absorption of surface water by capillary action. Many investigators are of the opinion that the concrete, carefully designed, efficiently executed with sound materials

will be impermeable to water. However, since the usual design, placing, curing and in general the various operations involved at the site of work leave much to be desired, it is accepted that a use of a well chosen admixture may prove to be of some advantage in reducing the permeability.

It is to be noted that the use of admixture should in no case be considered as a substitute for bad materials, bad design or workmanship. In no case can an admixture be expected to compensate for cracks or large voids in concrete causing permeability.

Waterproofing admixtures may be obtained in powder, paste or liquid form and may consist of pore filling or water repellent materials. The chief materials in the pore filling class are silicate of soda, aluminium and zinc sulphates and aluminium and calcium chloride. These are chemically active pore fillers. In addition they also accelerate the setting time of concrete and thus render the concrete more impervious at early age. The chemically inactive pore filling materials are chalk, fullers earth and talc and these are usually very finely ground. Their chief action is to improve the workability and to facilitate the reduction of water for given workability and to make dense concrete which is basically impervious.

Some materials like soda, potash soaps, calcium soaps, resin, vegetable oils, fats, waxes and coal tar residues are added as water repelling materials in this group of admixtures. In some kind of waterproofing admixtures inorganic salts of fatty acids, usually calcium or ammonium stearate or oleate is added along with lime and calcium chloride. Calcium or ammonium stearate or oleate will mainly act as water repelling material, lime as pore filling material and calcium chloride accelerates the early strength development and helps in efficient curing of concrete all of which contribute towards making impervious concrete.

Some type of waterproofing admixtures may contain butyl stearate, the action of which is similar to soaps, but it does not give frothing action. Butyl stearate is superior to soap as water repellent material in concrete.

Heavy mineral oil free from fatty or vegetable oil has been proved to be effective in rendering the concrete waterproof. The use of Asphalt Cut-back oils have been tried in quantities of  $2\frac{1}{2}$ , 5 and 10 per cent by weight of cement. Strength and workability of the concrete was not seriously affected.

Production of concrete of low permeability depends to a great extent on successful uniform placing of the material. An agent which improves the plasticity of a given mixture without causing deleterious effects or which limits bleeding and thereby reduces the number of large voids, might also be classified as a permeability reducing admixture. Air entraining agents may also be considered under this, since they increase workability and plasticity of concrete and help to reduce water content and bleeding. An air entrained concrete has lower absorption and capillarity till such time the air content do not exceed about 6 per cent.

The aspect of damp-proofing and waterproofing of concrete is a very complex topic. It embraces the fundamentals of concrete technology. Among many other aspects, the w/c ratio used in the concrete, the compaction, curing of concrete, the admixture used to reduce the w/c ratio, the heat of hydration, the micro-cracking of concrete and many other facets influence the structure of hardened cement paste and concrete, which will have direct bearing on permeability, damp-proofing and waterproofing. This aspect is dealt in little more detail under construction chemicals later.

### Gas Forming Agents

A gas forming agent is a chemical admixture such as aluminium powder. It reacts with the hydroxide produced in the hydration of cement to produce minute bubbles of hydrogen

gas throughout the matrix. The extent of foam or gas produced is dependent upon the type and amount of aluminium powder, fineness and chemical composition of cement, temperature and mix proportions. Usually unpolished aluminium powder is preferred. The amount added are usually 0.005 to 0.02 per cent by weight of cement which is about one teaspoonful to a bag of cement. Larger amounts are being used for the production of light weight concrete.

The action of aluminium powder, when properly controlled causes a slight expansion in plastic concrete or mortar and this reduces or eliminates the settlement and may, accordingly, increase the bond to reinforcing bars and improve the effectiveness of grout, in filling joints. It is particularly useful for grouting under machine bases. The effect on strength depends upon whether or not the concrete is restrained from expanding. If it is restrained, the effect on strength is negligible, and if not, the loss of strength may be considerable. It is, therefore, important that the forms be tight and the grout is completely confined.

In hot weather, the action of aluminium powder may occur too quickly and beneficial action may be lost. In cold weather, the action will be slower and may not progress fast enough to produce the desired effect before the concrete has set. At normal temperature the reaction starts at the time of mixing and may continue for  $1\frac{1}{2}$  to 4 hours. At temperatures above 38°C, the reaction may be completed in 30 minutes. At about 4°C the reaction may not be effective for several hours. Approximately twice as much aluminium powder is required at 4°C as at 21°C to produce the same amount of expansion.

Because very small quantity of aluminium powder is used and as it has a tendency to float on the water, the powder is generally pre-mixed with fine sand and then this mixture is added to the mixer.

Aluminium powder is also used as an admixture in the production of light weight concrete. Larger quantities of about 100 gms per bag of cement is used for this purpose. Sodium hydroxide or trisodium phosphate is sometimes added to accelerate the reaction. Sometimes an emulsifying agent may be added to stabilise the mix. By varying the proportions of aluminium powder depending upon the temperature and carefully controlling the gas formation, light weight concrete may be produced in a wide range of density. Zinc, magnesium powders and hydrogen peroxide are also used as gas forming agents.

### **Air-detraining agents**

There have been cases where aggregates have released gas into or caused excessive air entrainment, in plastic concrete which made it necessary to use an admixture capable of dissipating the excess of air or other gas. Also it may be required to remove a part of the entrained air from concrete mixture. Compounds such as tributyl phosphate, water-insoluble alcohols and silicones have been proposed for this purpose. However, tributyl phosphate is the most widely used air-detraining agent.

### **Alkali-aggregate expansion inhibitors**

We have already dealt with the alkali-aggregate expansion in Chapter 3. It has been seen that alkali-aggregate reaction can be reduced by the use of pozzolanic admixture. We have already dealt about the use of pozzolanic material early in this chapter. There are some evidences that air entraining admixture reduces the alkali-aggregate reaction slightly. The other admixtures that may be used to reduce the alkali-aggregate reaction are aluminium powder and lithium salts.

## Workability Agents

Workability is one of the most important characteristics of concrete, specially under the following circumstances:

- (a) If the concrete is to be placed around closely placed reinforcement, deep beams, thin sections etc.
- (b) Where special means of placement are required such as tremie, chute or pumping methods.
- (c) If the concrete is harsh because of poor aggregate characteristics or grading.
- (d) For making high strength concrete when w/c ratio is very low.

In the above circumstances even the cost of achieving the workability may have to be overlooked.

Some admixtures can be used to improve workability. The materials used as workability agents are:

- (a) finely divided material,
- (b) plasticizers and superplasticizers,
- (c) air-entraining agents

The use of finely divided admixture in appropriate quantity improves workability, reduces rate and amount of bleeding, increases the strength of lean concrete and may not increase water requirement and drying shrinkage. Common materials added as workability agents are bentonite clay, diatomaceous earth, fly ash, finely divided silica, hydrated lime and talc.

Use of plasticizers and superplasticizers are one of the most commonly adopted methods for improvement of workability in almost all the situations in concrete making practices. We have seen in good detail about the use of plasticizers and superplasticizers.

Though the chief use of air-entraining agent is to increase resistance to freezing and thawing, in our country, air-entrainment in concrete is mainly practised for improving workability. Air entraining admixtures are used as mortar and concrete plasticizers. This aspect has already been dealt with.

## Grouting Agents

Grouting under different conditions or for different purposes would necessitate different qualities of grout-mixture. Sometimes grout mixtures will be required to set quickly and sometimes grout mixtures will have to be in fluid form over a long period so that they may flow into all cavities and fissures. Sometimes in grout mixtures, a little water is to be used but at the same time it should exhibit good workability to flow into the cracks and fissures. There are many admixtures which will satisfy the requirements of grout mixture. Admixtures used for grouting are:

- (a) Accelerators
- (b) Retarders
- (c) Gas forming agents
- (d) Workability agents
- (e) Plasticizers.

Accelerating agents may be used in grout to hasten the set in situation where a plugging effect is desired. In such a case calcium chloride or triethanolamine can be used.

Retarders and dispersing agents may be used in a grout to aid pumpability and to effect the penetration of grout into fine cracks or seams. They include mucic acid, gypsum and a commercial brand known as RDA (Ray Lig Blinder) etc.



Gas forming admixtures can be used while grouting in completely confined areas, such as under machine bases. Aluminium powder is the most commonly used agent, which chemically reacts and forms small bubbles of hydrogen and produces expansion of the grout. This expansion eliminates settlement and shrinkage.

Plasticizers and superplasticizers in powder form is always one of the ingredients of the grout mixture for effective flowability and obtaining high strength.

### Corrosion Inhibiting Agents

The problem of corrosion of reinforcing steel in concrete is universal. But it is more acute in concrete exposed to saline or brackish water or concrete exposed to industrial corrosive fumes. A patented process by Dougill was used for the North Thames Gas Board in UK, in which sodium benzoate was used as corrosion inhibiting admixture to protect the steel in reinforced concrete. In this process 2 per cent sodium benzoate is used in the mixing water or a 10 per cent benzoate cement slurry is used to paint the reinforcement or both. Sodium benzoate is also an accelerator of compressive strength.

It is found that calcium lignosulphonate decreased the rate of corrosion of steel embedded in the concrete, when the steel reinforcement in concrete is subjected to alternating or direct current.

Sodium nitrate and calcium nitrite have been found to be efficient inhibitors of corrosion of steel in autoclaved products. Two or three per cent sodium nitrate by weight of cement is said to serve the purpose. There are number of commercial admixtures available now to inhibit corrosion. Mc-Corrodur is one such admixture manufactured by Mc-Bauchimie (Ind) Pvt. Ltd. They also manufacture a two component corrosion inhibiting coating for reinforcement. This coating is used in repair system.

More about corrosion of reinforcement will be dealt under Chapter 9 on durability of concrete.

### Bonding Admixture

Bonding admixtures are water emulsions of several organic materials that are mixed with cement or mortar grout for application to an old concrete surface just prior to patching with mortar or concrete. Sometimes they are mixed with the topping or patching material. Their function is to increase the bond strength between the old and new concrete. This procedure is used in patching of eroded or spalled concrete or to add relatively thin layers of resurfacing.

The commonly used bonding admixtures are made from natural rubber, synthetic rubber or from any organic polymers. The polymers include polyvinyl chloride, polyvinyl acetate etc.

Bonding admixtures fall into two general categories, namely, re-emulsifiable types and non-re-emulsifiable types. The latter is better suited for external application since it is resistant to water.

These emulsions are generally added to the mixture in proportions of 5 to 20 per cent by weight of cement. Bonding admixtures usually cause entrainment of air and a sticky consistency in a grout mixtures. They are effective only on clean and sound surfaces.

### Fungicidal, Germicidal and Insecticidal Admixtures

It has been suggested that certain materials may either be ground into the cement or added as admixtures to impart fungicidal, germicidal or insecticidal properties to hardened cement pastes, mortars or concretes. These materials include polyhalogenated phenols, dieldren emulsion or copper compounds.

## Colouring Agents

Pigments are often added to produce colour in the finished concrete. The requirements of suitable admixtures include (a) colour fastness when exposed to sunlight (b) chemical stability in the presence of alkalinity produced in the set cement (c) no adverse effect on setting time or strength development. Various metallic oxides and mineral pigments are used.

Pigments should preferably be thoroughly mixed or interground with the dry cement. They can also be mixed with dry concrete mixtures before the addition of mixing water.

RMC (India) Ltd., one of the Ready Mixed Concrete supplier markets ready mixed colour concrete for decorative pavements. Sometimes they make this colour concrete incorporating polypropylene fibres to arrest possible cracks and craziness in the concrete floor.

## Miscellaneous Admixtures

There are hundreds of commercial admixtures available in India. They effect more than one property of concrete. Sometimes they are ineffective and do not fulfil the claims of the manufacturers. It is not intended to deal in detail about these commercial admixtures. However, a few of the more important admixtures are briefly described and some of them are just named.

All these commercial admixtures can be roughly brought under two categories (a) Damp proofers (b) Surface hardeners, though there are other agents which will modify the properties like strength, setting time, workability etc.

### Damp Proofers

(a) **Accoproof:** It is a white powder to be mixed with concrete at the rate of 1 kg per bag of cement for the purpose of increasing impermeability of concrete structures.

(b) **Natsons Cement WaterProofer:** As the name indicates, it is a waterproofing admixture to be admixed at the rate of 1.5 kg per bag of cement.

(c) **Trip-L-Seal:** It is a white powder, the addition of which is claimed to decrease permeability of concrete and mortars and produce rapid hardening effect.

(d) **Cico:** It is a colourless liquid which when admixed with concrete, possesses the properties of controlling setting time, promoting rapid hardening, increasing strength and rendering the concrete waterproof.

(e) **Feb-Mix-Admix:** It is a light yellow coloured liquid claimed to impart waterproofing quality to concrete and increase workability and bond.

(f) **Cemet:** It is a waterproofing admixture. The recommended dose is 3 per cent by weight of cement. It is also claimed that its use in concrete will prevent efflorescence and growth of fungi.

In addition to the above the following are some of the commercial waterproofing admixtures:

- |                    |                    |
|--------------------|--------------------|
| (a) Arzok          | (b) Bondex         |
| (c) Impermo        | (d) Luna-Ns-1      |
| (e) Sigmet         | (f) Arconate No. 2 |
| (g) Swadco No. 1   | (h) Rela           |
| (i) Wet seal       | (j) Water lock     |
| (k) Scott No. 1    | (l) Hydrofuge      |
| (m) Omsons "Watse" |                    |

### Surface Hardeners

(a) **Metal Crete:** Metal crete is a metallic aggregate which is tough, ductile, specially processed, size graded iron particles with or without cement dispersing agent. It is claimed that it gives greater wear resistance, corrosion resistance, non-dusting and non-slipping concrete surface.

(b) **Ferrocrete No. 1:** It is a surface hardener and makes the concrete surface compact, dense and homogeneous.

(c) **Metal Crete Steel Patch:** It is a surface hardener. When added 20 per cent by weight of cement, it is supposed to increase the compressive strength and abrasion resistance.

(d) **Arconate No. 1:** It is a black powder composed of iron filings. It is used as surface hardener in concrete.

In addition to the above, the other admixtures used as surface hardeners are:

- (i) Ironite;                      (ii) Merconite;  
(iii) Meta Rock;              (iv) Purelite.

Another important admixture which has been very popular is "Lisspol N". It is a polyetheoxy surface active agent which improves workability, strength and many other important properties of concrete when used in a very small dose of  $\frac{1}{2}$  oz per bag of cement.

The commercial admixtures are not dependable. It has been common experience that many a time when these admixtures are tested in a laboratory the manufacturer's or distributor's claims are not fulfilled. So it will be wrong to have much faiths in these commercial admixtures though some of them give some encouraging results.

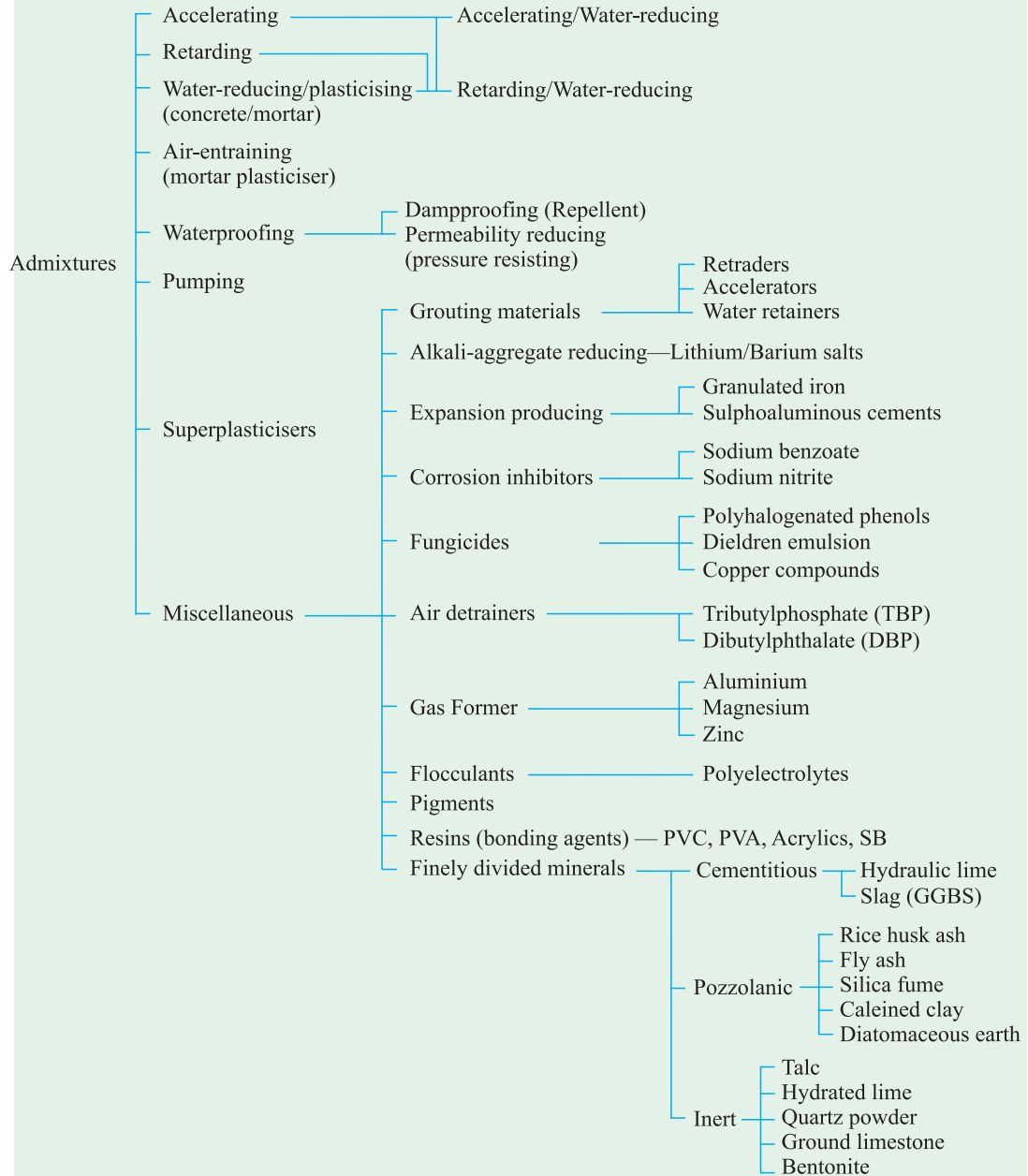
The classification of admixtures and the various materials used are shown in Table 5.22.

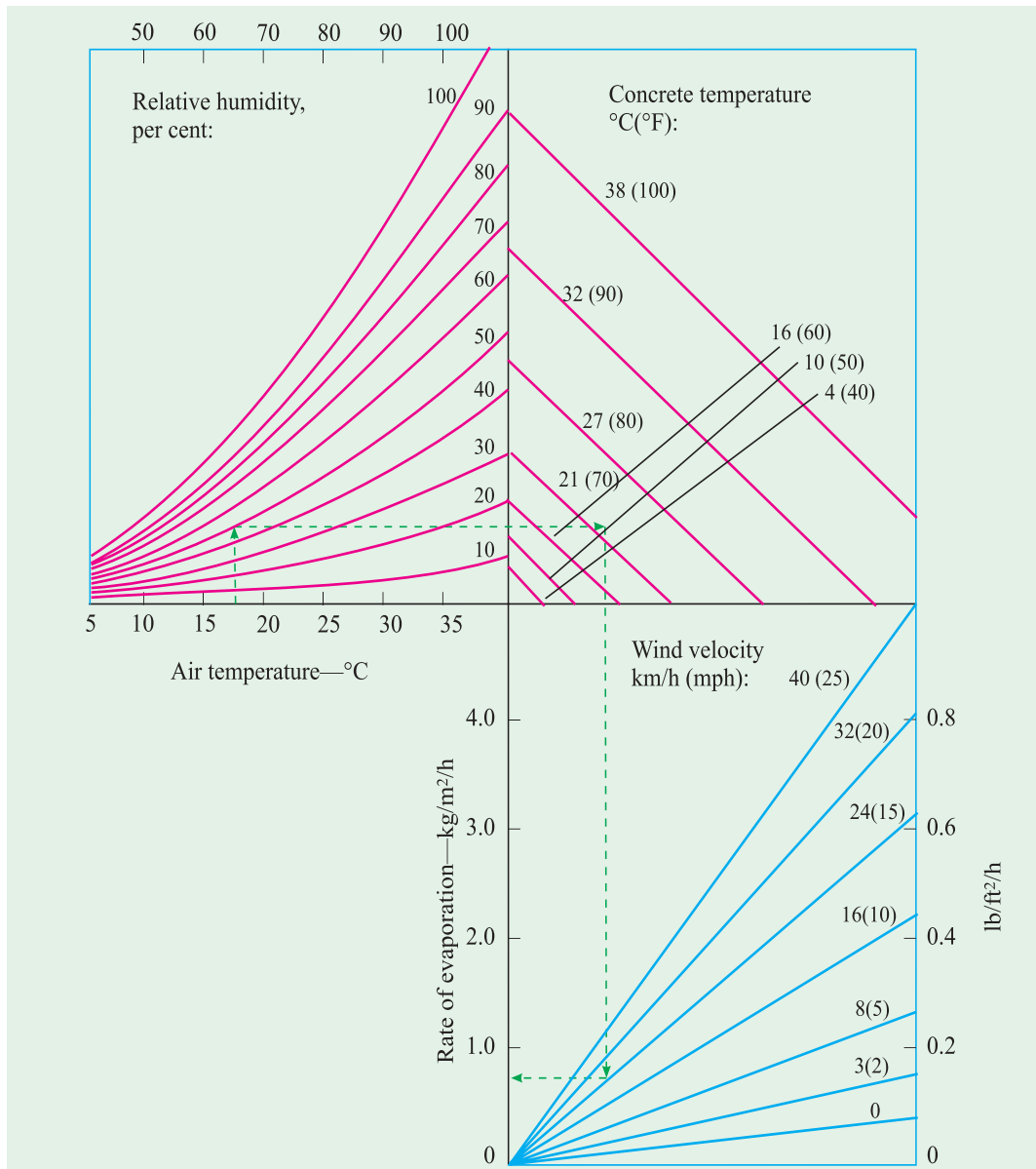
### Construction Chemicals

So far in this chapter we have discussed the materials that are used as admixtures to modify the properties of concrete. There are other chemicals not used as admixtures but used to enhance the performance of concrete, or used in concrete related activities in the field of construction. Such chemicals are called construction chemicals or building chemicals. The following is the list of some of the construction chemicals commonly used.

- Concrete Curing Compounds
- Polymer Bonding Agents
- Polymer Modified Mortar for Repair and Maintenance
- Mould Releasing Agents
- Installation Aids
- Floor Hardners and Dustproofers
- Non-Shrink High Strength Grout
- Surface Retarders
- Bond-aid for plastering
- Ready to use Plaster
- Guniting Aid
- Construction Chemicals for Waterproofing
  1. Integral Waterproofing Compounds
  2. Acrylic Based Polymer Coatings

**Table 5.22. Classification of Admixtures<sup>5.20</sup>**





3. Mineral based polymer modified coatings
4. Protective and Decorative coatings
5. Chemical DPC
6. Waterproofing Adhesive for Tiles, Marble and Granite
7. Silicon Based Water Repellent Material
8. Injection Grout for Cracks
9. Joint Sealants

### Membrane Forming Curing Compounds

In view of insufficient curing generally carried out at site of work, the increasing

importance of curing for around good qualities of concrete, in particular, strength and durability, the need for conservation of water and common availability of curing compounds in the country, it is felt that detail information is required on this vital topic – curing of concrete by membrane forming curing compounds.

Availability of enough moisture in concrete is the essence for uninterrupted hydration process. In fresh concrete, the moisture level in concrete is much higher than the relative humidity of atmosphere. Therefore, evaporation of water takes place from the surface of concrete. To recoup the loss of water from the surface of concrete and to prevent the migration of water from the interior of concrete to surface of concrete, that is to retain adequate moisture in the concrete, certain measures are adopted. Such measures taken are generally called curing of concrete.

### Drying Behaviour

Drying behaviour of concrete depends upon air temperature, relative humidity, fresh concrete temperature and wind velocity. Figure 5.33 shows drying behaviour as per Leach's investigation. The sketch is self explanatory.

### Types of Curing Compounds

Liquid membrane forming curing compounds are used to retard the loss of water from concrete during the early period of setting and hardening. They are used not only for curing fresh concrete, but also for further curing of concrete after removal of form work or after initial water curing for one or two days. In the case of white pigmented curing compound it also reduces the temperature rise in concrete exposed to radiation from sun. Curing compounds are made with the following bases.

- Synthetic resin
- Wax
- Acrylic
- Chlorinated rubber.

Resin and wax based curing compounds seals the concrete surface effectively. With time their efficiency will get reduced and at about 28 days they get disintegrated and peels off. Plastering can be done after about 28 days. If plastering is required to be done earlier, the surface can be washed off with hot water. As per one set of experiments it has been revealed that the typical curing efficiency was 96% for 24 hours, 84% for 72 hours 74% for 7 days and 65% for 14 days and the average efficiency of resin and wax based membrane forming curing compound can be taken as about 80%.

Acrylic based membrane forming curing compound has the additional advantage of having better adhesion of subsequent plaster. The membrane does not get crumbled down or it need not be washed with hot water. In fact on account of inherent characteristics of acrylic emulsion the bonding for the plaster is better.

Chlorinated rubber curing compounds not only form a thin film that protects the concrete from drying out but also fill the minute pores in the surface of concrete. The surface film will wear out eventually.

### Application Procedure

The curing compound is applied by brush or by spraying while the concrete is wet. In case of columns and beams the application is done after removal of formwork. On the horizontal surface, the curing compound is applied upon the complete disappearance of all

bleeding water. In case of road and Air field pavements where texturing is required, the curing compound is applied after texturing. In case of Pune-Mumbai express highway, the pavement is cast by slip form paver. In this process concrete is finished, texturing is done and curing compound is sprayed all by mechanical means. The young concrete is covered by tents to protect green concrete from hot sun and drying winds. In the above express highway it is specified that the concrete is also water cured after one day using wet hessian cloth. Water curing over membrane curing is seemingly superfluous, but it may be helpful in keeping the temperature down.

In case the concrete surface has dried, the surface should be sprayed with water and thoroughly wetted and made fully damp before curing compound is applied. The container of curing compound should be well stirred before use.

At present we do not have Bureau of Indian Standard Specification and Code of Practice for membrane forming curing compounds. It is under preparation. Since curing compounds are used very commonly in our country in many of the major projects, such as Sardar Sarovar dam projects, express highway projects, etc., a brief description in respect of ASTM: C 309 of 81, for "Liquid Membrane-forming Compounds for Curing concrete" and ASTM C 156 of 80 for "Water Retention by concrete Curing Materials" is given below for information of users.

**Scope:** The specification covers liquid membrane forming compounds suitable for retarding the loss of water during the early period of hardening of concrete. The white pigmented curing compound also reduces the temperature rise in concrete exposed to radiation from sun.

The following types of compounds are included:

- clear or translucent without dye
- clear or translucent with fugitive dye
- white pigmented.

**Base:** The membrane forming curing compound may be

- Resin based
- Acrylic based.

### General Characteristics

The clear or translucent compounds shall be colourless or light in colour. If the compound contains fugitive dye, it shall be readily distinguishable on the concrete surface for at least 4 hours after application, but shall become inconspicuous within 7 days after application, if exposed to sun light.

The white-pigmented compound shall consist of finely divided white pigment and vehicle ready mixed for immediate use as it is. The compound shall present in uniform white appearance where applied at the specified rate.

The liquid membrane forming compounds shall be of such consistency that it can be readily applied by spraying, brushing or rolling at temperature above 4°C.

The liquid membrane-forming compounds are generally applied in two coats. If need be more than two coats may be applied so that the surface is effectively sealed. The first coat shall be applied after the bleeding water, if any, is fully dried up, but the concrete surface is quite damp. In case of formed surfaces such as columns and beams etc., the curing compound shall be applied immediately on removal of formwork.

### Water Retention Test

**Scope:** This method covers laboratory determination of efficiency of liquid membrane

forming compounds as measured by its ability to prevent moisture loss during the early period of hardening.

### Apparatus

*Moulds:* Moulds shall be made of metal or plastic and shall be water tight. The size shall be 150 mm x 300 mm at the top, 145 mm x 295 mm at the bottom and 50 mm in height.

*Curing Cabinet:* A cabinet for curing the specimens at a temperature of  $37^{\circ}\text{C} \pm 1^{\circ}\text{C}$  and a relative humidity of  $30 \pm 2\%$ .

*Balances:* The balance for weighing the mould and content shall have a capacity of 10 kg, sensitive to 1 gram or less. The balance used for weighing the membrane forming compound shall have a capacity of 1 kg and shall be sensitive to 0.1 gram or less.

### Proportioning and Mixing Mortar

Make cement mortar of sufficient quantity required to fill the mould. The proportion of cement to standard sand is found out by making mortar of flow value of  $35 \pm 5$  with w/c ratio of 0.40. The mould is kept on glass plate and the mortar is filled in two layers and is fully compacted. The specimen is struck off level with a straight edge. The mould together with glass plate is cleaned by means of wet clean cloth. Seal the bottom junction between mould and glass plate with paraffin wax or any other suitable material to prevent oozing of water from the junction.

### Number of Specimen

A set of three or more test specimens for reference test and three or more for application of curing compound is done to constitute a test of a given curing compound.

### Storage of Specimen

Immediately after moulding cleaning and sealing, place all the specimen in curing cabinet maintained at temperature  $37^{\circ}\text{C} \pm 1^{\circ}\text{C}$  and relative humidity of  $30 \pm 2\%$ . The specimens are placed in the cabinet leaving a space of about 50 to 200 mm. Within this limit, the spacing shall be same for all the specimens. Keep all the specimens in the storage cabinet till such time, the bleeding water disappears. Apply two coats of curing compounds by means of brush. Take care to see that curing compound is applied only to the top surface and also effectively seal the junction between the mortar and mould by curing compound.

Weigh the coated specimens nearest to 1 gm. Find out the difference in weight between the coated and uncoated specimen. This gives the weight of the liquid membrane forming curing material. The weight of the curing material shall also be found out separately.

The entire operation of weighing, coating and reweighing shall not take more than 30 minutes. All the specimens are immediately placed in the storage cabinet and stipulated temperature and humidity is maintained.

### Duration of Test

The specimens are kept in the curing cabinet for 72 hours after the application of curing compounds.

### Corrections for Loss of Weight of Curing Compound

Take a metal pan or plate with edges raised 3 mm having an area equal to the top area of test specimen. Take the same quantity of curing material as coated to the specimen and coat the metal pan. Place the coated metal pan in the curing cabinet along with the specimen



and weigh this pan at the end of the test. Use the loss in weight of the curing compound as a correction factor in calculating the curing compound added.

#### Calculation of Loss in Weight

At the end of the specified curing period (72 hours) weigh the mould and specimen of the uncoated and coated samples. Find out the average loss in weight of the uncoated and coated specimen and express in kg/square meter of surface. This value could be used as an indicator of efficiency of liquid membrane forming curing compound.

#### Test results (Water Retention)

The liquid membrane forming compound, when tested as specified above shall restrict the loss of water to not more than. 0.55 kg/m<sup>2</sup> of surface area in 72 hours.

There are other tests for Reflectance and Drying time (not described).

#### Reflectance

The white-pigmented compound, when tested, shall exhibit a daylight reflectance of not less than 60% of that of magnesium oxide.

#### Drying Time

The liquid membrane-forming compound, when tested shall be dry to touch in not more than 4 hours. After 12 hours the compound shall not be tacky and one should be able to walk on the coating without any foot impression left on the surface coated.

In view of the requirement of large quantity of water for curing concrete and in view of continuous, uninterrupted curing is not done at the site, particularly on vertical surfaces, sloping surfaces and difficult inaccessible places, membrane forming curing compound, though less efficient than water curing, should be made popular in our construction practices.

Emcoril and Emcoril AC are the resin based and acrylic based liquid membrane forming curing compounds manufactured by Mc Bauchemie (Ind) Pvt. Ltd.

### Polymer Bonding Agents

It is one of the well known fact that there will not be perfect bond between old concrete and new concrete. Quite often new concrete or mortar is required to be laid on old concrete surface. For example, for providing an overlay on an existing pavement, in providing a screed over roof for waterproofing or repair work etc. The bonding characteristics can be greatly improved by providing a bond coat between old and new concrete surface or mixing the bonding agent with the new concrete or mortar. The use of bonding agent distinctly improves the adhesion of new concrete or mortar to old surface. The mixing of bonding agents with concrete or mortar improves the workability also at lower water cement ratio and thereby reduces the shrinkage characteristic. It also helps in water retention in concrete to reduce the risk of early drying. It further improves the water- proofing quality of the treated surface. Nafufull and Nafufill BB<sub>2</sub>, Nitobond EP, Nitobond PVA, Sikadur 32, Sikadur 41, Roff Bond ERB, Roff Bond Super are some of the commercial products available as bonding agents.

#### Polymer Modified Mortar for Repair and Maintenance

Sometime concrete surfaces require repair. The edge of a concrete column may get chipped off; or ceiling of concrete roof may get peeled off, or a concrete floor may get pitted in course of time. Hydraulic structures often require repairing. Prefabricated members such as pipes, poles, posts and roofing elements often gets chipped off while stripping formwork, handling and transportation. In the past cement mortar was used for any kind of repair and as an universal repair materials. Cement mortar is not the right kind of material for repair. Now there are many kinds of repair materials, mostly polymer modified, available for effective

repair. They adhere very firmly to the old concrete surface on account of greatly improved bond characteristics. These materials are often stronger than the parent materials. They are also admixed with some other materials which make them set and harden very rapidly. Sometime the material added eliminates the requirement for curing. Zentrifix F 82, Nafuquick, Zentrifix AS are some of the materials manufactured by Mc-Bauchemie.

### Mould Releasing Agents

Wooden planks, ordinary plywood, shuttering plywood, steel plates etc., are used as shuttering materials. Concrete when set and harden adhere to the surface of the formwork and make it difficult to demould. This affects the life and quality of shuttering materials and that of concrete. At times when extra force is used to demould from the form work, concrete gets damaged. Sometime mould surface could be cement plastered surface, in which case the demoulding or stripping of concrete member becomes all the more difficult. In the past to reduce the bond between formwork and concrete, some kind of materials such as burnt engine oil, crude oil, cowdung wash, polythylene sheet etc. were used. All the above are used on account of non availability of specially made suitable and effective mould releasing materials. Now we have specially formulated mould releasing agents, separately for absorptive surfaces like timber and plywood and for non absorbent surface like steel sheet are available. Nafuplan K and Nafuplan UST are the materials manufactured by Mc-Bauchemie. Reebol Formcote, Reebol spl, Reebol Emulsion are the materials supplied by Fosroc. Separol Sika Form oil are the materials from Sika Qualcrete.

### Installation Aids

Many a time we leave holes or make holes in walls, staircases, gate pillars etc., for fixing wash basin, lamp shades, hand rails or gates etc. Invariably, the holes made or kept, is larger than required. The extra space is required to be plugged subsequently. Material used in the past is cement mortar. Cement mortar takes a long time to set and harden, remain vulnerable for damage and it also shrinks. We have now specially manufactured materials which will harden to take load in a matter of 10-15 minutes and work as an ideal material from all points of view for the purpose of fixing such installations. Fig. 5.34 shows a few situations where fast curing installation aid could be used. They can also be used for fitting of antennae, fixing of pipes and sanitary appliances etc. Emfix is the name of the material manufactured by Mc-Bauchemie.

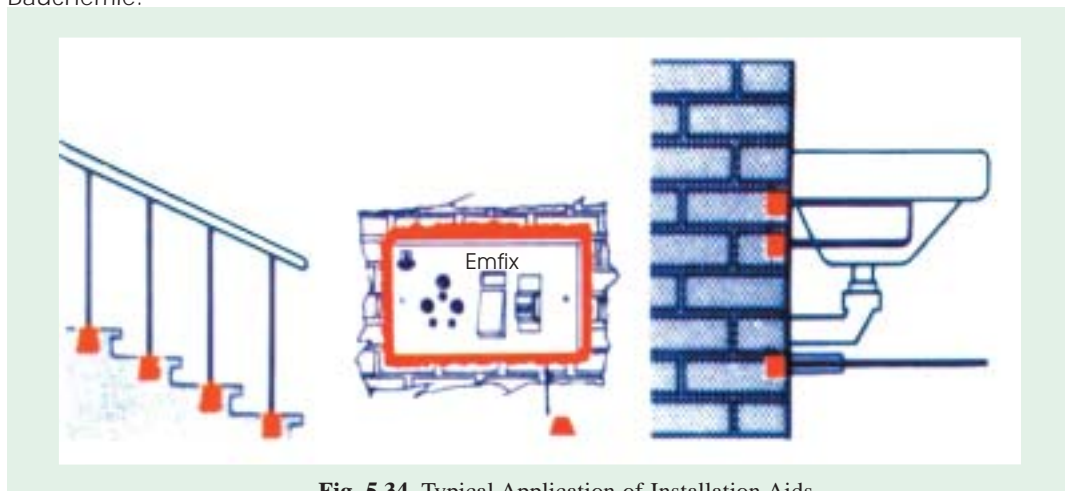
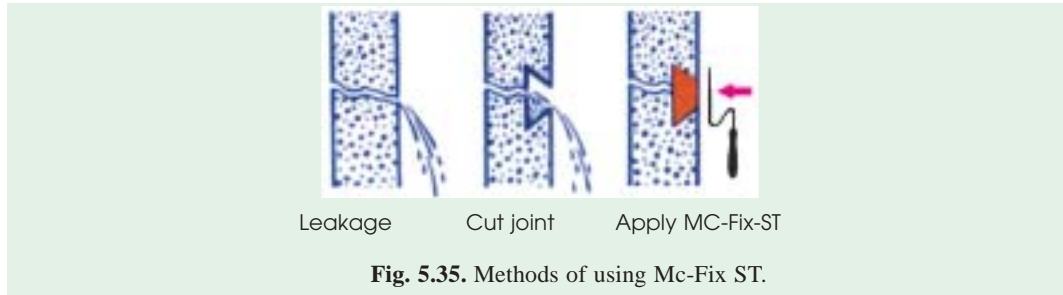


Fig. 5.34. Typical Application of Installation Aids.

Water tanks, deep pump houses, basements, pipes carrying water or sewage, sometimes develop cracks and leaks. Such leakages can be plugged by using a material called Mc-Fix ST manufactured by Mc-Bauchemie (India) Pvt. Ltd. Mc-Fix ST is a polymer modified, ready to use mortar for quick and reliable sealing and plugging of any kind of leaks. The mortar plug develops very high strength and is stone hard within about 5 to 7 minutes. Mc-Fix ST is mixed with a small quantity of water and kneaded into stiff mortar. This stiff mortar is kept pressed against the crack for 5 to 7 minutes.



**Fig. 5.35.** Methods of using Mc-Fix ST.

### Floor Hardeners and Dust Proofers

Floor is one of the parts of any building, particularly the industrial buildings, continuously subjected to wear and tear. The factory floor, on account of movement of materials, iron tyred trollies, vibrations caused by running machines is likely to suffer damages. Wear resistant and chemical resistant floor must be provided in the beginning itself. Replacing and repairing of old floor will interfere with the productivity and prove to be costly.

In the past, there were some materials such as Ironite, Hardonate, Metarock and other liquid floor hardeners were used to give better performance. But performances of these materials were not found to be satisfactory. Now we have modern floor toppings materials composed of corborandum or emery powders, systematically graded, mixed with processed and modified cement. This mixture when sprinkled over wet concrete floor of sufficient strength and depth is found to give an effective wear resistant, dust free, non slip floor. The quantity to be sprinkled is depending upon the degree of wear resistance required.

One difficulty is experienced in the application of wear resistant hard top material on the wet base concrete. If the sprinkling of this material is done when the base concrete is too wet, the finishing operation will make these hardwearing topping material sink, thus making the process ineffective. On the other hand if the sprinkling is delayed, the base concrete will have set and hardened to such an extent that the hardtop material will not become integral part of the floor. The hard topping material should be sprinkled at the appropriate time for optimum result.

Recently vacuum dewatering method is frequently adopted for casting factory floor, road, airfield pavements and concrete hardstanding. In India, Tremix System or Jamshedji Vaccum dewatering system is popular. Employment of vacuum dewatering of concrete for factory floor by itself will give improved performance. In addition, vacuum dewatering offers an ideal condition for broadcasting the floor topping on the top of the concrete floor slab. The hard wearing, sized and graded aggregate forms the top surface of concrete floor, to offer tremendous abrasion resistance.

Dreitop FH is the brand name of the product manufactured by Mc-Bauchemie: Nitoflor Hardtop is the brand name of the product manufactured by Fosroc. These products can also be used for existing floors with the provision of a compensating layer underscreed 25 to 30

mm thick. Use of polymer bonding agent to improve the bond between existing floor and compensating layer will improve the performance of the floor as a whole.

Abrasion and chemical resistance of industrial floor can also be improved by treating it with self-levelling epoxy coating or by screeding the floor top with epoxy mortar screeding. Nitoflor FC 140, Nitoflor TF 3000, Nitoflor TF 5000 are some of the materials manufactured by Fosroc, Sikafloor 91, Sikafloor 93, Sikafloor 81 etc., are the products from Sika and Rofflor Coat ERS, Rofflor top EFL, Rofflor top EFH are some of the Roff products. In addition to the above we have a number of epoxy flooring products such as MC-DUR 1500, MC DUR 1100, MC DUR grout etc. manufactured by MC-Bauchemie (India) Pvt. Ltd.

There are also certain materials which when applied on the concrete floor, convert the lime rich cement compounds into silicified products which gives extreme chemical and mechanical resistance and also dustproofing qualities.

### Non-Shrink High Strength Grout

Grouting aspects have been touched earlier in this chapter while dealing with waterproofing of basement slab and other concrete structure showing excess of permeability. Apart from the above, grouting has become one of the most important operations in civil engineering construction. Grouting below base plate or machine foundations, grouting of foundation bolt holes in industrial structures, grouting of prestressed concrete duct, grouting in anchoring and rock bolting systems, grouting of curtain walls, grouting of fissured rocks below dam foundation, grouting the body of the newly constructed dam itself, grouting of deteriorated concrete or fire affected structures to strengthen and rehabilitate, grouting of oil wells are some of the few situations where grouting is resorted to.

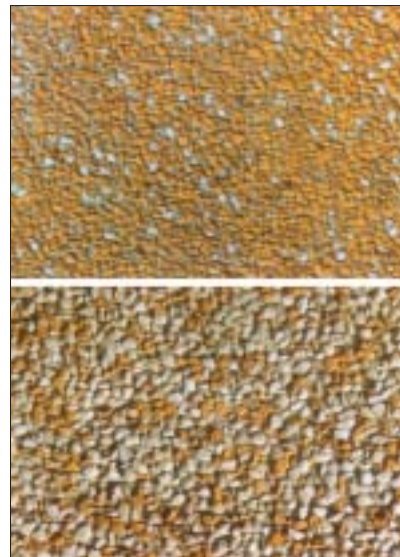
The grout material should have high early and ultimate strength, free flowing at low water content, should develop good bond with set concrete, essentially it should be non-shrink in nature.

The grouting materials can be broadly classified into two categories. One is free flow grout for use in machine foundations, foundation bolts and fixing crane rails etc. The second category of grout is meant for injection grouting to fill up the small cracks which is normally done under pressure.

Emckrete and Centicrete are the products of Mc-Bauchemie. Conbextra GP, Conbextra EP are the products of Fosroc.

### Surface Retarders

Exposed aggregate finish is one kind of architectural concrete. A few years back such an architectural concrete finish was achieved by bush hammering method, or by wire brushing and water spray methods. The above old methods are not giving a good finish. Now with the availability of surface retarders, both for "face up" or "face down" application, a very pleasing exposed aggregate finish can be obtained. Often exposed aggregate finish can be given for prefabricated



Exposed aggregate architectural concrete by making use of Surface Retarders.

panels or for in-situ concrete. The beauty of exposed aggregate can be further enhanced by using different coloured aggregates.

In the face down application surface retarders is brushed on the surface of moulds. This is generally done on prefab panels. After a day or so when the concrete is strong enough the panel is turned over. The concrete in the entire cross section will have hardened except the skin paste in touch with the mould. The unhardened paste is lightly brushed and washed off gently. The coarse aggregates becomes clean and fully exposed giving a pleasing architectural effect.

In case of face up, the surface retarder is directly sprayed or brushed on the concrete surface before hydration process begins. The cement mortar on the surface does not get set where as the mortar get set below certain depth of the surface where the coarse aggregate gets fully embedded in the hardened matrix. At an appropriate time the unhardened matrix and paste at the surface can be nicely brushed and washed, exposing the coarse aggregate.

Sometime such exposed aggregate finish is given to the foot paths and walk ways on either side of roads so that the surface will become non slippery. This kind of treatments are also given in the automobile service station and parking garages. Different surface retarders are available for different sizes of coarse aggregates. The above exposed aggregate technique is also used as mechanical key for adherence of plastering. Exposed aggregate finish can be adopted for "whisper concrete" surface in express highways.

A kind of exposed aggregate finish is given to hundreds of buildings at Asiad Village Complex, New Delhi.

### Bond Aid for Plastering

In the conventional system of construction, on removing the formwork, hacking is done on the surface of columns and beams and also on the ceiling of roof, to form a key between the structure and plaster. Hacking generally gives following problems:

- Uniform hacking is difficult to achieve.
- If there is delay, the structural concrete becomes so hard that hacking become difficult.
- Manual hacking is time consuming particularly at ceiling.
- Slender members particularly cantilever chajjas, louvers, sunbreakers develop structural cracks due to inconsiderate heavy hammer blows on young concrete.

To obviate the above problems liquid polymer bond aid in ready-to-use form is made use of. The surface should be clean, free from oil and grease. If washed it should be allowed to dry.

Bond aid for plastering should be applied in one coat by brushing or spraying. The plastering should be done on the principal of "wet-in-wet". That is to say that bond aid liquid should not dry when you apply plaster. A waiting period of about 60 to 90 minutes would be enough before plastering is applied.

### Ready to Use Plaster

One of the common defects in buildings is cracking of plaster. A lot of care is necessary with respect to quality of sand, surface preparation, proper proportioning, consistency and bonding of plaster to base materials. In the absence of such precautions, the plaster cracks and peels off.

In India, recently Ready Mixed Plaster has been introduced by a few industries. Roofit mix is one such brand name.

Ready mixed plaster is basically a pre-mixed materials in dry form consisting of good sand and cement in different proportions for various useage. The mix also includes, such as bonding agents, water retention and workability agents like hydrated lime, air-entraining agents, fly ash and other suitable admixtures to enhance the performance of a plaster material.

It is claimed that ready to use plaster will show the following benefits.

- Consistency in quality and finish
- Less storage and mixing area
- Lower material consumption
- Crack-free plaster
- No curing
- Better adhesion and workability
- Minimal wastage.

Roofit Ready to use Plaster is available in 40 kg bag and in many different grades for using in internal or external plaster, mortar for brick or block work, and as a screed material for tiling works.

**Guniting Aid.** Guniting and shortcreting have become popular methods of application of mortar or concrete in new constructions or repair techniques. To overcome the problems associated with sprayed concrete, we have now guniting aid in powder form or liquid form to accelerate the setting and hardening, to seal water seepage in tunnelling operations, to improve bonding, to reduce wastage of material by rebounding and to obtain many more advantage in sprayed concrete. Mc-Torkrethifile B.E. is the product of Mc-Bauchemie (India) Pvt. Ltd. and Conplast Spray Set is the Fosroc product for the above purpose.

## Construction Chemicals for Waterproofing

Inspite of many fold advancement made in Concrete Technology and the ability to produce high quality concrete, it has not been possible to really make waterproof structures. The problem of waterproofing of roofs, walls, bathrooms, toilets, kitchens, basements, swimming pools, and water tanks etc. have not been much reduced. There are number of materials and methods available in the country for waterproofing purposes. But most of them fail due to one or the other reasons. Waterproofing has remained as an unsolved complex problem. A successful waterproofing not only depends upon the quality and durability of material but also the workmanship, environment and type of structures. Leaving all other aspects, the material part is only discussed below.

It should be remembered that the use of plasticizers, superplasticizers, air-entraining agents, puzolanic materials and other workability agents, help in reducing the permeability of concrete by reducing the requirement of mixing water and hence they can also be regarded as waterproof material. In addition, there are other materials and chemicals available for waterproofing concrete structures.

These materials can be grouped as follows

- Integral waterproofing compounds
- Acrylic Based Polymer Coatings
- Mineral Based Polymer Modified Coatings
- Chemical DPC for Rising Dampness
- Waterproofing Adhesive for tiles, Marble and Granite
- Silicon Based Water Repellent material

- Injection grout for cracks
- Protective and Decorative Coatings
- Joint Sealants

### Integral Waterproofing Compounds

This topic has been partly covered on page 166.

The integral waterproofing compounds have been in use for the last 4 – 5 decades. They were used as admixtures to make concrete waterproof. These conventional waterproofing admixtures are either porefillers, or workability agents or water repellents, and as such they are useful to a limited extent. For example, roof slabs undergo thermal expansion and subsequent contraction. With the result concrete slabs develop minute cracks in the body of concrete. Concrete slab also develop minute cracks on account of long term drying shrinkage. In both the above cases, integral waterproofing compound will not be of much use. Only in situations where concrete is continuously in wet or in damp condition, integral water proofing will be of some use. The classical integral waterproofing compounds are Cico, Pudlo, Impermo, Accoproof etc.

There are new brands of integral waterproofing compounds such as Mc-special DM, Dichtament DM, Putz-Dichtament from MC Bauchemie and conplast prolapin 421 IC, conplast prolapin I – P etc. from Fosroc chemicals are useful in making concrete more workable and homogeneous. They also help in reducing w/c ratio, which properties extend better waterproffing quality. The modern integral waterproofing compounds are a shade better than the old products. The performance requirements of integral waterproofing of compound are covered in IS 2645 of 1975.

### Acrylic Based Polymer Coatings

One of the important reasons why a roof slab leaks, even if you take all the care in making good concrete, well compacted and well cured is that the roof is subjected to variations of temperature between day and night or season to season. Variation of temperature causes micro cracks in concrete and these micro cracks propagate with time and make the cracks grow wider and wider which leads to leaking of roof. The increase in long term drying shrinkage with age, is also another factor contributing to the leakage of roof or other concrete members.

Structural inadequacy, or failure to adhere to the proper detailing of reinforcement, or the unequal settlement etc are some of the additional reasons for development of cracks in concrete members.

In such situations a membrane forming waterproofing materials are ideal. The membrane should be tough, water resistant, solar reflective, elastic, elastomeric and durable. They allow the movement of the concrete members, but keep the qualities of the membrane intact.

One such material available today is Roofex 2000, material manufactured by MC-Bauchemie (Ind) Pvt. Ltd. The surface is cleaned, a priming coat and dust binder is applied over which Roofex 2000 is applied by means of brush or spray in two coats, right angles to each other. In applying this material manufacturers instructions should be strictly followed.



Waterproofing by Mineral Based Polymer Modified Coatings.

Any cracks in the plaster of parapet wall or vertical surface can be treated with this material. Generally this material is available in white colour but it can be made to order in any other colour for aesthetic requirements.

The Indian standard is being formulated for the use of such membrane forming waterproof coatings.

### Mineral Based Polymer Modified Coatings

Waterproofing of concrete, brick masonry and cement bound surfaces can be achieved by a specially made slurry coatings. Slurry consists of specially processed hydraulically setting powder component and a liquid polymer component. These two materials when mixed in a specified manner forms a brushable slurry. Two coats of this slurry when applied on roof surface or on any other vertical surface in basement, water tank or sunken portion of bathroom etc. forms a long lasting waterproofing coat. This coating requires curing for a week or so. The coating so formed is elastic and abrasion resistant to some extent. To make it long lasting the coatings may be protected by mortar screeding or tiles. The trade name of the above material is Dichtament DS, manufactured by MC-Bauchemie (India) Pvt. Ltd. The Brush Bond of Fosroc Coy and another material called xypex are also available in the market.

The materials described above although exhibit good waterproofing qualities the coating is not very elastic. Its performance in sunken portion of bathroom and such other areas where the concrete is not subjected variation in temperature, will be good. But it may not perform well on roof slab for not being flexible to the required extent, to cope up with the thermal movement of roof slab.

There is a modified version of Dichtament DS called Dichtament DS – flex. It is formulated in such a way that higher amount of polymer component is added to make it flexible to take care of possible small cracks in roof slab or such other situations.

A further modified version of the above has been made to give a better waterproofing and abrasion resistance to the treatment. The modified version will make the coating tough, more elastic and better waterproofing. This modified version of waterproofing system is specially applicable to terrace gardens, parking places, basements, swimming pools, sanitary areas etc. This coating also gives protection to chlorides, sulphates and carbonation attack on



bridges and also protect underground structures. The trade name is Zentrifix Elastic, manufactured by MC-Bauchemie (India) Pvt. Ltd.

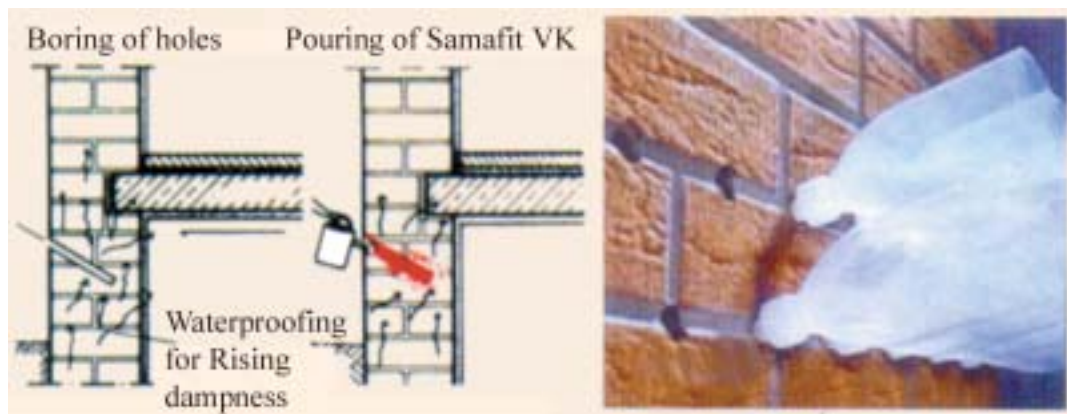
The above is one of the best waterproofing treatments when application is done strictly as per manufacturers instructions. Being flexible and having good crack bridging quality, it is an ideal material for prefabricated roof construction. Before applying the surface should be made damp but not wet. It can be applied by trowel or brush in two coats. A gap of about 3–4 hrs are given between successive coats. Though a standard thickness of 2–3 mm are achieved in two coats, in exceptional situation a maximum thickness of 4 mm could be allowed and in such a case the application should be done in three coats. A three coat treatment could be given to the external face of masonry wall in basement construction.

For the Mineral Based Polymer Modified Coatings the BIS specification is under preparation.

### Protective and Decorative Coatings

It was a popular belief that concrete structures do not require protection and the concrete is a naturally durable material. Lately it is realised that concrete needs protection and maintenance to increase its durability in hostile conditions. This aspect will be covered in greater detail under chapter 9 on durability of concrete. However, under the above topic consideration is given only to the waterproofing quality.

This RCC members such as sunbreakers, louvers, facia, facades, sun shades and chajjas, crack and spall off within a matter of a few years, particularly when the cover provided to these thin and delicate members are inadequate. Water seeps into these members and corrodes the reinforcement in no time. Corrosion is also accelerated by carbonation. To enhance the durability of such thin members and to make them waterproof, acrylic based waterproof, carbonation resistant coating is given. Incidentally it will present aesthetic and decorative look. A number of such protective, waterproof decorative paints, based on acrylic polymer and selected mineral filler are available in market. Emcecolour-Flex is one such paint



Water proofing for Rising dampness — Intrucing new DPC

manufactured by MC Bauchemie and Dekgaord S is the product of Fosroc chemicals. Generally they are white but could be produced in any colour in the factory.

### Chemical DPC

Often old buildings are not provided with damp-proof course. The water from the ground rises by capillary action. This rising water brings with it the dissolved salts and chemicals which result in peeling of plaster affecting the durability of structure, and also make buildings unhygienic. Attempts were made to cut the wall thickness in stages and introduce new DPC, but this method was found to be not only cumbersome but also ineffective. Now we have materials that can be injected into the wall at appropriate level to seal the capillaries and thereby to stop the upward movement of water. The system involves a two component material called Samafit VK<sub>1</sub> and Samafit VK<sub>2</sub> manufactured by MC Bauchemie (Ind) Pvt. Ltd. Above the ground level and below the plinth level, holes are drilled in a particular system. Samafit VK<sub>1</sub> is injected into this hole till absorption stops. After another 1/2 to 1 hour's time the other fluid namely Samafit VK<sub>2</sub> is similarly introduced. These two liquids react with each other to form a kind of jelly like substance which block the capillary cavities in the brickwall and stops the capillary rise of water. In this way rising dampness in buildings, where damp proof course is not provided earlier, can be stopped.

### Waterproofing Adhesives for Tiles, Marble and Granite

The normal practice followed for fixing glazed tiles in bathroom, lavatory, kitchen, and other places is the use of stiff neat cement paste. The existing practice, though somewhat satisfactory in the indoor conditions from the point of fixity, such practice is unsatisfactory when used in outdoor conditions and also from the point of view of waterproofing quality. The cement paste applied at the back of tiles do not often flow towards the edges of the tiles and as such water enter at the edges, particularly when white cement applied as joint filler become ineffective. In large number of cases it is seen that paintings and plaster gets affected behind these glazed tiles supposedly applied to prevent moisture movement from wet areas.

Cement paste is not the right material for fixing the glazed tiles. There are, polymer based, hydraulically setting, ready to use, waterproof tile adhesive available in the market. They offer many advantages over the conventional method of tile fixing such as better bond and adhesion, strengths, faster work, good waterproofing quality to the wall. They are also suitable for exterior and overhead surfaces. No curing of tile surface becomes necessary. If the wall and plastered surface is done to good plumb, a screeding of only 1 – 2 mm thickness of this modern material will be sufficient to fix the tiles in which case, the adoption of this material will also become economical. The modern tile adhesive material offers special advantages for fixing glazed tiles in swimming pools both on floor and at side walls. It provides one more barrier for the purpose of waterproofing.

Many a time, the glazed tiles fixed on the kitchen platform or bathroom floor gets dirty or damaged. It requires to be replaced. Normal practice is to chip off the old tile, screed



Waterproofing Adhesives for Tiles, Marble and Granite.

cement paste or mortar and then lay the new tiles. With modern tile adhesive, it is not necessary to remove the old tile. Tile adhesive can be screeded on the existing tiles and new tiles are laid over the old tiles. The bonding quality is such that good adherence takes place tile over tile. This saves considerable cost and time and the operation becomes simple.

Marble and granite are increasingly used for cladding wall surfaces both internally and externally. Marble and granite have become the most common treatment for external cladding of prestigious buildings. They are used in the form of tiles or large panels. In the past for fixing thin marble and granite tiles cement paste was used and for fixing large slabs and panels, epoxy and dowel pins were used. Now there are specially made ready to use high strength polymer bonding materials available which can be used with confidence both for internal and external use. Requirement of dowels are eliminated in most of the cases except for cladding of large panels at very high level for extra safety. Marble and granite can even be fixed on boards, inclined surface underside of beams and in ceilings by the use of this new powerful adhesives.

Zentrival PL for fixing glazed tiles and ceramic tiles and Zentrival HS for marble, granite and stones are the materials manufactured by Mc-Bauchemie (India) Pvt. Ltd., Nitobond EP, Nitobond PVA, Nitotile SP are some of the products manufactured by Fosroc.

#### **Silicon Based Water Repellant Materials**

Sometimes, in buildings brick works are not plastered. Bricks are exposed as they are. If good quality, well burnt bricks are not used in such constructions, the absorptive bricks permits the movement of moisture inside. Old heritage buildings built in stone masonry may suffer from minute cracks in mortar joints or plastered surface may develop craziness. In such situations one cannot use any other waterproofing treatment which will spoil the intended architectural beauty of the structures. One will have to go for transparent waterproofing treatment. For this purpose silicon based water repellant materials are used by spraying or brushing. This silicon based material forms a thin water repellant transparent film on the surface. The manufacturers slightly modify this material to make it little flexible to accommodate minor building movements due to thermal effect.

The application must be done in one liberal coat so that all the cracks and crevices are effectively sealed. Brick surface absorbs this material making the surface water repellant. Sometimes bricks or blocks are immersed in such materials before using for greater water repellant qualities.

This type of waterproofing materials are used in many monumental stone buildings and old palaces so that original look of the stone masonry is maintained, while making the masonry waterproof.

The treatment though effective, is not found to be long lasting on account of the movement of building components and the lack of required flexibility of the film. The treatment



Waterproofing by Silicon Based Water Repellant Material.

may have to be repeated at closer intervals, say once in 3–4 years. As it is not a costly material, one can afford to repeat the treatment.

This material is covered in IS 12027 of 1987. NISIWA SH is the brand name of one such material manufactured by MC-Bauchemie (Ind) Pvt. Ltd.

**Injection Grout for Cracks**

Injection grouting is one of the powerful methods commonly adopted for stopping leakages in dams, basements, swimming pools, construction joints and even in the leaking roofs. A few years back, cement was used for grouting purposes. Cement is not an ideal material for grouting, as it shrinks while setting and hardening. Non-shrink or expansive cementing material is the appropriate material. We have quite a few materials available in the market for filling up cracks and crevices in concrete structures to make them waterproof or for repair and rehabilitation of structures. The grouts are produced with selected water repellent, silicifying chemical compounds and inert fillers to achieve varied characteristics like water impermeability, non shrinkage, free flowability etc. They are suitable for gravity grouting as well as pressure grouting. Grouting of concrete structure is one of the powerful methods for strengthening and waterproofing of unhealthy structures. Centicrete is the trade name of one of the materials manufactured by MC-Bauchemie. Conbex 100 is the material marketed by Fosroc chemicals.

**Joint Sealants**

Joints in buildings, bridges, roads and airfield pavements are inescapable. They may be expansion joints, construction joints or dummy joints. Such joints must be effectively sealed to facilitate movement of structure, to provide waterproofing quality or to improve the riding qualities. While providing large openings and windows in buildings there exists gap between wall and window frames, through which water flows inside. Such gaps in the

<b>STAGES OF REPAIR WORK</b>	
	<p>diagrammatic view of steel bar and limits to exposure of reinforcement steel : Reinforcement steel, unsound concrete and areas over corroded reinforcement are removed concrete broken out. area of reinforcement steel to be treated with a protective coat. carbonated concrete (solid, over non corroded steel, is not removed). non carbonated concrete (solid).</p>
	<p><b>Surface Preparation</b> Hammer testing the concrete surface for cavities and chiselling of all loose portions to expose sound core concrete and expose rusted reinforcement.</p>
	<p><b>Cleaning Procedure</b> Clean rusted reinforcement and expose concrete surface by sandblasting, mechanical devices or any other established method.</p>
	<p><b>Corrosion inhibitor and bond coat</b> <b>Zentrifix KMH</b> Corrosion protection and bond coat to be mixed only with water prior to application in 2 coats</p>
	<p><b>Concrete Replacement</b> <b>Zentrifix GSE/GM2/KA50</b> Hydraulically setting coarse repair mortar <b>Zentrifix Elastic/F92</b> Flexible fine repair mortar</p>
	<p><b>Surface protection</b> <b>EmceColor-flex/ Betonflair W/Bentonflair CT</b> Anti carbonation, crack bridging coating to be applied in two coats.</p>

window should also be effectively sealed. The gaps resulting in installation of sanitary appliances are also required to be sealed. There were no effective materials in Indian market hitherto. Now we have modern materials like Polysulphide sealants and gun applied Silicone Rubber sealants, Sanitary sealant and Acrylic sealants. Nitoseal 215 (1) of Fosroc, Sikalastic, Sika-SII A, Sikacryl GP of Sika Qialcrete and sani seal of Roff are some of the materials available in the market for the purpose of sealing the joints.

### Concrete Repair System

It was once thought that concrete structures are durable and lasts almost forever. But now it is realised that concrete is not as durable as it was thought to be. It was also the earlier belief that concrete needs no protection. It was discussed earlier that concrete needs to be maintained and protected. Another wrong notion that prevailed was that concrete cannot be repaired. Now there are materials and methods for effective repair of damaged concrete structures which is discussed below.

Concrete is constantly under attack of environmental pollution, moisture ingress, penetration of chlorides and sulphates and other deleterious chemicals. The durability of concrete is then affected. Of all forces of degradation, carbonation is believed to be one of the potent causes of deterioration of concrete. This aspect is going to be discussed in detail under chapter 9 – durability of concrete.

Concrete repair has become a major subject all over the world. In India, a few newly constructed major bridges have come for repair. In places like Mumbai, innumerable buildings require repair. Many government departments have constituted their own separate "Repair Boards" to deal only with repair. Water tanks are one type of structures often come to repair prematurely.

In the past, there was no effective method of repairing cracked, spalled and deteriorated concrete. They were left as such for eventual failure. In the recent past, guniting was practised for repair of concrete. Guniting has not proved to be an effective method of repair. But now very effective concrete repair system is available. The repair system can take care of the concrete cancer and increase the longevity of the structure. The repair material used are stronger than the parent material. The efficient bond coat, effective carbonation resistant fine mortar, corrosion inhibiting primer, protective coating make the system very effective. Where reinforcement is corroded more than 50%, extra bars may be provided before repair mortar is applied. The whole repair process becomes a bit costly but often repair is inevitable and the higher cost has to be endured

Mc-Bauchemie (India) Pvt. Ltd. have a series of repair materials and well designed repair system. The Figure shows the repair process which is self explanatory.

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