12
CHAPTER

Special Concrete and Concreting Methods

SPECIAL CONCRETE

Light-weight Concrete

One of the disadvantages of conventional concrete is the high self weight of concrete. Density of the normal concrete is in the order of 2200 to 2600 kg/m^3. This heavy self weight will make it to some extent an uneconomical structural material. Attempts have been made in the past to reduce the self weight of concrete to increase the efficiency of concrete as a structural material. The light-weight concrete as we call is a concrete whose density varies from 300 to 1850 kg/m^3.

There are many advantages of having low density. It helps in reduction of dead load, increases the progress of building, and lowers haulage and handling costs. The weight of a building on the foundation is an important factor in design, particularly in the case of weak soil and tall structures. In framed structures, the beams and columns have to carry load of floors and walls. If floors and walls are made up of light-weight concrete it will result in considerable economy. Another most important characteristic of light-weight concrete is *the relatively low thermal conductivity, a property which improves with decreasing density. In extreme climatic conditions and also in case of buildings where air-conditioning is to be installed, the use of light-weight concrete with low thermal conductivity will be of considerable advantage from the point of view of thermal comforts and lower power consumption. The adoption of light-weight concrete gives an outlet for industrial wastes such as clinker, fly ash, slag etc. which otherwise create problem for disposal.*

Basically there is only one method for making concrete light i.e., by the inclusion of air in concrete. This is achieved in actual practice by three different ways.

(a) By replacing the usual mineral aggregate by cellular porous or light-weight aggregate.

(b) By introducing gas or air bubbles in mortar. This is known as aerated concrete.

(c) By omitting sand fraction from the aggregate. This is called 'no-fines' concrete.

The Table 12.1 shows the whole ranges of light-weight concrete under three main groups.

Light-weight concrete has become more popular in recent years owing to the tremendous advantages it offers over the conventional concrete. Modern technology and a better understanding of the concrete has also helped much in the promotion and use of light-

Table 12.1. Groups of Light-weight Concrete

No-fines Concrete	Light-weight aggregate concrete	Aerated Concrete	
		Chemical aerating	Foaming mixture
(a) Gravel	(a) Clinker	(a) Aluminium powder method	(a) Preformed foam
(b) Crushed stone	(b) Foamed slag	(b) Hydrogen peroxide and bleaching powder method	(b) Air-entrained foam
(c) Coarse clinker	(c) Expanded clay		
(d) Sintered pulverised fuel ash	(d) Expanded shale		
(e) Expanded clay or shale	(e) Expanded slate		
(f) Expanded slate	(f) Sintered pulverised fuel ash		
(g) Foamed Slag	(g) Exfoliated vermiculite		
	(h) Expanded perlite		
	(i) Pumice		
	(j) Organic aggregate		

weight concrete. A particular type of light-weight concrete called structural light-weight concrete is the one which is comparatively lighter than conventional concrete but at the same time strong enough to be used for structural purposes. It, therefore, combines the advantages of normal normal weight concrete and discards the disadvantages of normal weight concrete. Perhaps this type of concrete will have great future in the years to-come. Out of the three main groups of light-weight concrete, the light-weight aggregate concrete and aerated concrete are more often used than the 'no-fines' concrete. Light-weight concrete can also be classified on the purpose for which it is used, such as structural light weight concrete, non-load bearing concrete and insulating concrete. The aerated concrete which was mainly used for insulating purposes is now being used for structural purposes sometimes in conjunction with steel reinforcement. The aerated concrete is more widely manufactured and used in the Scandinavian countries; whereas in U.K., France, Germany and U.S.A. owing to the production of large scale artificial industrial light-weight aggregate, light-weight aggregates concrete is widely used. In some countries the natural dense graded aggregate are either in short supply or they are available at a considerable distance from the industrial cities. In such cases the use of locally produced light-weight aggregates in the city area offers more economical solutions. These factors have led to the development and widespread use of considerable varieties of industrial light-weight aggregates of varying quality by trade names such as Leca (expanded clay), Aglite (expanded shale), Lytag (sintered pulverised fuel ash), Haydite (expanded shale).

Light Weight Aggregates

Light-weight aggregates can be classified into two categories namely natural light-weight aggregates and artificial light-weight aggregates.

Natural light-weight aggregate	Artificial light-weight aggregate
(a) Pumice	(a) Artificial cinders
(b) Diatomite	(b) Coke breeze
(c) Scoria	(c) Foamed slag
(d) Volcanic cinders	(d) Bloated clay
(e) Sawdust	(e) Expanded shales and slate
(f) Rice husk	(f) Sintered fly ash
	(g) Exfoliated vermiculite
	(h) Expanded perlite
	(i) Thermocole beads.

Natural Aggregates

Natural light-weight aggregates are not found in many places and they are also not of uniform quality. As such they are not used very widely in making light-weight concrete. Out of the natural light-weight aggregates pumice is the only one which is used rather widely.

Pumice

These are rocks of volcanic origin which occur in many parts of the world. They are light enough and yet strong enough to be used as light-weight aggregate. Their lightness is due to the escaping of gas from the molten lava when erupted from deep beneath the earth's crest. Pumice is usually light coloured or nearly white and has a fairly even texture of interconnected cells.

Pumice is one of the oldest kinds of light-weight aggregates which has been even used in Roman structures. Pumice is mined, washed and then used. Pumice may be sintered to the point of incipient fusion when a much stronger aggregate is required. The density and other properties of pumice concrete can be seen from Table 12.3.

Diatomite

This is a hydrated amorphous silica derived from the remains of microscopic aquatic plants called diatoms. It is also known a Kieselguhr. The deposits of this aquatic plants are formed beneath the deep ocean bed. Subsequently when the ocean bed is raised and becomes continent, the diatomaceous earth become available on land. In pure form diatomite has an average weight of 450 kg/m^3. But due to impurities, the naturally available diatomite may weight more than 450 kg/m^3. It has been pointed out earlier that diatomite is used as a workability agent and also as one of the good pozzolanic material. Diatomite or diatomaceous earth can also be sintered in rotary kilns to make artificial light-weight aggregates.

Scoria

Scoria is also light-weight aggregate of volcanic origin which is usually dark in colour and contains larger and irregularly shaped cells unconnected with each other. Therefore, it is slightly weaker than pumice.

Volcanic Cinders

These are also loose volcanic product resembling artificial cinder.

Saw Dust

Sometimes saw dust is used as a light-weight aggregate in flooring and in the manufacture of precast products. A few difficulties have been experienced for its wide-spread use. Saw dust affect adversely the setting and hardening of Portland cement owing to the content of tannins and soluble carbohydrates. With saw dust manufactured from soft wood, the addition of lime to the mix in an amount equal to about 1/3 to 1/2 the volume of cement will counteract this. But the above method i.e., addition of lime is not found effective when the saw dust is made from some of the hard woods. Others methods such as boiling in water and ferrous sulphate solutions also have been tried to remove the effect of tannins, but the cost of the process limits its application. To offset the delay in setting and hardening, addition of calcium chloride to the extent of about 5 per cent by weight of cement has been found to be successful.

The shrinkage and moisture movement of saw dust is also high. The practical mix is of the ratio of 1 : 2 to 1 : 3 i.e., cement to saw dust by volume.

Saw dust concrete has been used in the manufacture of precast concrete products, jointless flooring ad roofing tiles. It is also used in concrete block for holding the nail well. Wood aggregate also has been tried for making concrete. The wood wool concrete is made by mixing wood shavings with Portland cement or gypsum for the manufacture of precast blocks. This has been used as wall panels for acoustic purposes.

Rice Husk

Limited use of the rice husk, groundnut husk and bagasse have been used as light-weight aggregate for the manufacture of light-weight concrete for special purposes.

Artificial Aggregates

Brick Bats

Brick bats are one of the types of aggregates used in certain places where natural aggregates are not available or costly. The brick bat aggregates cannot be really brought under light-weight aggregates because the concrete made with this aggregate will not come under the category of light-weight concrete. However since the weight of such concrete will be less than the weight of normal concrete it is included here. Wherever brick bat aggregates are used, the aggregates are made from slightly overburnt bricks, which will be hard and absorb less water. Brick bat aggregates are also sometimes used in conjunction with high alumina cement for the manufacture of heat resistant concrete.

Cinder, Clinker and Breeze

The term clinker, breeze and cinder are used to cover the material partly fused or sintered particles arising from the combustion of coal. These days the use of these materials as light-weight aggregate in the form of coarse or fine aggregate is getting abated owing to the wider use of pulverised coal rather than lumps of coal. Cinder aggregates undergo high drying shrinkage and moisture movement. Cinder aggregates have been also used for making building blocks for partition walls, for making screeding over flat roofs and for plastering purposes.

The unsoundness of clinker or cinder aggregates is often due to the presence of excessive unburnt coal particles. Sometimes unburnt particles may be present as much as 15 to 25%. This high proportion of coal expand on wetting and contract on drying which is responsible for the unsoundness of concrete made with such aggregate.

Foamed Slag

Foamed slag is one of the most important types of light-weight aggregates. It is made by rapidly quenching blast furnace slag, a by-product, produced in the manufacture of pig iron. If the cooling of the slag is done with a large excess of water, granulated slag is formed which is used in the manufacture of blast furnace slag cement. If the cooling done with a limited amount of water, in such a way as to trip steam in mass, it produces a porous, honeycombed material which resembles pumice. Sometimes, the molten slag is rapidly agitated with a limited amount of water and the steam and gas produced are made to get entrapped in the mass. Such a product is also called foamed slag or expanded slag.

The texture and strength of foamed slag depends upon the chemical composition and the method of production. But in general, the structure is similar to that of natural pumice. The foamed slag must be

(a) Free from contamination of heavy impurities

(b) Free from volatile impurities such as coke or coal.

(c) Free from excess of sulphate.

In India foamed slag is manufactured in many steel mills. In Mysore. Iron and Steel Works at Bhadravati large quantity of foamed slag is being manufactured. Industries have come up near the steel mills to manufacture ready-made building blocks and partition wall pnels. Such prefabricated items being lighter in weight, could be transported at comparatively low cost. Foamed slag is also used for the manufacture of precast RCC lintels and other small structural numbers. By controlling the density, foamed slag can be used for load bearing walls and also for the production of structural light-weight concrete.

Bloated Clay

When certain glass and shales are heated to the point of incipient fusion, they expand or what is termed as bloat to many times their original volume on account of the formation of gas within the mass at the fusion temperatures. The cellular structure so formed is retained on cooling and the product is used as light-weight aggregate. "Haydite", "Rocklite", "Gravelite", "Leca", "Aglite", "Kermazite" are some of the patent names given to bloated clay or shale manufactured in various western countries adopting different techniques.

Central Building Research Institute of India (CBRI) has also developed a process technique for the manufacture of bloated clay for structural use. The experimental building constructed at CBRI using bloated clay as structural light-weight aggregate has been standing well.

Sintered Fly Ash (Pulverised Fuel Ash)

Fly ash is finely divided residue, comprising of spherical glassy particles, resulting from the combustion of powdered coal. By heat treatment these small particles can be made to combine, thus forming porous pellets or nodules which have considerable strength.

The fly ash is mixed with limited amount of water and is first made into pellets and then sintered at a temperature of 1000° to 1200°C. The sintering process is nearly similar to that used in the manufacture of Portland cement. The fly ash may contain some unburnt coal which may vary from 2 to 15 per cent or more depending upon the efficiency of burning. The aim is always to make use of the fuel present in the fly ash and to avoid the use of extra fuel which incidentally improves the quality of sintered fly ash. Sintered fly ash is one of the most important types of structural light-weight aggregate used in modern times. In U.K., it is sold by the trade name "Lytag". It has high strength/density ratio and relatively low drying shrinkage.

Exfoliated Vermiculite

Raw vermiculite is a micaceous mineral and has a laminar structure. When heated with certain percentage of water it expands by delamination in the same way as that of slate or shale. This type of expansion is known as exfoliation. Due to exfoliation, the vermiculite expands many times its original volume. The fully exfoliated vermiculite which may have expanded even as much as 30 times will have a density of only 60 to 130 kg/m^3. The concrete made with vermiculite as aggregate, therefore, will have very low density and hence very low strength. This concrete is used for insulating purposes. It is also used for *in situ* roof and floor screeds or for the manufacture of blocks, slabs and tiles which are used for sound insulation and heat insulation. Vermiculite concrete products can be cut, sawn, nailed or screwed. The prefabricated vermiculite concrete panels can be used for floor sound deadner or wall and partition sound deadner. The hollow blocks made by vermiculite concrete can be used for enacasing pipes carrying steam or hot water. This can also be used as a heat resistant material being non-inflammable. Vermiculite plaster made in conjunction with gypsum is completely incombustible in addition to possessing sound absorption quanlity and thermal insulation characteristics.

In India, Mineral Refining Corporation at Mysore produces vermiculite in many grades for use in concrete industry.

Expanded Perlite

Perlite is one of the natural volcanic glasses like pumice. This when crushed and heated to the point of incipient fusion at a temperature of about 900 to 1100°C it expands to form a light cellular material with density of about 30 to 240 kg/m^3. This light material is crushed carefully to various sizes and used in concrete. Due to its very low density this is also used for insulation grade concrete. Table 12.2 gives some of the properties of insulating grade light weight concrete.

Light-weight Aggregate Concrete

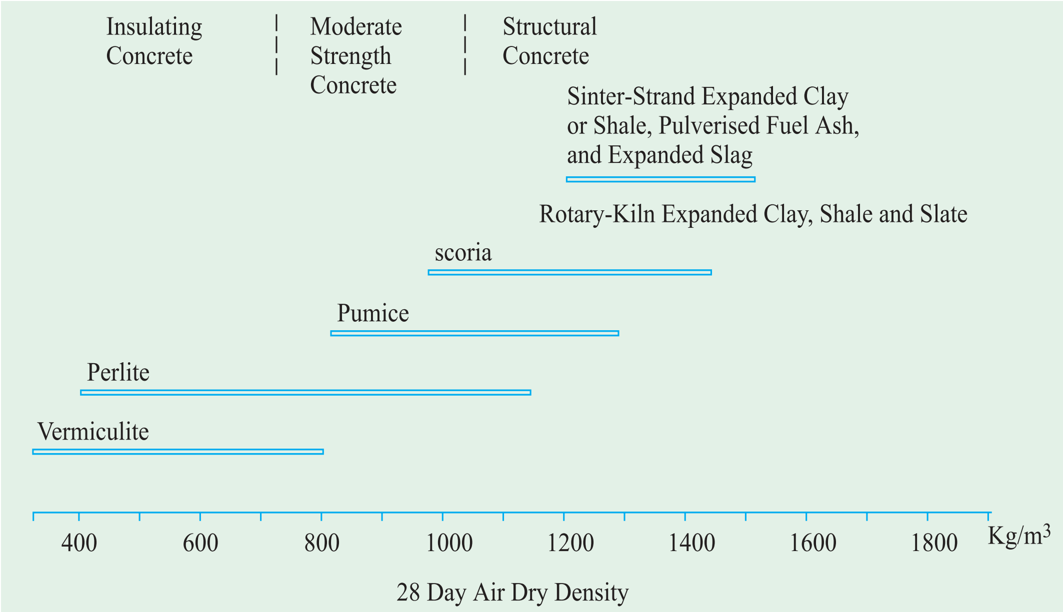
Very often light-weight concrete is made by the use of light weight aggregates. We have seen that different light-weight aggregates have different densities. Naturally when this aggregate is used, concrete of different densities are obtained. By using expanded perlite or vermiculite, a concrete of density as low as 300 Kg/m^3 can be produced, and by the use of expanded slag, sintered fly ash, bloated clay etc., a concrete of density 1900 kg/m^3 can be obtained. The strength of the light-weight concrete may also vary from about 0.3 N/mm^2 to 40 N/mm^2. A cement content of 200 kg/m^3 to about 500 kg/m^3 may be used. Fig. 12.1 shows typical ranges of densities of concrete made with different light-weight aggregates, and Table 12.3 gives the typical properties of light-weight aggregate concrete.

Strength of light-weight concrete depends on the density of concrete. Less porous aggregate which is heavier in weight produces stronger concrete particularly with higher cement content. The grading of aggregate, the water/cement ratio, the degree of compaction also effect the strength of concrete.

Table 12.2. Typical Properties of Common Light-weight Concretes

Sl. No.	Type of Concretes	Bulk density of aggregates kg/m^3	Dry density of kg/m^3	Compressive strength of 28 days	Drying Shrinkage 10^{-6}	Thermal conductivity Jm/m^2 5°C
1.	Sintered fly ash					
	Fine	1050	1500	25	300	–
	Coarse	800	1540	30	350	–
2.	Sintered fly ash with natural sand					
	Coarse	800	1700	25	300	–
3.	Pumice	500–800	1200	15	1200	0.14
4.	Perlite	40–200	400–500	1.2–3.0	2000	0.05
5.	Vermiculite	60–200	300–700	0.3–3.0	3000	0.10
6.	Cellular (Fly ash)	950	750	3.0	700	0.19
	Sand	1600	900	6.0	–	0.22
7.	Autoelaved aerated	–	800	4.0	800	0.25

Most of the light-weight aggregate with the exception of bloated clay and sintered fly ash are angular in shape and rough in texture. They produce a harsh mix. Particular care should be taken to improve workability with the addition of excess of fine material, pozzolanic material or some other plasticizing admixtures. The strength of aggregate will also be influenced by the type of fine aggregates. For increasing the strength, for improving the workability and for reducing the water requirement, sometimes natural sand is used instead



of crushed sand made out of light-weight aggregate. Use of air-entrainment will greatly improve the workability, and the tendency for bleeding in the light-weight concrete. But the use of air-entrainment will result in further reduction in strength also.

Most of the light-weight aggregates have a high and rapid absorption quality. This is one of the important difficulties in applying the normal mix design procedure to the light-weight concrete. But it is possible to water-proof the light-weight aggregate by coating it with Bitumen or such other materials by using a special process. The coating of aggregate by Bitumen may reduce the bond strength between aggregate and paste. Coating of aggregate by silicon compounds does not impair the bond characteristics but at the same time makes it non-absorbant.


Light-weight Structural Concrete convention hall built on the lake at Branson, Missouri, USA.

Light-weight concrete being comparatively porous, when used for reinforced concrete, reinforcement may become prone to corrosion. Either the reinforcement must be coated with anticorrosive compound or the concrete must be plastered at the surface by normal mortar to inhibit the penetration of air and moisture inside. Some of the aggregates like clinker or cinder whhich has more sulphur in themselves cause corrosion of reinforcement. In such cases coating of steel by corrosion inhibiting admixtures is of vital importance.

Table 12.3. Typical Properties of Light-weight Concrete

Type of Concrete		Bulk density of Aggregate kg/m³	Mix Proportion by volume Cement: Aggregate	Dry density of concrete kg/m³	Compressive strengths MPa	Drying shrinkage 10^{-6}	Thermal Conductivity Jm/m²s°C
Foamed Slag	Fine	900	1 : 8	1700	7	400	0.45
			1 : 6	1850	21	500	0.69
Rotary kiln expanded clay	Fine	100	1 : 11	650–1000	3–4	–	0.17
			1 : 6	1100	14	550	0.31
Rotary kiln expanded slate	Fine	950	1 : 6	1700	28	400	0.61
			1 : 4.5	1750	35	450	0.69
Sintered	Fine	1050	1 : 6	1450	28	400	0.47
Pulverised			1 : 4.5	1500	36	500	0.49
Fuel ash			1 : 3.5	1550	41	600	0.50
Pumice		500–800	1 : 6	1200	14	1200	–
			1 : 4	1250	19	1000	0.14
			1 : 2	1450	29	–	–
Exfoliated Vermiculite		65–130	1 : 6	300–500	2	3000	0.10
Perlite		95–130	1 : 6	–	–	2000	0.05

Structural Light Weight Concrete

The structural light weight concrete is going to be one of the important materials of construction. A concrete which is light in weight and sufficiently strong to be used in conjunction with steel reinforcement will be a material which is more economical than the conventional concrete. Therefore, a concrete which combines strength and lightness will have the unquestionable economic advantage.

Structural light-weight aggregate concrete is a concrete having 28 day compressive strength more than 17 MPa and 28 day air dried unit weight not exceeding 1850 kg/m^3. The concrete may consist entirely of light-weight aggregates (all light-weight concrete) or combination of light weight and normal-weight aggregates. For practical reasons, it is common practice to use normal sand as fine aggregate and light-weight coarse aggregate of maximum size 19 mm. Such light-weight concrete is termed as "sanded light-weight concrete", in contrast to "all light-weight concrete".

Workability

Considerable attention is required to be given to the workability aspect for structural light weight concrete. In case of high slump and overvibration, the mortar goes down and aggregate tends to float. This phenomenon is reverse of that of normal weight concrete. In case of floor, or deck slab, the finishing operation will be difficult. To avoid this difficulty it is usual to limit the maximum slump to 100 mm. It should be remembered that there is going to be higher slump loss on account of continued absorption of water by aggregate.

Light-weight concrete exhibits higher moisture movement than the normal weight concrete. Concrete while wetting swells more and the concrete while drying shrinks more. The higher magnitude of drying shrinkage coupled with lower tensile strength makes the light weight aggregate concrete to undergo shrinkage cracks. But the higher extensibility and lower modulus of elasticity help to reduce the tensile cracks.

Since light-weight concrete contains large per cent of air, it is naturally a better material with respect to sound absorption, sound proofing and for thermal insulations.

The coefficient of thermal expansion of concrete made with light-weight aggregate is generally much lower than ordinary concrete. The typical values are shown in Table 12.4.

Table 12.4. Coefficient of Thermal Expansion Made with Light Weight Aggregate

Concrete with light weight aggregate	Linear coefficient of thermal expansion (determined over a range of $-22°C$ to $52°C$) 10^{-6} per°C
Pumice	9.4 to 10.8
Perlite	7.6 to 11.0
Vermiculite	8.3 to 14.2
Cinders	about 3.8
Expanded shale	6.5 to 8.1
Expanded slag	7.0 to 11.2

Light-weight aggregate concrete exhibits a higher fire resistance property than the normal concrete. Light weight concrete particularly made with slag or pumice or brick bats as aggregate shows higher fire resistance property.

Design of Light -weight Aggregate Concrete Mix

Mix design methods applying to normal weight concrete are generally difficult to use with light weight aggregate concrete. The lack of accurate value of absorption, specific gravity, and the free moisture content in the aggregate make it difficult to apply the water/cement ratio accurately for mix proportioning.

Light-weight concrete mix design is usually established by trial mixes. The proportions of fine to coarse aggregate and the cement and water requirement are estimated based on the previous experiences with particular aggregate. Various degree of water absorption by different light-weight aggregates is one of the serious difficulties in the design of mix proportions. A reliable information of saturated, surface-dry bulk specific gravity becomes difficult.

Sometimes the aggregate is saturated before mixing so that it does not take up the water used for mixing. The quality of concrete does not get altered on account of absorption by aggregate. It has been seen that the strength of the resulting concrete is about 5 to 10 per cent lower than when dry aggregate is used for the same content and workability. This is due to the fact that in the latter case some of the mixing water is absorbed prior to setting. This water having contributed to the workability at the time of placing gets absorbed later, thus reducing the bad effect of excess of water. Moreover, the density of concrete made with saturated aggregate is higher and the durability of such concrete, especially its resistance to frost is lower. On the other hand, when aggregate with high absorption is used, it is difficult to obtain a sufficiently workable and yet cohesive mix, and generally aggregates with absorption of over 10 per cent are presoaked.

Mixing Procedure

Mixing procedure for light-weight concretes may vary with different types of aggregates. The general practice for structural light-weight concrete is to mix the aggregate and about 2/3 of the mixing water for a period upto one minute prior to the addition of cement and the balance mixing water. Mixing is done continuously as required for homogeneity. Usually 2 or more minutes are required to get uniform mixing. In case of some insulating concrete, the aggregate is added at the end of mixing to minimise degradation.

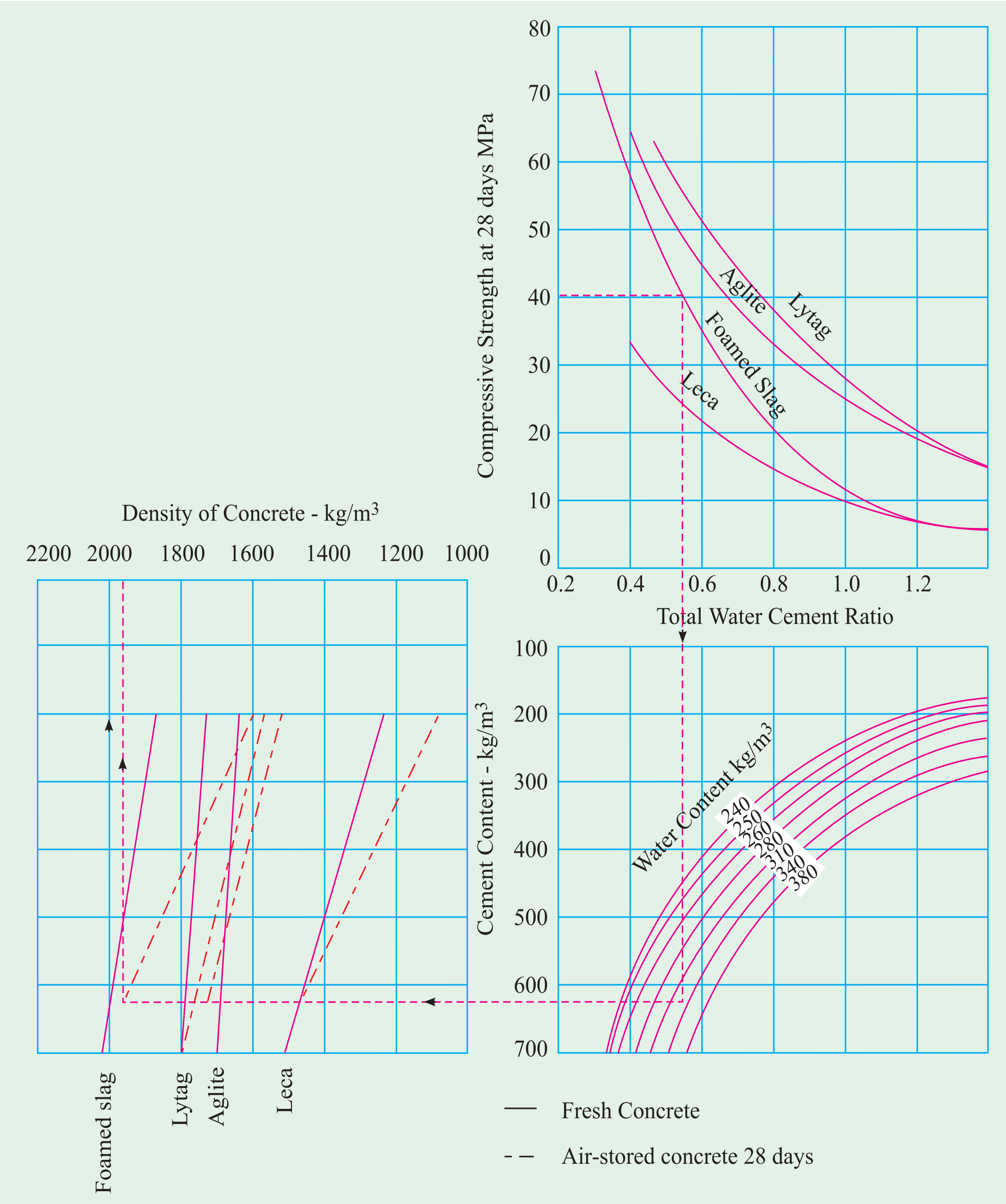
Mix design data have been prepared for several, proprietary light-weight aggregates available in the United Kingdom. The design charts prepared by Teychenne is reproduced in Fig 12.2. The parameters obtained from these charts cannot be taken as final answers. However, they may give information for first trial.[12.3]

Aerated Concrete

Aerated concrete is made by introducing air or gas into a slurry composed of Portland cement or lime and finely crushed siliceous filler so that when the mix sets and hardens, a uniformly cellular structure is formed. Though it is called aerated concrete it is really not a concrete in the correct sense of the word. As described above, it is a mixture of water, cement and finely crushed sand. Aerated concrete is also referred to as gas concrete, foam concrete, cellular concrete. In India we have at present a few factories manufacturing aerated concrete. A common product of aerated concrete in India is Siporex.

There are several ways in which aerated concrete can be manufactured.

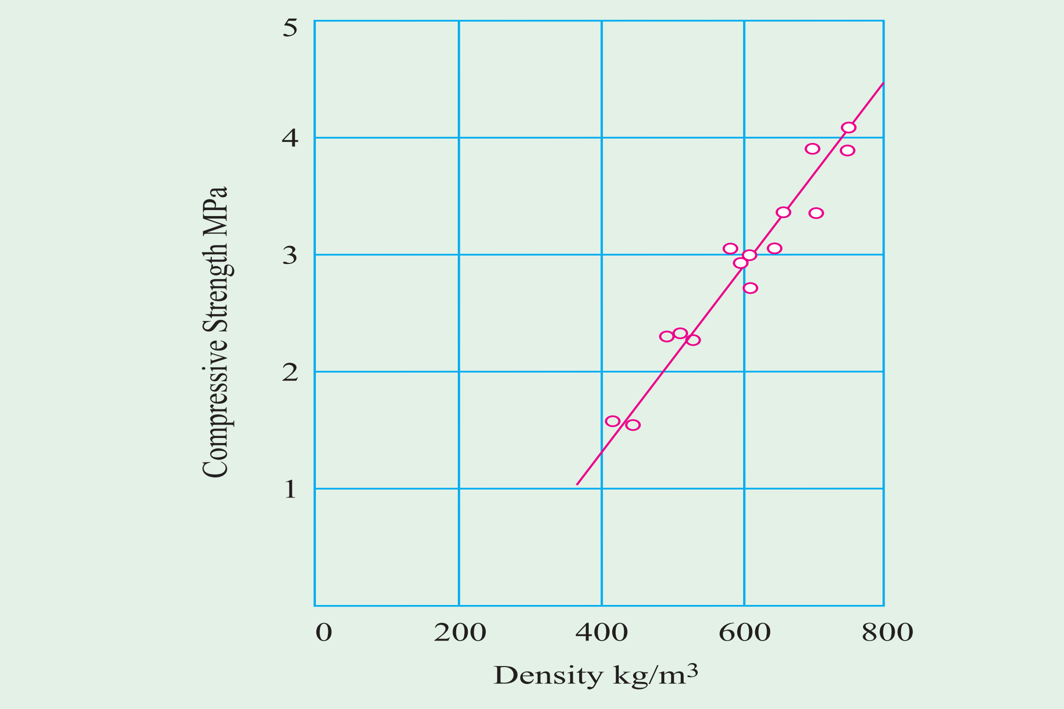
(a) By the formation of gas by chemical reaction within the mass during liquid or plastic state.



(b) *By mixing preformed stable foam with the slurry.*

(c) *By using finely powdered metal (usually aluminium powder) with the slurry and made to react with the calcium hydroxide liberated during the hydration process, to give out large quantity of hydrogen gas. This hydrogen gas when contained in the slurry mix, gives the cellular structure.*

Powdered zinc may also be added in place of aluminum powder. Hydrogen peroxide and bleaching powder have also been used instead of metal powder. But this practice is not widely followed at present.



In the second method preformed, stable foam is mixed with cement and crushed sand slurry thus causing the cellular structure when this gets set and hardened. As a minor modification some foam-giving agents are also mixed and thoroughly churned or beaten (in the same manner as that of preparing foam with the white of egg) to obtain foam effect in the concrete. In a similar way, air entrained agent in large quantity can also be used and mixed thoroughly to introduce cellular aerated structure in the concrete. However, this method cannot be employed for decreasing the density of the concrete beyond a certain point and as such, the use of air entrainment is not often practised for making aerated concrete.

Gasification method is of the most widely adopted methods using aluminium powder or such other similar material. This method is adopted in the large scale manufacture of aerated concrete in the factory wherein the whole process is mechanised and the product is subjected to high pressure steam curing i.e., in other words, the products are autoclaved. Such products will suffer neither retrogression of strength nor dimensional instability.

The practice of using preformed foam with slurry is limited to small scale production and in situ work where small change in the dimensional stability can be tolerated. But the advantage is that any density desired at site can be made in this method.

Properties

Use of foam concrete has gained popularity not only because of the low density but also because of other properties mainly the thermal insulation property. Aerated concrete is made in the density range from 300 kg/m³ to about 800 kg/m³. Lower density grades are used for insulation purposes, while medium density grades are used for the manufacture of building blocks or load bearing walls and comparatively higher density grades are used in the manufacture of prefabricated structural members in conjunction with steel reinforcement.

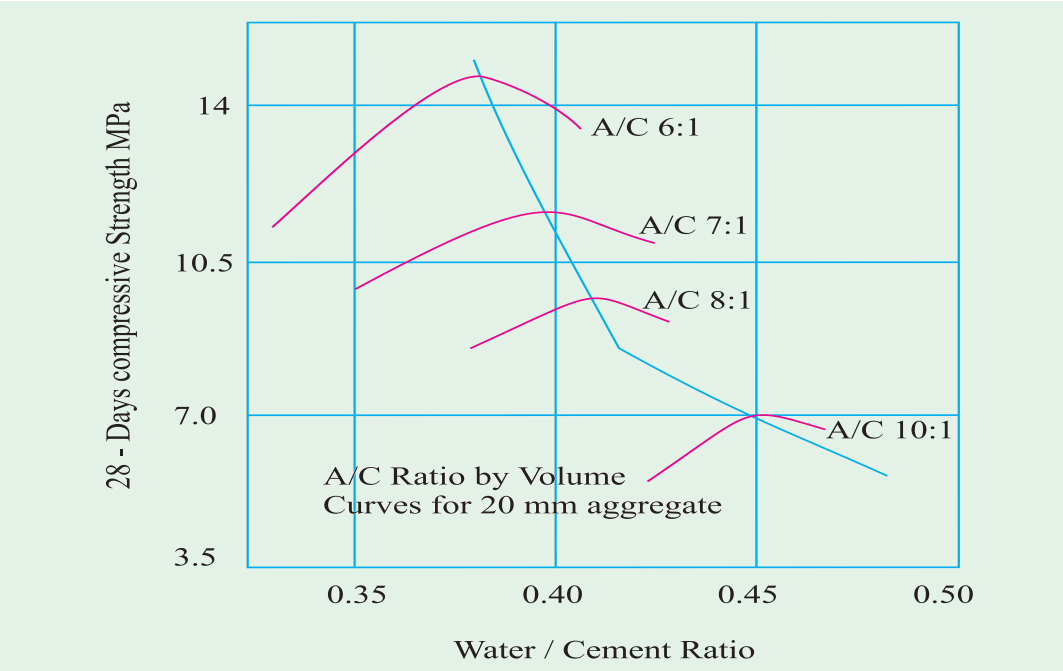


Figure 12.3 shows relation between strength and density of high pressure steam cured aerated concrete.

No-fines Concrete

The third method of producing light concrete is to omit the fines from conventional concrete.

No-fines concrete as the term implies, is a kind of concrete from which the fine aggregate fraction has been omitted. This concrete is made up of only coarse aggregate, cement and water. Very often only single sized coarse aggregate, of size passing through 20 mm retained on 10 mm is used. No-fines concrete is becoming popular because of some of the advantages it possesses over the conventional concrete.

The single sized aggregates make a good no-fines concrete, which in addition to having large voids and hence light in weight, also offers architecturally attractive look.

Mix-proportion

No-fines concrete is generally made with the aggregate/cement ratio from 6 : 1 to 10 : 1. Aggregates used are normally of size passing through 20 mm and retained on 10 mm. Unlike the conventional concrete, in which strength is primarily controlled by the water/cement ratio, the strength of no-fines concrete, is dependent on the water/cement ratio, aggregate cement ratio and unit weight of concrete. Figure 2.4 shows the relationship of compressive strength, water/cement ratio and aggregate/cement ratio for no-fines concrete.

The water/cement ratio for satisfactory consistency will vary between a narrow range of 0.38 and 0.52. Water/cement ratio must be chosen with care. If too low a water/cement ratio is adopted, the paste will be so dry that aggregates do not get properly smeared with paste which results in insufficient adhesion between the particles. On the other hand, if the water/cement ratio is too high, the paste flows to the bottom of the concrete, particularly when *vibrated and fills up the voids between the aggregates at the bottom and makes that portion dense. This condition also reduces the adhesion between aggregate and aggregate owing to the paste becoming very thin.*

No standard method is available, like slump test or compacting factor test for measuring/ the consistency of no-fines concrete. Perhaps a good, experienced visual examination and trial and error method may be the best guide for deciding optimum water/cement ratio.

No-fines concrete, when conventional aggregates are used, may show a density of about 1600 to 1900 kg/m^3, but when no-fines concrete is made by using light weight aggregate, the density may come to about 360 kg/m^3.

No-fines concrete does not pose any serious problem for compaction. Use of mechanical compaction or vibratory methods are not required. Simple rodding is sufficient for full compaction.

No-fines concrete does not give much side thrust to the formwork as the particles are having point to point contact and concrete does not flow. Therefore, the side of the formworks can be removed in a time interval shorter than for conventional concrete. However, formwork may be required to be kept for a longer time, when used as a structural member, as the strength of concrete is comparatively less. The compressive strength of no-fines concrete varies between 1.4 MPa to about 14 MPa. Table 12.5 shows the compressive strength of no-fines concrete.

The bond strength of no-fines concrete is very low and, therefore, reinforcement is not used in conjunction with no-fines concrete. However, if reinforcement is required to be used in no-fines concrete, it is advisable to smear the reinforcement with cement paste to improve the bond and also to protect it from rusting.

Drying Shrinkage

The drying shrinkage of no-fines concrete is considerably lower than that of conventional concrete. No-fines concrete made with river gravel, may show a drying shrinkage of the order of 200 x 10^{-6} which is only about 50% of the conventional concrete. Since there is only a very thin layer of paste existing between aggregates and aggregates, and since the aggregate are having point to point contact, the value of drying shrinkage becomes low. However, the rate of drying shrinkage is generally much higher than conventional concrete. For no-fines concrete 50 to 80% of the total drying shrinkage takes place within about 10 days. The corresponding value for conventional concrete in 10 days is 20 to 30%. Further all the drying shrinkage will get completed in just over a month.

Table 12.5. Compressive Strength of No-fines Concrete Made with Different Grading of Crushed Limestone

Water cement ratio by weight	*Aggregate grading*	*Aggregate cement ratio by weight*	*Cement content kg/m³*	*Unit weight of fresh concrete kg/m³*	*Compressive strength of 150 x 300 mm Cylinders*	
					7 days MPa	*28 days MPa*
0.36	A	8 : 1	359	1910	7.1	8.4
			364	1871	4.8	6.7
			369	1858	5.5	7.5
			368	1813	6.0	5.6
			368	1884	4.7	7.1
0.36	B	9 : 1	360	1820	4.0	5.7
			364	1801	4.4	5.1
0.36	C	7 : 1	361	1877	7.4	8.8
			365	1851	5.4	7.1
			360	1826	5.6	6.9
			368	1826	6.5	6.5

The Thermal Conductivity

The value of coefficient of thermal conductivity of no-fines concrete is much less than conventional concrete. Typical values are shown in Table 12.6.

Table 12.6. Typical values of Thermal Conductivity of No-fines and Conventional Concrete

Type of concrete	*Type of aggregate*	*Thermal conductivity* $\frac{\text{k.cal} \times \text{m}}{\text{m}^2 \times \text{hr} \times \text{degC}}$	*Density of concrete* *kg/m³*
No-fines	Conventional	0.74	1760
	Light weight	0.42	1280
	Igneous	1.28	2540
Conventional	Dolomite	3.28	2560
	Light weight	0.12 to 0.52	480 to 1760

Application of No-fines Concrete

No-fines concrete can be used for a variety of purposes. It is used in large scale for load bearing cast in-situ external walls for single storey and multistoreyed buildings. This type of *concrete has been used for temporary structures because of low initial cost and also for the ease with which it can be broken and reused as aggregate. Architects consider this as an attractive construction material. Owing to its slightly higher thermal insulating property, it cab be used for external walls for heat insulation. Because of rough texture, it gives a good base for plastering. Even if the outside surface of the no-fines concrete wall is subjected to rain beating, the inside of the wall will be free from dampness because of low capillary action on account of large voids. Where sand is not available, no-fines concrete should become a popular construction material.*

High Density Concrete

Density of normal concrete is in the order of about 2400 kg. per cubic metre. The density of light-weight concrete will be less than about density 1900 kg per cubic metre. To call the concrete, as high density concrete, it must have unit weight ranging from about 3360 kg per cubic metre to 3840 kg per cubic metre, which is about 50% higher than the unit weight of conventional concrete. They can, however be produced with the densities upto about 5280 kg per cubic metre using iron as both fine and coarse aggregate. The high density concrete is used in the construction of radiation shields.

The advent of the nuclear energy industry presents a considerable demand on the concrete technologists. Large scale production of penetrating radiaion and radioactive materials, as a result of the use of nuclear reactors, particle accelerator, industrial radiography, and, X-ray, gamma-ray therapy, require the need of shielding material for the protection of operating personnel against the biological hazards of such radiation. Concrete, both normal and high density are effective and economic construction materials for permanent shielding purposes.

Types of Radiation and Hazards

There are two general classes of radiation. They are considered in the design of biological shields:

(*a*) *Electro-magnetic waves,*

(*b*) *Nuclear particles.*

Of the electromagnetic waves, the high energy, high frequency waves known as X- and gamma rays are only types which require shielding for the protection of personnel. They are similar to light rays but of higher energy greater penetrating power. Gamma-rays are identical with X-rays, except for the source. Both X-rays and Gamma-rays have high power of penetration but can be adequately absorbed by an appropriate thickness of concrete shield.

Nuclear particles consist of nuclei of atoms or fragments thereof. They include neutrons, protons, alfa and beta particles. Of these all but the neutrons possess an electric charge. Neutrons, on the other hand, are uncharged and continue unaffected by electrical fields, until they interact by collision with a nucleus. They have no definite range, and some will penetrate any shield.

Protons, and alfa and beta particles carry electrical charges which interact with the electrical field, surrounding the atom of the shielding material and lose their energy considerably. They generally do not constitute a separate shielding problem, although, accelerated protons at high energy levels may require heavy shielding comparable to that required for neutrons.

The question of shielding resolves into protection against X- and Gamma rays and neutrons. The X- and Gamma-rays are similar except in energy and origin. The biological *hazards of radiation arise from the fact that the radiation interacts with human tissues, losing some of their energy in the process. This energy loss is sufficient to ionize atoms in the cells, upsetting the delicate chemical balance and causing the death of the cells. If enough cells are affected the organism dies. Therefore, the radiations must be attenuated sufficiently so that what is left cannot render permanent damage to the persons exposed to it.*

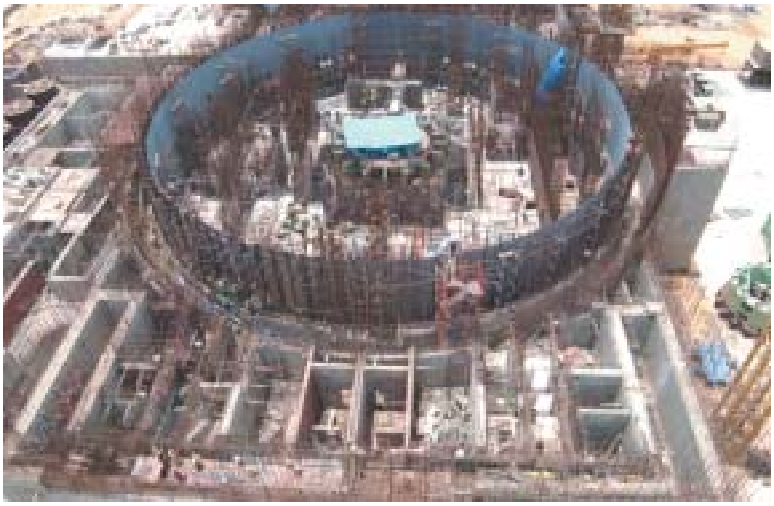
Apart from the biological hazards, along with the nuclear reaction very high temperature is also generated and shielding is necessary to protect the electronic and other sensitive equipment in the vicinity.

Shielding ability of Concrete

Concrete is an excellent shielding material that possesses the needed characteristics for both neutron and gamma-ray attenuation, has satisfactory mechanical properties and has a relatively low, initial as well as maintenance cost. Also the ease of construction makes concrete a specially suitable material for radiation shielding. Its only disadvantage is space and weight.

There are many aggregates whose specific gravity is more than 3.5 for making a heavy weight concrete. Out of these, commercially employed aggregates are, barite, magnetite, ilmenite, limonite hematite etc. are used. Also available, are steel and iron aggregates in the form of shots, punching scrap for use as a heavy weight aggregate. In determining, which aggregate to use, consideration should be given to availability of aggregates locally and their physical properties.

Rajasthan Atomic Nuclear Power Project



Kudankulam Nuclear Power Project

Heavy-weight concrete was used for radiation shielding in the above Nuclear Projects.

These days heavy-weight concrete is being used in many major hospitals in India where cancer treatment is carried out.

In general, heavy-weight aggregates should be clean, strong, inert and relatively free from deleterious material which might impair the strength of concrete. Since the capacity of various heavy aggregates to absorb gamma-rays is almost directly proportional to their density, also the heavier elements are more effective in absorbing fast neutrons by inelastic collisions than are the lighter ones, as heavy aggregate, as possible should be used for this purpose.

However, density is not the only factor to be considered in the selection of an aggregate for neutron concrete shield. The desired increase in hydrogen content, required to slow down fast neutrons, can be accomplished by the use of hydrous ores. These materials contain a high percentage of water of hydration. On heating the concrete, some of this fixed water in the aggregate may be lost. Lemonite and goethite are reliable sources of hydrogen as long as shield temperature does not exceed 200°C, whereas serpentine is good upto about. 400°C.

Concrete for Radiation Shielding

It has already been pointed out that the effectiveness of radiation shielding quality of concrete can be increased by increasing the density. Another important requirement of shielding concrete is its structural strength even at high temperature. To produce high density and high strength concrete, it is necessary to control the water cement ratio very strictly. Use of appropriate admixture and vibrators for good compaction are required to be employed. Good quality control be followed.

High density concrete used for shielding differs from normal weight concrete, in that it should contain sufficient material of light atomic weight, which produces hydrogen. Serpentine aggregates are used sometimes, because of the ability to retain water of crystallisation at elevated temperature which assures a source of hydrogen, not necessarily available in all heavy weight aggregates.

High modulus of elasticity, low thermal expansion and low elastic and creep deformations are ideal properties for both conventional and high density concrete. High density concrete, may contain high cement, in which case, it may exhibit increased creep and shrinkage. Because of the high density of aggregates, there will be a tendency for segregation. To avoid this, pre-placed aggregate method of concreting is adopted. Coarse aggregate may be consisting of only high density mineral aggregate or a mixture of mineral aggregate and steel particles or only steel particles. Experiments have indicated that if only smooth cubical pieces of steel or iron are used as coarse aggregate, the compressive strength will not exceed about 21 MPa. cm. regardless of the grout mixture or water cement ratio. If sheared reinforcing bars are used as aggregate, with good grout, normal strength will be produced.

The grout used in high density preplaced aggregate concrete should be somewhat richer than that used in normal density preplaced concrete.

Concreting practice with respect to mixing, transporting, placing as adopted for normal concrete may also be adopted to high density concrete but extra care must be taken with respect to segregation of heavier aggregates from rest of the ingredients. In this regard, higher cement content, better workability may help reducing segregation. Wear and tear of mixer drum may be high. The formwork is required to be made stronger to withstand higher load. Cognisance must also be taken to the strength development of concrete and the dead weight of concrete while removing the formwork.

The Table 12.7 shows the physical properties of high density concrete.

Table 12.7. Physical Properties of High Density Concrete[12.5]

Aggregate	*Limonite*	*Limonite + magnetite*	*Barite*	*Barite*	*Magnetite*	*Iron limonite*
Placement	*Conventional*	*Pre-packed*	*Conventional*	*Pre-packed*	*Conventional*	*Pre-packed*
Density (kg. per m^3)	*2960*	*3360*	*3620*	*3680*	*3580*	*4370*
Compressive strength MPa	*42.0*	*33.0*	*44.0*	*24.0*	*41.0*	*23.0*
Modulus of Elasticity GPa	*32.0*	*36.0*	*31.0*	*26.0*	*31.0*	*39.0*
Shrinkage (Per cent)	*0.021*	*0.023*	*0.029*	*0.029*	*0.018*	*0.013*

Table 12.8. Typical Value of Compressive Strength of (50 mm) Moist Cured and Sulphur-Infiltrated Cubes.

Duration of moist curing-hr.	Duration of drying hr.	Age at test hr.	Moist cured Cubes	Compressive strength sulphur-infiltrated cubes			
				Procedure A		Procedure B	
			MPa	Sulphur loading per cent	Mpa	Sulphur loading per cent	Mpa
24	24	54	13.6	9.1	68.0	12.6	108.5

Mix proportions used were: W/C ratio = 0.70
Aggregate/cement ratio = 8.5 : 1
Ratio between C.A. and F.A. = 1 : 1.

Table 12.9. Typical Value of Compressive and Splitting-tensile Strengths of (75 x 150 mm) Moist Cured and Sulphur-infiltrated Cylinders.

Duration of moist curing-hr.	Duration of drying hr.	Age at test hr.	Moist cured cylinders		Sulphur-infiltrated cylinders using procedure B only		
			Compressive strength MPa	Splitting tensile MPa	Sulphur loading per cent	Compressive strength MPa	Splitting tensile strength MPa
24	24	54	9.0	1.9	12.4	72.0	10.5

Mix proportions used were: W/C ratio = 0.70
Aggregate/cement ratio = 8.5 : 1
Coarse Aggregate to fine aggregate ratio = 1 : 1.

Sulphur-Infiltrated Concrete

New types of composites have been produced by the recently developed techniques of impregnating porous materials like concrete with sulphur. Sulphur impregnation has shown great improvement in strength. Physical properties have been found to improve by several hundred per cent and large improvements in water impermeability and resistance to corrosion have also been achieved.

In the past, some attempts have been made to use sulphur as a binding material instead of cement. Sulphur is heated to bring it into molten condition to which coarse and fine aggregates are poured and mixed together. On cooling, this mixture gave fairly good strength, exhibited acid resistance and also other chemical resistance, but it proved to be costlier than ordinary cement concrete.

Recently, use of sulphur was made to impregnate lean porous concrete to improve its strength and other useful properties considerably. In this method, the quantity of sulphur used is also comparatively less and thereby the processes is made economical. It is reported that compressive strength of about 100 MPa could be achieved in about 2 day's time. The following procedures have been reported in making sulphur-infiltrated concrete.[12.6]

A coarse aggregate of size 10 mm and below, natural, well graded, fine aggregate and commercial sulphur of purity 99.9 per cent are used. A large number of trial mixes are made to determine the best mix proportions. A water/cement ratio of 0.7 or over has been adopted in all the trials. A number of 5 cm cubes, 7.5 cm x 15 cm cylinders and also 10 cm x 20 cylinders are cast from each batch of concrete. These samples are stored under wet cover for 24 hours, after which they are removed from moulds and the densities determined. Control specimens are moist cured at 24°C for 26 hours.

Two procedures are adopted. In procedure "A" after 24 hours of moist curing, the specimen is dried in heating cabinet for 24 hours at 121°C. Then the dried specimen are placed in a container of molten sulphur at 121°C for 3 hours. Specimens are removed from the container, wiped clean of sulphur and cooled to room temperature for one hour and weighed to determine the weight of sulphur infiltrated concrete.

In procedure "B", the dried concrete specimen is placed in an airtight container and subjected to vacuum pressure of 2 mm mercury for two hours. After removing the vacuum, the specimens are soaked in the molten sulphur at atmospheric pressure for another half an hour. The specimen is taken out, wiped clean and cooled to room temperature in about one hour. The specimen is weighed and the weight of sulphur-impregnated concrete is determined.

The specimens made adopting procedure A and B are tested by compression and splitting tension tests. It is seen that the compression strength of sulphur-infiltrated cubes and cylinders are enormously greater than the strength of plain moist cured specimen. It is found that when water/cement ratio of 0.7 is adopted an achievement of about 7 fold increase in the strength of the test cube when procedure B is adopted and five-fold increase in strength when procedure A is adopted was obtained. When water/cement ratio of 0.8 is adopted, procedure B gave about a tenfold increase in strength.

Similarly, the sulphur-infiltrated concrete showed more than four times increase in splitting tensile strength when procedure B was adopted.

It was also found that the elastic properties of sulphur-infiltrated concrete has been generally improved 100 per cent and also sulphur-infiltrated specimen showed a very high resistance to freezing and thawing. When the moist cured concrete was disintegrated after *about 40 cycles, the sulphur impregnated concrete was found to be in fairly good condition, even after 1230 cycles, when procedure B was adopted and the sample deteriorated after 480 cycles when the sample was made by procedure A. Table 12.8 and Table 12.9, show the typical values of strength test conducted.*

The improvement in strength test attributed to the fact that porous bodies having randomly distributed pores have regions of stress concentration when loaded externally. The impregnation of a porous body by some material would modify these stress concentrations. The extent of modification will depend on how well the impregnant has penetrated the smaller pores.

Application of Sulphur-infiltrated Concrete

The sulphur-infiltration can be employed in the precast industry. This method of achieving high strength can be used in the manufacture of pre-cast roofing elements, fencing posts, sewer pipes, and railway sleepers, Sulphur-infiltrated concrete should find considerable use in industrial situations, where high corrosion resistant concrete is required. This method cannot be conveniently applied to cast-in place concrete.

Preliminary studies have indicated that sulphur-infiltrated precast concrete units is cheaper than commercial concrete. The added cost of sulphur and process should be offset by considerable savings in concrete.

The techniques are simple, effective and inexpensive. The tremendous strength gained in pressure application, wherein immersion accompanied by evacuation may also offset the extra cost. The attainment of strength in about two days time makes this process all the more attractive.

Fibre Reinforced Concrete

Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal microcracks are inherently present in the concrete and its poor tensile strength is due to the propagation of such microcracks, eventually leading to brittle fracture of the concrete.

In the past, attempts have been made to impart improvement in tensile properties of concrete members by way of using conventional reinforced steel bars and also by applying

Dramix glued steel fibres. The above fibres were used for casting tunnel segments in the construction of channel tunnel rail link (UK).

restraining techniques. Although both these methods provide tensile strength to the concrete members, they however, do not increase the inherent tensile strength of concrete itself.

In plain concrete and similar brittle materials, structural cracks (micro-cracks) develop even before loading, particularly due to drying shrinkage or other causes of volume change. The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be of higher magnitude.

When loaded, the micro cracks propagate and open up, and owing to the effect of stress concentration, additional cracks form in places of minor defects. The structural cracks proceed slowly or by tiny jumps because they are retarded by various obstacles, changes of direction in bypassing the more resistant grains in matrix. The development of such microcracks is the main cause of inelastic deformations in concrete.

It has been recognised that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete.

Fibre reinforced concrete can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable fibres. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete fibres.

Fibres Used

Although every type of fibre has been tried out in cement and concrete, not all of them can be effectively and economically used. Each type of fibre has its characteristic properties and limitations. Some of the fibres that could be used are steel fibres, polypropylene, nylons, asbestos, coir, glass and carbon.

Fibre is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fibre is often described by a convenient parameter called "aspect ratio". The aspect ratio of the fibre is the ratio of its length to its diameter. Typical aspect ratio ranges from 30 to 150.

Steel fibre is one of the most commonly used fibre. Generally, round fibres are used. The diameter may vary from 0.25 to 0.75 mm. The steel fibre is likely to get rusted and lose some of its strengths. But investigations have shown that the rusting of the fibres takes place only at the surface. Use of steel fibre makes significant improvements in flexural, impact and fatigue strength of concrete, It has been extensively used in various types of structures, particularly for overlays of roads, airfield pavements and bridge decks. Thin shells and plates have also been constructed using steel fibres.

Polypropylene and nylon fibres are found to be suitable to increase the impact strength. They possess very high tensile strength, but their low modulus of elasticity and higher elongation do not contribute to the flexural strength.

Asbestos is a mineral fibre and has proved to be most successful of all fibres as it can be mixed with Portland cement. Tensile strength of asbestos varies between 560 to 980 N/mm^2. The composite product called asbestos cement has considerably higher flexural strength than the Portland cement paste. For unimportant fibre concrete, organic fibres like coir, jute, canesplits are also used.

Glass fibre is a recent introduction in making fibre concrete. It has very high tensile strength 1020 to 4080 N/mm^2. Glass fibre which is originally used in conjunction with cement was found to be effected by alkaline condition of cement. Therefore, alkali-resistant glass fibre by trade name "CEM-FIL" has been developed and used. The alkali resistant fibre reinforced concrete shows considerable improvement in durability when compared to the conventional E-glass fibre.

Carbon fibres perhaps posses very high tensile strength 2110 to 2815 N/mm² and Young's modulus. It has been reported that cement composite made with carbon fibre as reinforcement will have very high modulus of elasticity and flexural strength. The limited studies have shown good durability. The use of carbon fibres for structures like clading, panels and shells will have promising future.

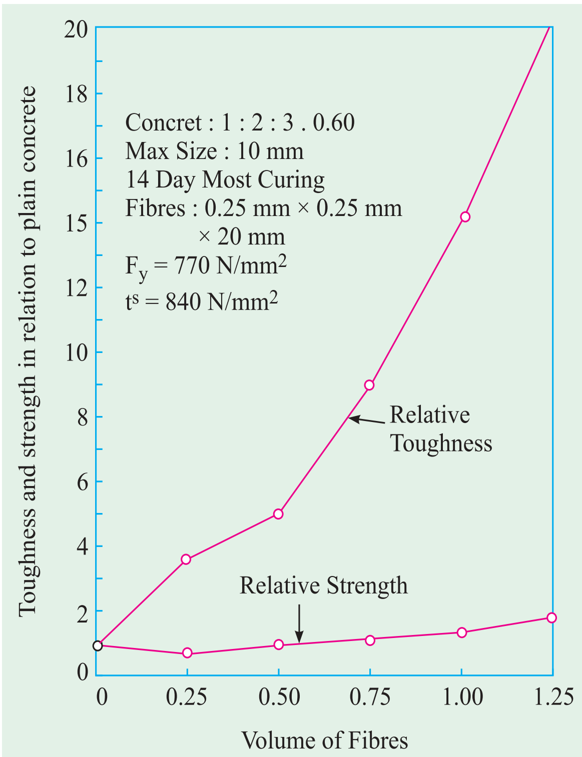
Factors Effecting Properties of Fibre Reinforced Concrete

Fibre reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibres, which is largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate. These factors are briefly discussed below:

Relative Fibre Matrix Stiffness

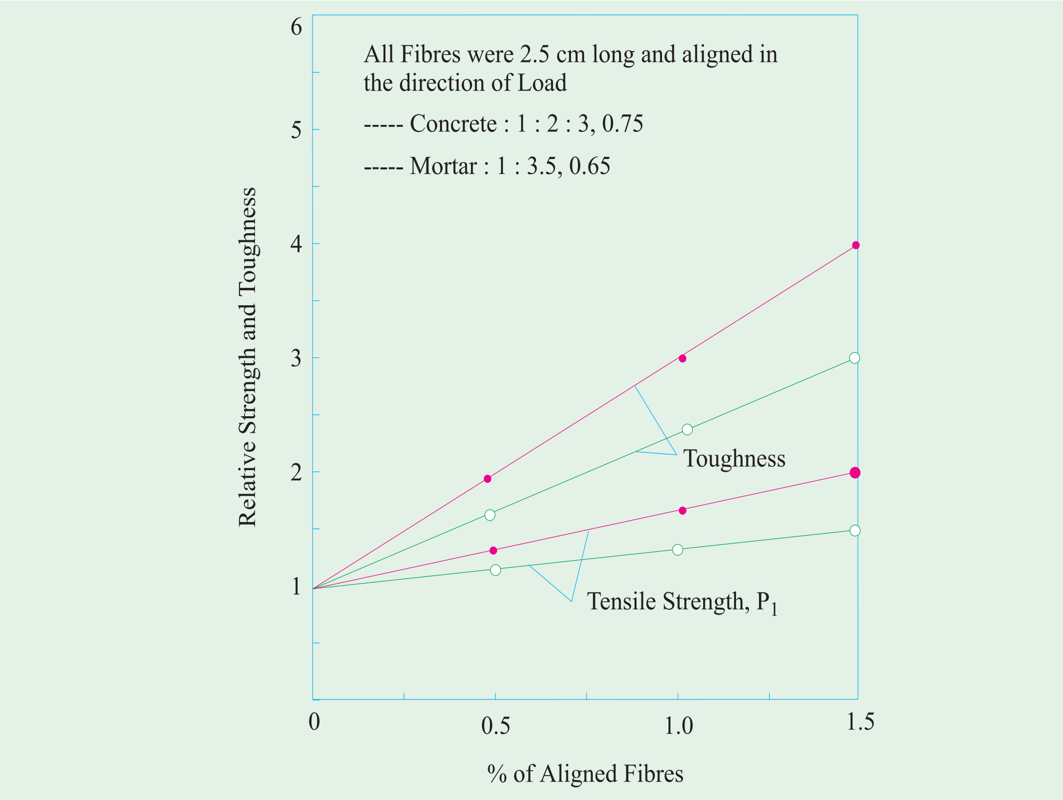
The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer. Low modulus of fibers such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but they help in the absorption of large energy and, therefore, impart greater degree of toughness and resistance to impact. High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite.

Interfacial bond between the matrix and the fibres also determine the effectiveness of stress transfer, from the matrix to the fibre. A good bond is essential for improving tensile strength of the composite. The interfacial bond could be improved by larger area of contact, improving the frictional properties and degree of gripping and by treating the steel fibres with sodium hydroxide or acetone.



Volume of Fibres

The strength of the composite largely depends on the quantity of fibres used in it. Fig. 12.5 and Fig. 12.6 show the effect of volume on the toughness and strength. It can be seen from Fig. 12.6 that the increase in the volume of fibres, increase approximately linearly, the tensile strength and toughness of the composite[12.7]. Use of higher percentage of fibre is likely to cause segregation and harshness of concrete and mortar.



Aspect Ratio of the Fibre

Another important factor which influences the properties and behaviour of the composite is the aspect ratio of the fibre. It has been reported that upto aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced. Table 12.10 shows the effect of aspect ratio on strength and toughness.

Table 12.10. Effect of Aspect Ratio on Strength and Toughness

Type of Concrete	Aspect Ratio	Relative strength	Relative toughness
Plain concrete	0	1.00	1.0
with	25	1.50	2.0
Randomly	50	1.60	8.0
dispersed fibres	75	1.70	10.5
	100	1.50	8.5

Orientation of Fibres

One of the differences between conventional reinforcement and fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while fibres are randomly oriented. To see the effect of randomness, mortar specimens reinforced with 0.5 per cent volume of fibres were tested. In one set specimens, fibres were aligned in the direction *of the load, in another in the direction perpendicular to that of the load, and in the third randomly distributed.*

It was observed that the fibres aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibres.

Workability and Compaction of Concrete

Incorporation of steel fibre decreases the workability considerably. This situation adversely affects the consolidation of fresh mix. Even prolonged external vibration fails to compact the concrete. The fibre volume at which this situation is reached depends on the length and diameter of the fibre.

Another consequence of poor workability is non-uniform distribution of the fibres. Generally, the workability and compaction standard of the mix is improved through increased water/cement ratio or by the use of some kind of water reducing admixtures.

Size of Coarse Aggregate

Several investigators recommended that the maximum size of the coarse aggregate should be restricted to 10 mm, to avoid appreciable reduction in strength of the composite. Fibres also in effect, act as aggregate. Although they have a simple geometry, their influence on the properties of fresh concrete is complex. The inter-particle friction between fibres, and between fibres and aggregates controls the orientation and distribution of the fibres and consequently the properties of the composite. Friction reducing admixtures and admixtures that improve the cohesiveness of the mix can significantly improve the mix.

Steel wire fibre reinforced shotcrete

Mixing

Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation, and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendencies. A steel fibre content in excess of 2 per cent by volume and an aspect ratio of more than 100 are difficult to mix. The typical proportions for fibre reinforced concrete is given below:

Cement content	:	*325 to 550 kg/m³*
W/C Ratio	:	*0.4 to 0.6*
Percentage of sand to total aggregate	:	*50 to 100 per cent*
Maximum Aggregate Size	:	*10 mm*
Air-content	:	*6 to 9 per cent*

Fibre content	:	*0.5 to 2.5 per cent by volume of mix*
	:	*Steel —1 per cent 78 kg/m^3*
	:	*Glass —1 per cent 25 kg/m^3*
	:	*Nylon —1 per cent 11 kg/m^3*

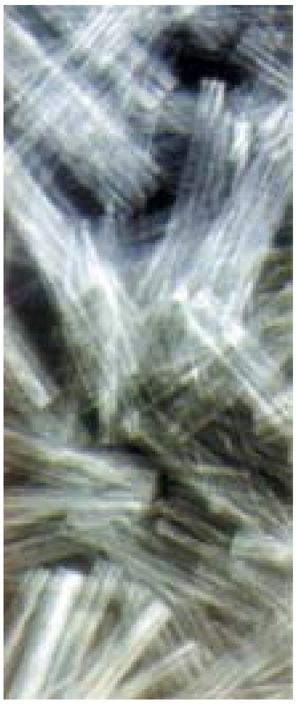
It is important that the fibres are dispersed uniformly throughout the mix, This can be done by the addition of fibres before the water is added. When mixing in a laboratory mixer, introducing the fibres through a wire mesh basket, will help even distribution of fibres. For field use, other suitable methods must be adopted.

Applications

Fibre reinforced concrete is increasingly used on account of the advantages of increased static and dynamic tensile strength, energy absorbing characteristics and better fatigue strength. The uniform dispersion of fibres throughout the concrete provides isotropic properties not common to conventionally reinforced concrete. Fibre reinforced concrete has been tried on overlays of air-field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings etc. The fibre reinforced concrete can also be used for the fabrication of precast products like pipes, boats, beams, stair case steps, wall panels, roof panels, manhole covers etc... Fibre reinforced concrete sometimes called fibrous concrete, is manufactured under the trade name "Wirand Concrete". After extensive research, the Wirand concrete is used very extensively in United States. Fibre reinforced concrete in also being tried for the manufacture of prefabricated formwork moulds of "U" shape for casting lintels and small beams.

Glass Fibre Reinforced Cement (GRC)

With the development of alkali resistant glass fibre (by trade name 'CEM-FIL) by the U.K. Building Research Establishment and Pilkington glass, U.K. a wide ranging applications of fibrous concrete is being made in many areas of building construction.[12.9] Glass reinforced cement consists of 4 to 4.5 per cent by volume of glass fibre mixed into cement or cement sand mortar. This glass reinforced cement mortar is used for fabricating concrete products having a sections of 3 to 12 mm in thickness. Methods of manufacture vary and include spraying, casting, spinning, extruding and pressing. Each technique imparts different characteristics to the end product. Spray deposition constitutes a very appropriate and by far the most developed method of processing. In the simplest form of spray processing, simultaneous sprays of cement or cement sand mortar slurry and chopped glass fibre are deposited from a dual spray gun into, or onto a suitable mould. Mortar slurry is fed to the spray gun from a metering pump unit and is atomised by compressed air. Glass fibre is fed to a chopper and feeder unit that is mounted on the same gun assembly. Glass reinforced cement (GRC) has been used for clading of buildings, permanent and temporary formwork, pressure pipes, doors and doors frames, decorative grills, sun



Typical glass fibre

breakers, bus shelters and park benches. This will find its use in many application as building components.

Current Development in FRC

The following are the three new developments taking place in FRC.

- *High fibre volume micro-fibre systems.*
- *Slurry infiltrated fibre Concrete (SIFCON).*
- *Compact reinforced composites.*

High Fibre Volume Micro-fibre Systems

Micro-fibres are the fibres generally of size about 3 mm long and 5 to 25 μ in cross-section in contrast to macro-fibre of length about 25 mm and cross-section dimension of about 0.5 mm. The specific surface of micro-fibres is more than 200 cm^2/gram in contrast to specific surface less than 20 cm^2/gm.

Conventional mixing techniques and mix proportions usually lead to fibre balling, improper dispersion and poor workability in micro-fibre cements with large volumes of fiber. Various innovative techniques of mixing in mixers called omni mixer, use of admixtures such as carboxyl methyl cellulose, Silica fume and ground granulated blast furnace slag are practised. The System also requires large dosages of superplasticizers, low sand/cement ratio, longer mixing time and sand particles of size not exceeding one mm.

High fibre volume micro-fibre can replace asbestos fibre with improved properties of high toughness and much greater impact strength. These properties make it attractive for thin precast products such as roofing sheets, cladding panels etc. High fibre volume micro-fibres cement composite will be a very useful material for repair and rehabilitation works.

Slurry Infiltrated fibre Concrete

Slurry infiltrated fibre concrete (SIFCON) was invented by Lankard in 1979. Steel fibre bed is prepared and cement slurry is infiltrated. With this techniques, macro-fibre contents up to about 20% by volume can be achieved, with a consequent enormous increase in both flexural load carrying capacity and toughness. With such high fibre volume, a very high compressive strength is also achieved. SIFCON can be used for blast resistant structures and burglar proof safe vaults in banks and residential buildings.

Compact Reinforced Composites

Compact Reinforced Composites (CRC) is a material consisting of an extremely strong, dense cement matrix, 20 – 30% silica fume by weight of cement, 10 – 20% by volume off conventional reinforcement and 5 – 10% of fine fibres of 6 mm long and 0.15 mm diameter. While such a material is extremely expensive, it exhibits a flexural strength up to 260 MPa and compressive strength of about 200 MPa. It is a material almost as strong as structural steel. Advantage is that it can be moulded and fabricated at site.

Polymer Concrete

Continuous research by concrete technologists to understand, improve and develop the properties of concrete has resulted in a new type of concrete known as, "Polymer Concrete". It is referred time and again in the earlier chapters that the concrete is porous. The porosity is due to air-voids, water voids or due to the inherent porosity of gel structure itself. On account of the porosity, the strength of concrete is naturally reduced. It is conceived by many research workers that reduction of porosity results in increase of strength of concrete.

Therefore, process like vibration, pressure application spinning etc., have been practised mainly to reduce porosity. All these methods have been found to be helpful to a great extent, but none of these methods could really help to reduce the water voids and the inherent porosity of gel, which is estimated to be about 28%. The impregnation of monomer and subsequent polymerisation is the latest technique adopted to reduce the inherent porosity of the concrete, to improve the strength and other properties of concrete.

The pioneering work for the development of polymer concrete was taken up by United States Bureau of Reclamation (USBR). The initial exploratory works carried out at the Brookhaven National Laboratory (BNL) in cooperation with USBR and US in Atomic Energy Commission (AEC) revealed great improvement in compressive strength, permeability, impact resistance and abrasion resistance.

The development of concrete-polymer composite material is directed at producing a new material by combining the ancient technology of cement concrete with the modern technology of polymer chemistry.

Type of Polymer Concrete

Four types of polymer concrete materials are being developed presently. They are:

(*a*) Polymer Impregnated Concrete (PIC).
(*b*) Polymer Cement Concrete (PCC).
(*c*) Polymer Concrete (PC).
(*d*) Partially Impregnated and surface coated polymer concrete.

Polymer Impregnated Concrete (PIC)

Polymer impregnated concrete is one of the widely used polymer composite. It is nothing but a precast conventional concrete, cured and dried in oven, or by dielectric heating from which the air in the open cell is removed by vacuum. Then a low viscosity monomer is diffused through the open cell and polymerised by using radiation, application of heat or by chemical initiation.

Mainly the following types of monomer are used:

(*a*) Methylmethacrylate (MMA),
(*b*) Styrene,
(*c*) Acrylonitrile,
(*d*) *t*-butyl styrene,
(*e*) Other thermoplastic monomers.

The amount of monomer that can be loaded into a concrete specimen is limited by the amount of water and air that has occupied the total void space. It is necessary to know the concentration of water and air void in the system to determine the rate of monomer penetration. However, the main research effort has been towards obtaining a maximum monomer loading in concrete by the removal of water and air from the concrete by vacuum or thermal drying, the latter being more practicable for water removal because of its rapidity.

Another parameter to consider is evacuation of the specimen prior to soaking in monomer. This eliminates the entrapment of air towards the centre of the specimen during soaking which might otherwise prevent total or maximum monomer loading. The application of pressure is another technique to reduce monomer loading time.

Polymer Cement Concrete (PCC)

Polymer cement concrete is made by mixing cement, aggregates, water and monomer. Such plastic mixture is cast in moulds, cured, dried and polymerised. The monomers that are used in PCC are:

(a) Polyster-styrene.

(b) Epoxy-styrene.

(c) Furans.

(d) Vinylidene Chloride.

However, the results obtained by the production of PCC in this way have been disappointing and have shown relatively modest improvement of strength and durability. In many cases, materials poorer than ordinary concrete are obtained. This behaviour is explained by the fact that organic materials (monomers) are incompatible with aqueous systems and sometimes interfere with the alkaline cement hydration process.

Recently Russian authors have reported the production of a superior Polymer cement concrete by the incorporation of furfuryl alcohol and aniline hydrochloride in the wet mix. This material is claimed to be specially dense and non-shrinking and to have high corrosion resistance, low permeability and high resistance to vibrations and axial extension.

Washington State University in cooperation with Bureau of Reclamation tested the incorporation of several monomers into wet concrete for preparing PCC for fabrication of distillation units for water disalination plants. However, it is reported that only epoxy resin produced a concrete that showed some superior characteristics over ordinary concrete.

Polymer Concrete (PC)

Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement as in conventional concrete.

The main technique in producing PC is to minimise void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregates. This is achieved by properly grading and mixing the aggregates to attain the maximum density and minimum void volume. The graded aggregates are prepacked and vibrated in a mould. Monomer is then diffused up through the aggregates and polymerisation is initiated by radiation or chemical means. A silane coupling agent is added to the monomer to improve the bond strength between the polymer and the aggregate. In case polyester resins are used no polymerisation is required.

An important reason for the development of this material is the advantage it offers over conventional concrete where the alkaline Portland cement on curing, forms internal voids. Water can be entrapped in these voids which on freezing can readily crack the concrete. Also the alkaline Portland cement is easily attacked by chemically aggressive materials which results in rapid deterioration, whereas polymers can be made compact with minimum voids and are hydrophobic and resistant to chemical attack. The strength obtained with PC can be as high as 140 MPa with a short curing period.

However, such polymer concretes tend to be brittle and it is reported that dispersion of fibre reinforcement would improve the toughness and tensile strength of the material. The use of fibrous polyester concrete (FPC) in the compressive region of reinforced concrete beams provides a high strength, ductile concrete at reasonable cost. Also polyester concretes are viscoelastic in nature and will fail under sustained compressive loading at stress levels greater than 50 per cent of the ultimate strength. Therefore, polyester concrete should be considered for structures with a high ratio of live load to dead load and for composite structures in which the polymer concrete may relax during long-term loading. Experiments conducted on FPC composite beams have indicated that they are performance effective when compared to reinforced concrete beam of equal steel reinforcement percentage. Such beams utilise steel in the region of high tensile stress, fibrous polyester concrete (FPC) with its favourable compressive behaviour, in the regions of high compressive stress and Portland cement concrete in the regions of relatively low flexural stress.

Partially Impregnated (or Coated in Depth CID) and Surface Coated (SC) Concrete

Partial impregnation may be sufficient in situations where the major requirement is surface resistance against chemical and mechanical attack in addition to strength increase. Even with only partial impregnation, significant increase in the strength of original concrete has been obtained. The partially impregnated concrete could be produced by initially soaking the dried specimens in liquid monomer like methyl methacrylate, then sealing them by keeping them under hot water at 70°C to prevent or minimise loss due to evaporation. The polymerisation can be done by using thermal catalytic method in which three per cent by weight of benzoyl peroxide is added to the monomer as a catalyst. It is seen that the depth of monomer penetration is dependent upon following:

(a) Pore structure of hardened and dried concrete.

(b) The duration of soaking, and

(c) The viscosity of the monomer.

The potential application of polymer impregnated concrete surface treatment (surface coated concrete, SC) is in improving the durability of concrete bridge decks. Bridge deck deterioration is a serious problem everywhere, particularly due to a abrasive wear, freeze-thaw deterioration, spalling and corrosion of reinforcement. Excellent penetration has been achieved by ponding the monomer on the concrete surface. Due care should be taken to prevent evaporation of monomer when ponded on concrete surface. A 5 cms thick slab, on being soaked by MMA for 25 hours produced a polymer surface coated depth of 2.5 cms. Significant increases in the tensile and compressive strengths, modulus of elasticity and resistance to acid attack have been achieved.

The application of monomer for field application like in bridge decks poses more problems than laboratory application. A typical surface treatment in the field can be done in the following manner.

(a) The surface is dried for several days with electrical heating blanket.

(b) Remove the heating blanket and cover the slab with 0.64 m^3 oven-dried light-weight aggregate per 100 sq.m.

(c) Apply initially 2,000 to 3,000 ml of the monomer system per square metre.

(d) Cover the surface with polyethylene to retard evaporation.

(e) Shade the surface to prevent temperature increase which might initiate polymerisation prematurely, that may reduce penetration into the concrete.

(f) Add periodically additional monomer to keep the aggregate moist for minimum soak time of 8 hours.

(g) Apply heat to polymerise the monomer. Heating blanket, steam or hot water can be used for this purpose.

Some of the promising monomer systems for this purpose are:

(a) Methylmethacrylate (MMA), 1% Benzoyl peroxide (BP), 10% Trimethylopropane trimethacrylate (TMPTMA).

(b) Isodecyl methacrylate (IDMA), 1% BP, 10% TMPTMA.

(c) Isobutyl methacrylate (IBMA), 1% BP, 10% TMPTMA.

BP acts as a catalyst and TMPTMA is a cross linking agent which helps in polymerisation at low temperature of 52%C.

Properties of Polymer Impregnated Concrete

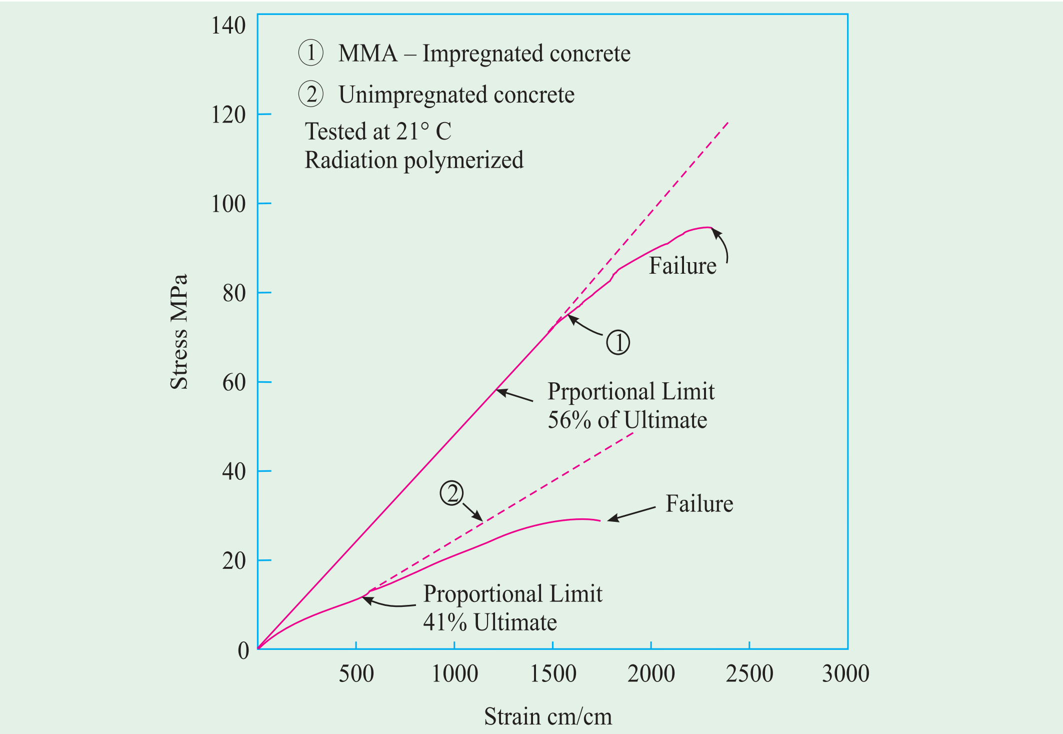
Since Polymer impregnated concrete (PIC) is one of the most important category of polymer concrete, the properties of PIC is discussed below.

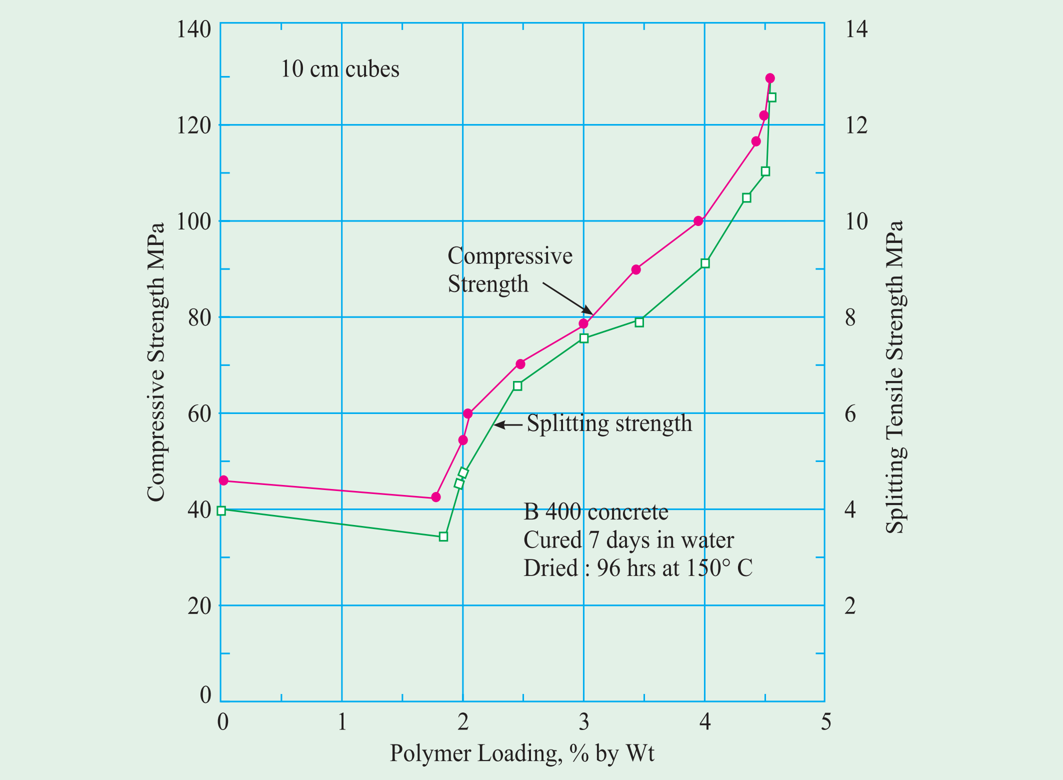
Stress-Strain Relationship

The stress-strain curve for MMA-impregnated concrete tested to failure is shown in Fig. 12.7. PIC has a nearly linear stress-strain relationship to failure. There is very little departure from linearity upto 90 per cent of ultimate strength and there is no abrupt change at the proportional limit. The stress strain curves for Styrene-TMPTMA impregnated concrete also show the same characteristics as for MMA impregnated concrete. The modulus of elasticity increased from 27 GPa for unimpregnated specimen to 49 GPa for MMA impregnated specimens.

Compressive Strength

The effect of polymer loading on the compressive strength in PIC is given in Fig. 12.8 Using methylemethacrylate as monomer and with a polymer loading of 6.4%, strength of the order of 144 MPa have been obtained using radiation technique of polymerisation. (The





control specimen had compressive strength of 38 MPa). The compressive strength obtained with thermal catalytic process was 130 MPa.

Styrene impregnated specimens exhibited similar trends, except that the strength levels were somewhat lower. The polymerisation by radiation method produced a concrete of higher strength than that produced by thermal catalytic method.

Perlite concrete impregnated with MMA and polyester styrene have also shown considerable increases in compressive strength. It is found that higher strengths are obtained with MMA impregnated sample than with polyster styrene. The average compressive strength for a 1 : 8 non-air entrained perlite concrete samples, impregnated with MMA was 56 MPa for a polymer loading of 63% compared to a control specimen of compressive strength 1.2 MPa.

Tensile Strength

The increase in tensile strength in the case of PIC has been observed to be as high as 3.9 times that of the control specimen for a polymer loading of 6.4% MMA i.e., impregnated concrete have shown tensile strength of the order of 11.6 MPa compared to the strength of control specimen of 3 MPa using radiation process of polymerisation. Thermal catalytically initiated polymerisation, produced concrete with tensile strength 3.6 times that of the control specimen and 7.3 per cent less than that of radiation produced concrete.

PCC

Polymer cement concrete using polymer latex has given tensile strength of 5.8 MPa with a latex/cement ratio of 0.25; compared to the control specimen of 4.4 MPa strength. The increase in tensile strength is very modest.

Table 12.11. Classification of Concrete—Polymer Materials[12.14]

Type of concrete	Polymer Loading weight % (PMMA)	Density gm/cc	Strength (Compressive) MPa	Strength / Weight ratio	Durability	Benefit/ cost index
1. Conventional concrete control	0.0	2.40	35.3	33	Poor	1.0
2. Surface coating (SC) paint or overlay	0.0	2.40	35.3	33	Limited	1.1
3. Coating in Depth (CID)	1.0	2.40	42.3	40	Good	1.3
4. Polymer Cement Concrete (PCC) premix	35.0	2.08	52.8	58	Fair	0.4
5. Polymer Impregnated Concrete (PIC)						
Standard Aggregate						
a. Undried-dipped	2.0	2.45	70.5	49	Fair	1.4
b. Dried-evacuated-filled	6.0	2.55	141.0	126	Very good	2.0
c. High-Silica steam cured	8.0	2.55	268.0	240	Very good	3.0
Light-weight Aggregate						
a. Structural light-weight concrete	15.0	2.08	176.0	193	Very good	2.5
b. Insulated light-weight concrete	65.0	0.96	35.3	84	Very good	2.5
6. Polymer Concrete (PC) cement-less	6.0	2.40	141.0	133	Excellent	4.0

PC

Polyester resin concrete with binder content varying from 20 to 25% have shown tensile strengths in the range of 9 to 10 MPa at 7 days.

Flexural Strength

Polymer impregnated concrete with polymer loading of 5.6% MMA and polymerised by radiation have shown flexural strength 3.6 times more than that of the control specimen, i.e. the flexural strength was increased to 18.8 MPa from 5.2 MPa.

Polymer Concrete (PC)

Polyester resin concrete has been reported to give flexural strength of the order of 15 MPa at 7 days.

Creep

Compressive Creep deformation of MMA impregnated concrete and styrene—impregnated concrete has been observed to be in direction opposite to that of the applied load i.e., Negative Creep. After the typical initial movement during load application, these concretes expand under sustained compression.

The reason for this negative creep in PIC is not very clear though it may be possible that it is due to residual stresses generated in the concrete after polymerisation of monomers. The increased volume may also be due to phase changes induced by pressure. This behaviour has been noticed at a relatively low loading of 5.7 MPa. Otherwise creep deformation of PIC concrete is generally one-tenth of conventional concrete, when compared on a basis of deformation per unit load. Creep deformation generally stabilises after two to three months.

Shrinking due to Polymerisation

Shrinkage occurs through two stages of impregnation treatment i.e., through initial drying and through polymerisation. The shrinkage through polymerisation is peculiar to PIC and could be several times greater than the normal drying shrinkage.

It has been seen that for the same base material, different monomer systems cause different amounts of shrinkage. It is expected that the shrinkage due to polymerisation will be less for a base that has higher modulus of elasticity.

Durability

The saturation of the hydrated cement with corrosion resistant polymer probably acts as a protective coating and results in excellent improvement in durability.

(a) Freeze Thaw Resistance: *Polymer impregnated concrete has shown excellent resistance to freeze-thaw MMA impregnated and radiation polymerised specimens have withstood 8110 cycles of freeze-thaw compared to 740 cycles in case of unimpregnated concrete. Even partially impregnated concrete withstood 2310 cycles.*

(b) Resistance to Sulphate Attack: *Keeping a failure criteria of 0.5% expansion, it has been observed that there is at least 200 per cent improvement in the resistance of polymer impregnated concrete and 89% improvement in the case of partially impregnated concrete over the conventional concrete.*

(c) Acid Resistance: *The acid resistance of PIC has been observed to improve by 1200 per cent, when exposed to 15% HCl for 1395 days.*

Water Absorption

A maximum reduction of 95 per cent in water absorption has been observed with concrete containing 5.9 per cent polymer loading.

Co-efficient of Thermal Expansion

Polymer impregnated concrete has higher co-efficient of thermal expansion compared to conventional concrete. Compared to the unimpregnated concrete having a value of 4.02 x 10^{-6}, a 5.5% MMA, radiation polymerised concrete has a co-efficient of thermal expansion of 5.63 x10^{-6} and styrene impregnated specimens have shown a value off 5.10 x 10^{-6}.

Resistance to Abrasion

Polymer impregnated concrete has shown appreciable improvement in resistance to abrasion. A 5.5% MMA impregnated concrete has been found to be 50 to 80 per cent more resistant to abrasion than the control specimen. Even surface impregnated concrete slabs have shown an improvement of 20 to 50%.

Wear and Skid Resistance

Though there may be apprehension that polymer filled voids in polymer concrete might produce a slippery surface, on actual wear track test, it was found that the treated surfaces show excellent skid resistance compared to the unimpregnated surfaces. The wear after 50,000 simulated vehicular passes has been less than 0.025 cm.

Fracture of Polymer Impregnated Concrete

Polymer impregnation of concrete changes its microstructure radically resulting in a change in the cracking behaviour of the impregnated concrete under load. Impregnation improves the strength of the mortar matrix and also the strength of the paste-aggregate interface by elimination of microcracks. Polymer probably enters the aggregates also and forms a network of polymer fibres across the interface, thus strengthening it.

Radiographic studies have shown that microcracking starts first around 70 to 80% of the ultimate load, very often in the mortar phase. When an advancing crack reaches an aggregate, it does not follow the aggregate boundary as in ordinary concrete, but usually propagates through the aggregate. This indicates that the paste aggregate interface bond is significantly improved by polymer impregnation.

It has been observed that PIC indicates nearly linear behaviour to failure, which is typical of brittle material. The brittle nature of PIC presents a severe design limitation. It would be ideal to produce a material with the slow failure mode of normal concrete while retaining the high strength and modulus of elasticity of PIC.

One method to achieve this ideal is to adjust the paste aggregate bond so that the failure mode is through the interface like in ordinary concrete. In principle this can be achieved by using a very strong and tough aggregate, so that the advancing crack is diverted round to the paste-aggregate interface.

The fracture mode of PIC can also be altered by incorporating a small quantity (1% by volume) of fibres in the matrix. The fibres do not affect the modulus of elasticity of concrete due to their low concentration, but serve to inhibit crack propagation through the mortar by acting as crack arrestors. Table 12.11 shows properties of various type of polymer modified concretes.

Application of Polymer Impregnated Concrete

Keeping in view the numerous beneficial properties of the PIC, it is found useful in a large number of applications, some of which have been listed and discussed below:

(*a*) Prefabricated structural elements.

(*b*) Prestressed concrete.

(*c*) Marine works.

(*d*) Desalination plants.

(*e*) Nuclear power plants.

(*f*) Sewage works—pipe and disposal works.

(*g*) Ferrocement products.

(*h*) For water proofing of structures.

(*i*) Industrial applications.

(*a*) Prefabricated Structural Elements: For solving the tremendous problem of Urban housing shortage, maintaining quality, economy and speed, builders had to fall back on prefabricated techniques of construction. At present due to the low strength of conventional concrete, the prefabricated sections are large and heavy, resulting in costly handling and erection. These reasons have prevented wide adoption of prefabrication in many countries.

At present, the technique of polymer impregnation is ideally suited for precast concrete. It will find unquestionable use in industrialisation of building components. Owing to higher strength, much thinner and lighter sections could be used which enables easy handling and erection. They can be even used in high rise building without much difficulties.

(*b*) Prestressed Concrete: Further development in prestressed concrete is hindered by the inability to produce high strength concrete, compatible with the high tensile steel available for prestressing. Since PIC provides a high compressive strength of the order of 100 to 140 MPa, it will be possible to use it for larger spans and for heavier loads. Low creep properties of PIC will also make it a good material for prestressed concrete.

(*c*) Marine Works: Aggressive nature of sea water, abrasive and leaching action of waves and inherent porosity, impair the durability of conventional concrete in marine works. PIC, possessing high surface hardness, very low permeability and greatly increased resistance to chemical attack, is a suitable material for marine works.

(*d*) Desalination Plants: Desalination of sea water is being resorted to augment the shortage of surface and ground water in many countries. The material used in the construction of flash distillation vessels in such works has to withstand the corrosive effects of distilled water, brine and vapour at temperature upto 143°C. Carbon steel vessels which are currently in use are comparatively costly and deteriorate after prolonged use. Preliminary economic evaluation has indicated a savings in construction cost over that of conventional concrete by the use of PIC.

(*e*) Nuclear Power Plants: To cope up with the growing power requirements for industrial purposes, many countries are resorting to nuclear power generation.

The nuclear container vessel (pressure vessel) is a major element which is required to withstand high temperatures and provide shield against radiations. Another attendant problem of nuclear power generation is the containment of spent fuel rods which are radioactive over long period of time to avoid radiation hazards. At present heavy weight concrete is being used *for this purpose, which is not very effective. PIC having high impermeability coupled with high strength and marked durability provide an answer to these problems.*

(f) Sewage Disposal Works: *It is common experience that concrete sewer pipes deteriorate due to the attack of effluents and when buried in sulphate infested soils. Further, in the sewage treatment plant, concrete structures are subjected to severe attack from corrosive gases particularly in sludge digestion tanks. Polymer-impregnated concrete due to its high sulphate and acid resistance will prove to be a suitable material in these situations.*

(g) Impregnation of Ferrocement Products: *The ferrocement techniques of construction is being extensively used in the manufacture of boats, fishing trawlers, domestic water tanks, grain storage tanks, manhole cove, etc. Ferrocement products are generally thin (1 to 4 cms) and as such are liable to corrode. Application of polymer impregnation techniques should improve the functional efficiency of ferrocement products.*

(h) Water Proofing of Structures: *Seepage and leakage of water through roof and bathroom slabs, is a nagging problem and has not been fully overcome by the use of conventional water proofing methods. The use of polymer impregnated mortar should solve this problem.*

(i) Industrial Applications: *Concrete has been used for floor in tanneries. Chemical factories, dairy farms and in similar situations for withstanding the chemical attack, but performance has not been very satisfactory. The newly developed PIC will provide a permanent solution for durable flooring in such situations.*

SPECIAL CONCRETING METHODS

Cold Weather Concreting

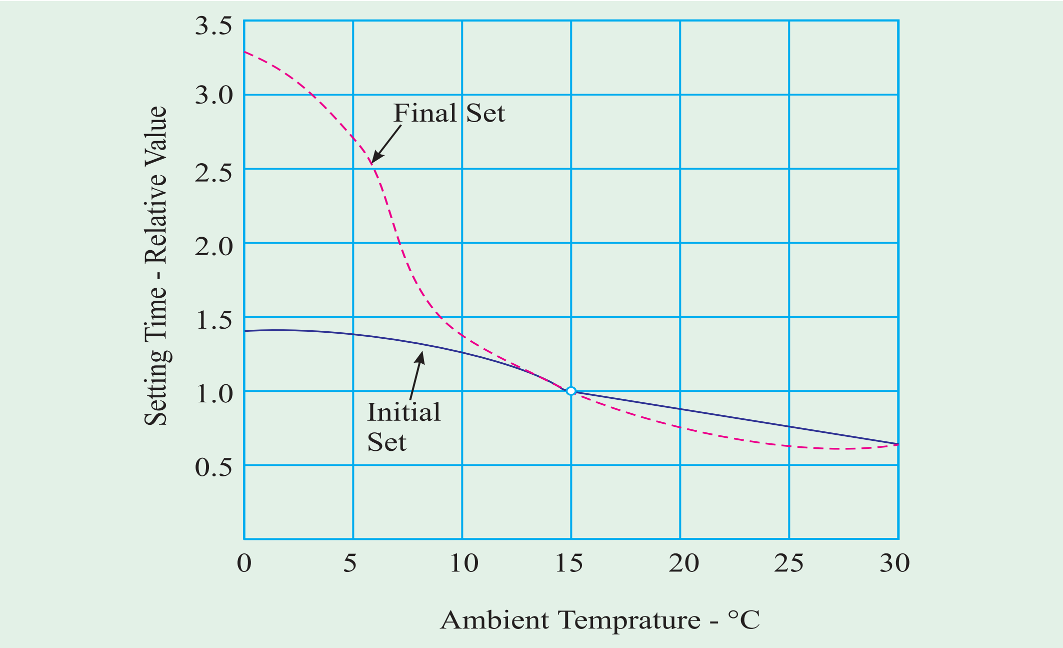
The normal procedure adopted for concreting in fair weather will not be valid for concreting when the temperature is low or below the freezing point. In India, such areas are fairly small when compared to fair weather regions. The production of concrete in cold weather introduces special and peculiar problems, such as delay in setting and hardening, damage to concrete in plastic condition when exposed to below freezing point owing to the formation of ice lenses. Therefore, it is essential to maintain the temperature of the concrete positively above 0°C, possibly at much higher temperature.

Effects of Cold Weather on Concrete

(a) Delay in setting and hardening: *Rate of hydration depends upon the temperature. If temperature is low, concrete takes a long time to set and a longer time to harden i.e., for the development of strength. Fig. 12.9 shows the effect of ambient temperature on setting time. The delay in setting time makes concrete vulnerable to frost attack and other disturbances. Delay in hardening period does not facilitate removal of formwork in a short period. Also the rate of progress of work will be very slow, all of which affects economy.*

(b) Freezing of concrete at early age: *When the temperature goes below freezing point, the free water contained in the plastic concrete freezes. Freezing of water, not only prevents the hydration of cement but also makes the concrete expand. This expansion causes disruption of concrete due to which irrepairable loss of strength and quality takes place.*

(c) Freezing and Thawing: *It is likely that due to varied behaviour of climatic conditions in the cold weather regions, the fresh concrete or hardened concrete gets subjected to freezing and thawing cycles. The durability of concrete gets greatly impaired due to this alternate freezing and thawing. Freezing and thawing may also exert fatigue in the concrete.*



In dealing with the aspect of cold weather concerting, the following conditions may be discussed.

(*a*) *Low temperature, but above 0°C at the time of concreting and later during hardening period.*

(*b*) *Low temperature at the time of concreting but below 0°C during the hardening period.*

(*c*) *Temperature below 0°C at the time of concreting and during hardening period.*

(*d*) *Hardened concrete subjected to alternate freezing and thawing.*

It is necessary to deal with the above four conditions to understand the behaviour of concrete clearly and to take appropriate steps to offset the harmful effects of such conditions for the successful placing of concrete.

Low Temperature but above 0°C

If the temperature is only low but always above the freezing point, it only retards the rate of development of strength as shown in the maturity equations stated earlier. There is no other bad effect on the fresh concrete or hardening concrete. As a matter of fact, the ultimate strength of the concrete cured at 9°C has been found to be of a higher order than that of the concrete cured at higher temperature. This may be due to the surperiority of gel structure on account of slow growth. No other precautions are necessary except recognition of the fact of delayed strength for stripping the formwork or for putting the concrete into service.

Low Temperature at the Time of Concreting but Below 0°C after Concreting

The first condition has been discussed in the above para. But after concreting, if the temperature falls below 0°C, it is again necessary to view the conditions under the following two catagories:

(*a*) *Temperature falling below 0°C when the concrete is still green.*

(*b*) *Temperature prevailing below 0°C after the concrete is sufficiently hardened.*

Many times it may so happen that the concrete will have been mixed and placed when the ambient temperature is above freezing point. But before the concrete has attained sufficient strength, the temperature of the air and also temperature within the concrete may fall below freezing point, in which case the free water still available in the concrete to freeze and form ice lenses in microscopic scale. These ice lenses formed in the capillary cavities may cause capillary suction of water from the ground, if the ground is saturated, and become bigger to disrupt the mass which disturbs the compaction of concrete. Ice formations may also appear as ice needles in the contact surfaces between aggregates and cement paste. Fig. 9.18 shows the increase in volume of concrete as a function of age at which freezing starts. Fig. 9.19 also shows the increase in volume against number of cycles of freezing and thawing. After thawing these ice needles will melt forming cavities. Therefore, it can be concluded that freezing of freshly laid concrete seriously impair the structural integrity of concrete and results in considerable loss of strength.

In extreme cases, it may make the concrete an absolutely useless friable mass.

On the other hand if the concrete is sufficiently hardened when freezing takes place, there will not be much harm to the structural integrity of the concrete. If the concrete has sufficiently hardened, the water that has been mixed for making concrete will have been lost either being used up in hydration process or lost by evaporation. Due to the formation of cement gels, the capillary cavities also will have been very much reduced, with the results that there exists very little of free water in the body of concrete to freeze. Therefore, firstly the magnitude of volume change due to the formation of microscopic ice lens is much less. Secondly, the concrete at this stage is strong enough to resist whatever osmotic pressure resulting from the freezing. Therefore, there is no immediate danger to the concrete.

Temperature Below 0°C at the Time of Concreting and During Hardening Period

Certain precautions are absolutely necessary for concreting when the temperature is below 0°C, so that the fresh concrete does not get frozen. The consequences of freezing of fresh concrete and the effect of sub-zero temperature on the hardened but not fully matured concrete has been explained in the above para. Precautions to be taken and methods for carrying out concreting operations will be explained later.

Hardened Concrete subjected to Alternate Freezing and Thawing

Concrete pavements constructed at high altitude is normally subjected to alternate freezing and thawing. The interval of cycles may be between season to season or between day and night or even a couple of times in a day. It has been found that the durability of hardened concrete is reduced to 1/3 to 1/7 when it is subjected to alternate freezing and thawing depending on the quality of concrete.

It is to be noted that concrete is a pervious material. Degree of porosity is depending upon the Gel/space ratio. A concrete member is likely to get saturated due to the absorption of moisture from surface or from bed. The free water that has filled the capillary cavities of concrete will get frozen with the fall of temperature. Subsequently when the temperature goes above 0°C, the ice lens melts. Due to this alternate freezing and thawing, concrete is subjected to distress and surface scaling. The distress of concrete can be measured by the loss of weight against number of cycles of freezing as shown in Fig. 5.18.

Concreting Methods at Sub-zero Temperature

Having discussed the effect of sub zero-temperature on fresh concrete, hardening concrete and hardened concrete, it is clear that fresh concrete should not be subjected to *freezing condition till such time it attains a certain amount of strength. This time interval is known as 'Pre-hardening Period'. The recommended pre-hardening period as recommended by IS 7861 (Part-2)—1979 is given in the following table:*

Table No. 12.12. Time Taken by Different Grades of Concrete

Specified minimum strength at 28 days for ordinary Portland cement MPa	*Requisite Pre-hardening period*			
	At any concrete temperature above freezing in units of maturity °C hr	*At stated conctrete temperature in hours.*		
		20°C	*10°C*	*5°C*
M 20	1050	35	53	70
M 25	780	26	39	52
M 30	660	22	33	44
M 40	480	16	24	32

The precautions to be taken and methods adopted for concreting in sub-zero temperature is listed below:

- (*a*) Utilisation of the heat developed by the hydration of cement and practical methods of insulation.
- (*b*) Selection of suitable type of cement.
- (*c*) Economical heating of materials of concrete.
- (*d*) Admixtures of anti-freezing materials.
- (*e*) Electrical heating of concrete mass.
- (*f*) Use of air-entraining agents.

An enormous quantity of heat is generated in the hydration of cement. If this heat is preserved within the body of the concrete for a duration equal to the prehardening period, it can do the useful job of offsetting the harmful effect of low temperature. To conserve the heat the concrete can be insulated by a membrane, burlap, saw dust or hessain cloth. In case of beams and columns, keeping the formwork without stripping is a good step to conserve the heat, in concrete. In case of very low temperature, it is very necessary that the insulation of concrete be so efficient as to keep the surface temperature of concrete higher than 0°C during pre-hardening period.

Certain type of cement, hydrates fast, in turn gives out much larger quantity of heat and develops early strength. The pre-hardening period for such a cement will be about 40 to 50% of the normal Portland cement. Such cement contains higher percentage of tricalcium silicate (C_3S) and comparatively lower percentage of dicalcium silicate (C_2S). Rapid hardening cement is one such cement that can be used. Extra rapid hardening cement. High Alumina cement or mixture of ordinary Portland cement and high alumina cement in certain proportions can also be used for this purpose. All the above will only reduce the time for which the concrete is vulnerable to frost attack.

Preheating of the materials of concrete is one of the methods very commonly employed in sub-zero temperature concreting. Heating of water is the easiest to be adopted. If the ambient temperature is not very low, heating of water alone will be sufficient, if the aggregates and cement are not in frozen condition. The Figures 12.10, (a), 12.10 (b) and 12.10 (c) show

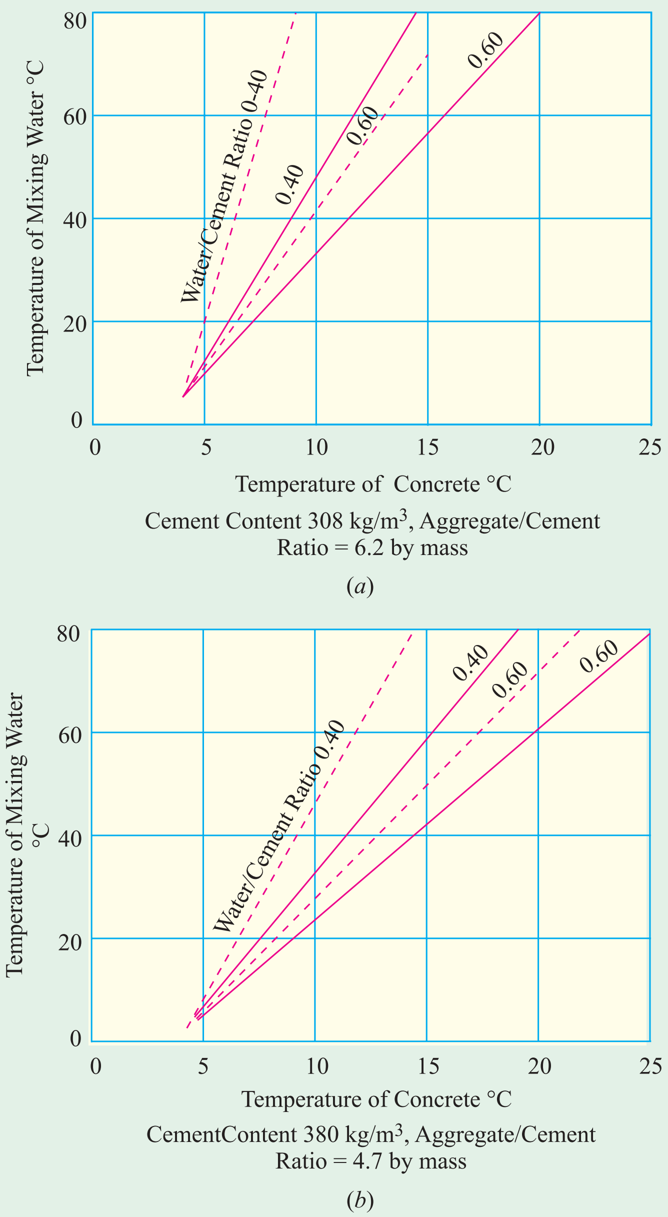
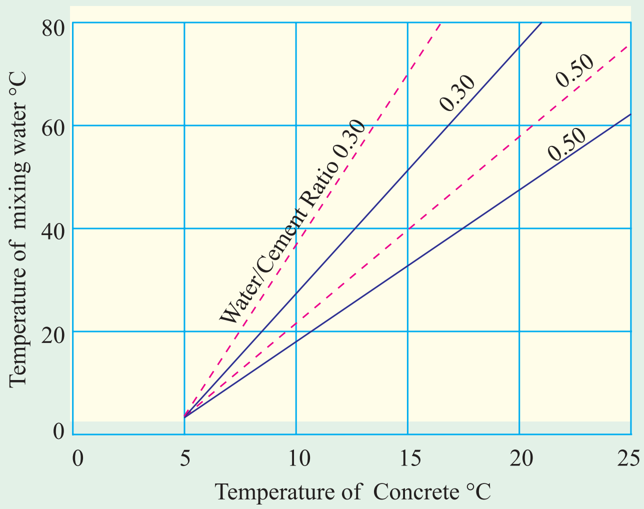


Fig. 12.10. Required Temperature of Mixing Water to Produce Heated Concrete.

the temperature to which the water should be heated to maintain the temperature of the resultant concrete at a stipulated temperature for different aggregate/cement ratio and cement content. As can be seen for the figure, the desirable concrete temperature can be achieved by heating water alone provided the aggregates are free from ice and the formwork and top surface are properly insulated. In case of very low temperature or if it is estimated that a good amount of heat is lost in transportation and placing, the heating of mixing water alone may prove to be inadequate to maintain the required temperature in concrete. In such cases, aggregate is also heated either by closed steam coils under the stock piles or by injecting live *steam into the stock piles or by hot air blowers. Fine aggregate can also be heated on hot plates. Overheating of aggregates should be avoided. Cement should never be heated.*



(c)

Fig. 12.10. Required Temperature of Mixing Water to Produce Heated Concrete.

Note:
— Moisture content of fine aggregate 4 per cent and that of coarse aggregate 1 per cent (damp)
— Moisture content of fine aggregate 8 per cent and that of coarse aggregate and 2 per cent (wet)
— Temperature of aggregate and contained moisture = 1°C
— Temperature of cement = 5°C.

To maintain the prehardening temperature, electrical heating of the entire mass of concrete may be adopted where plenty of cheap power is available. Only alternating current should be used for this purpose. Electricity is conducted through mats or reinforcing bars. Sometimes special electrodes are carefully positioned in such a way that uniform heat is generated. In order to protect the workers, only low current should be used. The heating has to be designed very carefully including the voltage, the type and location of the electrodes as well as heating for each element. Evaporation of the mixing water has to be restricted by covering the entire surface effectively with vapour tight memberane.

Inspite of these precautions it is found that the strength of electrically heated concrete is about 20% less than normally cured concrete because of water loss and temperature stresses caused by the cooling of the heated concrete. Electrical heating is justified only in very cold climatic conditions where cheap power is available, but it has the disadvantage of high cost of installation, power consumption and loss of strength. In Sweden, Russia, and Japan electrical curing is being used quite extensively for protecting concrete from frost.

One of the widely adopted practices in winter concreting is the use of accelerating admixtures which incidentally works as antifreeze also. The most commonly employed material is calcium chloride. There are divergent views about the quantity of calcium chloride to be admixed for optimum results. Many specifications do not permit the use of more than 3% $CaCl_2$ by weight of cement for fear of flash set and loss of long term strength. However, there are other reports that the $CaCl_2$ can be used in much higher quantity where the temperature is very low, without any fear of retrogression of strength or corrosion of reinforcement. But *the use $CaCl_2$ may cause some increase in volume change, greater tendency for alkali aggregate reaction and lower resistance to sulphate attack.*

It is reported that in Russia the use of chlorides are extensively employed for concreting at subzero temperature. They have tried large additions of 20% of $CaCl_2$ by weight of mixing water in the construction of Gorky Hydro Power Projects. But the Russian practice is to use the combination of $CaCl_2$ and NaCl to offset the effect of low temperature and also to give optimum benefit to the concrete at plastic stage and hardened stage.

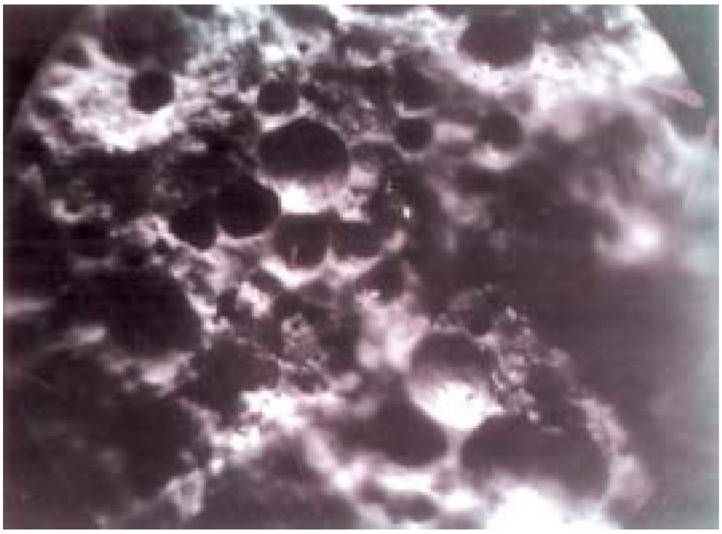
It is commonly believed that NaCl reduces the 28 days strength of concrete by 12% though it accelerates the early strength. It has never been accepted as one of the standard accelerating agent. In view of the fact that the Russian practice is to use high concentration of NaCl or NaCl in combination with $CaCl_2$, it is worth discussing to some detail in this regard.

All existing methods of winter concreting namely thermos, steam heating, electric heating or their combined application are based on maintaining positive temperatures during the early age of concrete, till such a time it develops minimum strength at which freezing has no detrimental effect. The addition of NaCl and $CaCl_2$ makes it possible to regulate the freezing point of water in concrete and help to promote the continued hydration. $CaCl_2$ forms high hydro-complexes particularly with C_3A, to make it active for accelerating the hydration. As the temperature goes down, the rate of chemical reaction becomes much slower. If NaCl alone is added, almost the same condition as stated above will result except that it exhibits a better plasticising properties. But it is found that if a combination of $CaCl_2$ and NaCl is used, the concrete will show quicker hardening property, a much higher frost resistance property and also better placeability characteristics.

The suggested quantities of the salt mixture is shown in Table 12.13.

It was seen that very little corrosion has taken place in the reinforcing bars even with large addition of salts, when the concrete is compacted well. The corrosion problems become serious only in the case of insufficient compaction and lack of cover for reinforcing steel.

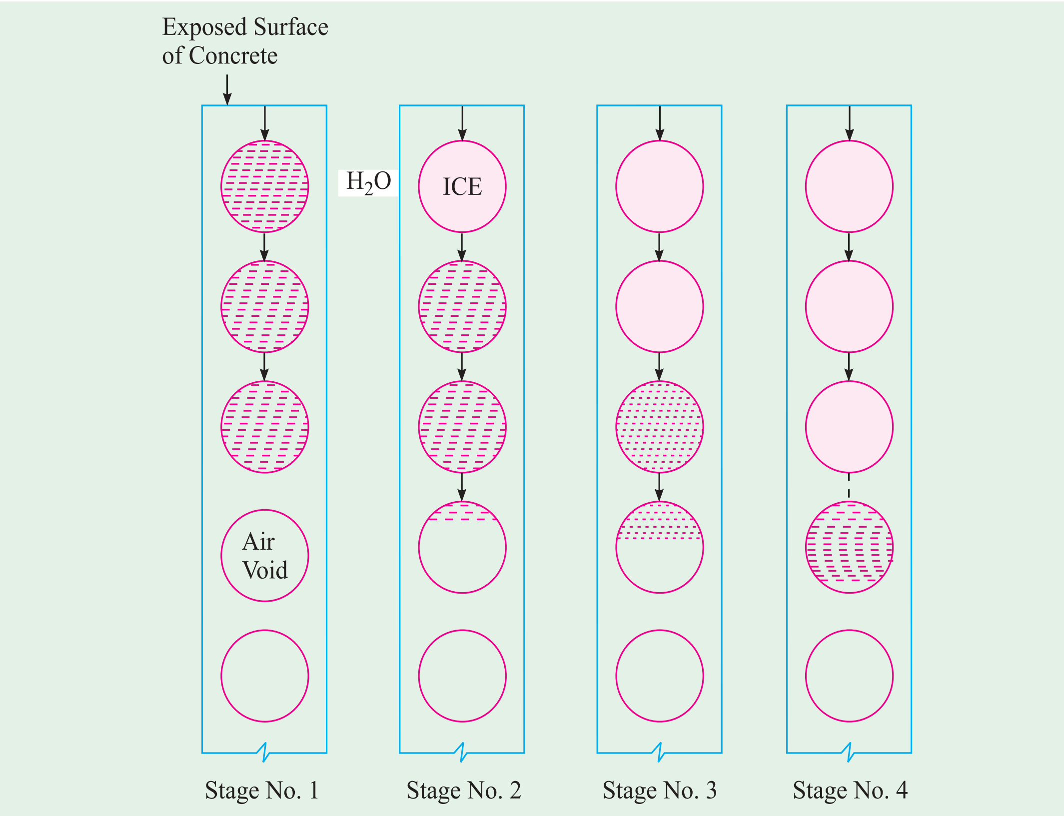
Till recently concrete technologists were of the view that durability of concrete is dependant upon the compressive strength only. But with the innovation of air-entrained concrete, the opinion got reversed. It is now known that weaker concrete with air-entrainment is more durable under freezing condition than that of strong concrete without air-entrainment. The superiority of air-entrained concrete over plain concrete is shown in fig. 5.18. In general the entrainment of air will increase durability to the extent of about 3 to 7 times of that of ordinary concrete.



Photograph (25 times magnification) showing the presence of air-entrainment in hardened concrete, generated by Ritha powder as air-entraining admixture. *(source M.E. Dissertation work of M.S. Shetty —1964)*

Table 12.13. Addition of the appropriate quantity of $CaCl_2$ and NaCl in winter concreting

Open Air temperature	*Percentage contents of salts per degree fall of temperature by weight of mixing water*	*Quantity of $CaCl_2$ and NaCl by weight of mixing water*
From 0°C to –5°C	*1.3*	*3% $CaCl_2$ + 3.5% NaCl or 6.5% NaCl or 6.5 $CaCl_2$*
From – 6°C to –10°C	*1.2*	*4% $CaCl_2$ + 8% NaCl or 12% NaCl or 6% $CaCl_2$ + 6% NaCl*
From –11°C to –15°C	*1.1*	*10% $CaCl_2$ + 6% NaCl or 8% $CaCl_2$ + 8% NaCl*
From –16°C to –20°C	*1.0*	*15% $CaCl_2$ + 5% NaCl or 10% $CaCl_2$ + 10% NaCl*



Modification of pore structure caused by air-entrainment is believed to be responsible for the marked improvement in resistance to frost attack. The hypothesis as to how the air-entrainment enhances the resistance of concrete to freezing and thawing is shown in Fig. 12.11. It is assumed that the concrete member is wet and quick freezing occurs. The surface is immediately sealed due to the freezing of water at the surface and when freezing continues ice crystals are formed inside the voids. Since the volume of ice is 10% more than that of water, only 90% of water in the voids will turn into ice. The excess of water is forced out through the capillary channels into the adjoining lower air-voids, and the pressure is relieved. Stage No. 3 and 4 show progressive freezing and relief of pressure in the interior of concrete. If sufficient water free voids are available, pressure build up will not occur and the eventual disruption of the concrete will not take place.

The reduction in water cement ratio that might be permitted by the use of air entrainment in concrete may also account for the greater resistance to freezing and thawing action.

From the above discussion, it can be seen that the use of air-entraining admixtures in concrete is positively useful in increasing the durability of concrete in very cold regions.

To summerise, the following general precautions may be observed in cold weather concreting:

(a) Preparation for concreting in cold weather may be completed well in advance of severe conditions. Wind breakers shall be erected to shield the mixing and batching plants; tarpaulins, plastic sheets and other covering and insulating materials may be made available at the site and the steam generating plant or other necessary equipments may be installed and checked for correct functioning.

(b) The concrete shall be delivered to the point of placing at not less than 5°C. It is necessary to place the concrete quickly and cover the top of the concrete with an insulating material.

(c) Before any concrete is placed, all ice, snow and frost shall be completely removed and the temperature be raised as close to the temperature of fresh concrete to be placed thereon, as practicable. No concrete shall be placed on a frozen subgrade or on that contains frozen materials. Where concrete is to be placed over permanently frozen ground, subgrade materials may be thawed deep enough to ensure that it will not freeze back up to the concrete or it may be covered with a sufficient depth of dry granular material.

(d) During cold weather, all concrete surfaces shall be covered as soon as the concrete has been placed in order to preserve the heat and to help prevent freezing. Clean straw bankets about 50 mm thick, sacks, tarpaulins, expanded polystyrene, plastic sheets and waterproof paper can all be used in conjunction with air gap as an insulation. If possible insulating material shall be placed against any formwork before concreting and the same can be used as protection after the formwork has been stripped.

(e) Heated enclosures are commonly used for protecting concrete when air temperatures are near or below freezing. Enclosures may be heated by steam, steam pipes and other types of heaters. Enclosures may be made of wood, canvas, fibre insulation board, plywood etc.

(*f*) *During placement of unformed concrete, tarpaulins or other readily movable coverings supported on frame work shall follow closely the placing of concrete, so that only a small area of finished slab is exposed to outside air at any time.*

Such tarpaulins shall be used so that hot air can be circulated freely on the slab. Layers of insulating materials placed directly on the concrete are also effective in protecting the concrete.

(*g*) *During periods of freezing or near-freezing conditions, water curing is not necessary as the loss of moisture from the concrete by evaporation will be greatly reduced in cold air conditions.*

(*h*) *For concrete cast in insulated formwork it is only necessary to cover the member completely in order to retain sufficient water for the hydration of cement. On removal of the formwork and insulation, the member shall immediately be covered with plastic sheet or tarpaulins, properly lapped and made air-tight. On no account should such concrete, just released from insulated formwork, be saturated with cold water. When protective measures are to be discontinued, the surface temperature of the concrete shall be gradually adjusted to the air temperature.*

(*i*) *Low pressure wet steam provides the best means of both heating the enclosures and for moist curing the concrete. Early curing with liquid membrane forming compounds may be followed on concrete surface with heated enclosures. It is better to cure first with steam curing during the initial period of protection and then apply a curing compound after the protection is removed and the air temperature is above freezing.*

(*j*) *Forms shall not be released until the concrete has achieved a strength of at least twice the stress to which the concrete may be subjected at the time of removal of formwork. In the normal circumstances where ambient temperature does not fall below 15°C and where OPC cement is used and adequate curing is done, the striking period as shown in Table.12.14 is a satisfactory guideline. For other cements and lower temperature, the stripping time recommended in Table 12.14. may be suitably modified.*

(*k*) *In cold weather protection offered by formworks other than of steel, is often of greater importance. With suitable insulations, the forms, including those of steel, in many cases will provide adequate protection without supplementary heating. Therefore, it is often advantageous not to remove forms until the end of a minimum period of protection or even later.*

(*l*) *During cold weather, inspection personnel should keep a record of the date, time, outside air temperature, temperature of concrete at the time of placing and general weather (calm, windy, clear, cloudy, etc.). The record should also include the temperature at several points within the enclosure and on the concrete surface, corners and edges in sufficient number to show the highest and lowest temperatures of the concrete.*

Thermometers should be inserted in those parts of the concrete where maximum stresses will appear at removal of forms.

To control the hardening process, it is necessary to measure the temperature of concrete at placing, at the time of applying the protection and three times each day until resistance to freezing has been obtained.

Concreting in winter times, requires that the quality control of concrete is carried with great care. The test results should be used for fixing the time of removal of insulations and formwork. Control test specimens should also be cast and cured in a standard way to indicate the potential strength properties of the mix.

In addition to the control test cubes, it is necessary to cast a number of specimens, the curing conditions of which are maintained in the same way as that of the actual structure. These specimens are tested before stripping the formwork to indicate the strength development of the actual structures.

Hot Weather Concreting

Normal methods of mixing, transporting and placing of concrete discussed in Chapter No. 6, will not be exactly applicable to extreme weather conditions. Special problems are faced in making, placing and compacting concrete in hot weather and in cold weather. In India most of the areas are in tropical regions and some areas in extremely cold weather regions. Therefore, it is necessary for us to be aware of the special problems faced in making concrete structures in both hot weather and cold weather regions. The procedure of concreting in such a situation is set out in IS 7861 (Part I) ans IS 7861 (Part II).

Table No. 12.14.

Recommended Minimum Time Limits for stripping Formwork to Normal Structural Concrete when the Member is carrying only its own Weight as per IS 456 of 2000.

	Type of Formwork	Minimum Period Before Striking Formwork
(1)	Vertical formwork to Columns, Walls, Beam	16 – 24 hours
(2)	Soffit formwork to slabs	
	(Props to be refixed immediately	
	after removal of formwork)	3 days
(3)	Soffit formwork to Beams	
	(Props to be refixed immediately	
	after removal of formwork)	7 days
(4)	Props to Slabs	
	(a) Spanning up to 4.5 m	7 days
	(b) Spanning over 4.5 m	14 days
(5)	Props to Beams and Arches	
	(a) Spanning up to 6 m	14 days
	(b) Spanning over 6 m	21 days

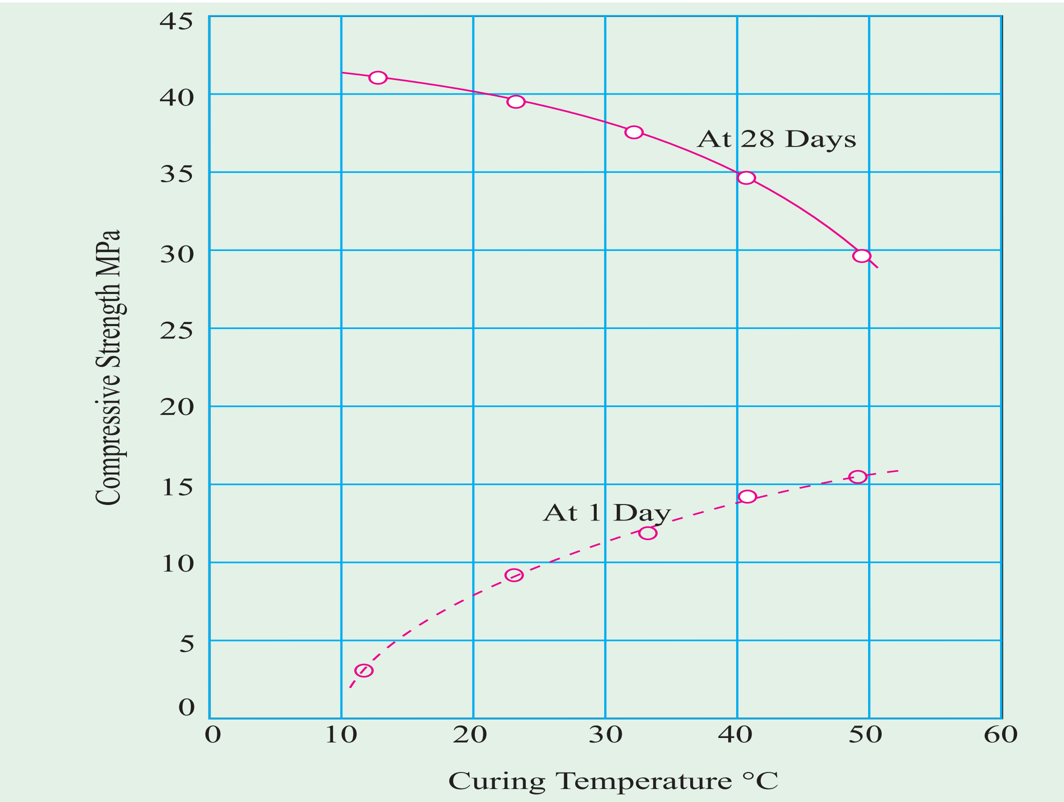
It is difficult to define what is hot weather condition. However, just for convenience it is regarded that the concrete placed at an atmospheric temperature above 40°C is considered as hot weather concreting. At this temperature certain special problems are usually encountered. They are:-

(a) Rapid rate of hydration of cement, quick setting and early stiffening.
(b) Rapid evaporation of mixing water.
(c) Greater plastic shrinkage.
(d) Less time for finishing.
(e) Reduced relative humidity.
(f) Absorption of water from the concrete by the subgrade and formwork.
(g) Difficulty in continuous and uninterrupted curing.
(h) Difficulty in incorporation of air entrainment.

The effect of the above situations on the production of quality concrete is required to be fully identified and care must be taken to make the concrete strong and durable.

(a) Rapid rate of hydration: It is brought out in chapter one that the rate of hydration depends upon the temperature. At high ambient temperature the setting time of the cement is reduced considerably. It must be remembered that the setting time as discussed earlier pertains to a temperature range of 27 ± 2°C. At a higher temperature, naturally setting time will be reduced with the result that early stiffening takes place which makes the concrete lose the workability. Partially set concrete may reduce the bond between the successive lifts more than anticipated.

This is also pointed out that the quality of gel and gel structure formed at higher temperature in the early period of hydration is of poor quality. Concrete placed in hot weather no doubt develops high early strength, but it will suffer certain loss of long term strength. Fig. 12.12 shows the effect of curing temperature on one day and 28 days compressive strength.



(b) Rapid evaporation of mixing water: *Hot weather condition is normally associated with relatively lower relative humidity. On account of this, the water mixed with the concrete to give the required workability will be lost. The concrete turns to be unworkable with the result, inordinate amount of compacting effort is required to compact concrete fully. If this is not forthcoming, large voids will remain in the concrete, which are responsible for all the ills in concrete.*

(c) Greater plastic shrinkage: *The rate of evaporation of water from the surface of the concrete will be faster than the rate of movement of water from the interior to the surface. As a result, a moisture gradient will be set up which results in surface cracks known as plastic shrinkage cracks. The plastic shrinkage is more pronounced, in case of floors, roads and pavement concrete where the surface area exposed is more when compared to depth.*

(d) Finishing time: *In hot weather, finishing must be done as early as possible after placing. In certain cases if early finishing is not possible due to faster stiffening and quicker evaporation of water, the quality of finishing will be of poor standard. Usually extra fresh mortar is required to be used for finishing which results in poor performance.*

(e) Absorption of water by subgrade: *In hot weather regions the subgrade is normally dry and absorptive. The subgrade or surface of formwork is required to be wetted before placing the concrete. If this is not done carefully with proper considerations, the water in the concrete may be lost by absorption by the surface in contact with concrete making the contact zone poorer in quality.*

(f) Curing: *In hot weather comparatively early curing becomes necessary, particularly where 53 grade cement is used. Hot weather requires a continuous effort for curing. If there is any lapse, the concrete surface dries up fast and interrupts the continuous hydration. Once the interruption takes place, the subsequence wetting does not fully contribute to the development of full strength. No doubt, continuous curing in hot weather entails greater cost of water and labour.*

(g) Air-Entrained: *Air-entrained concrete is rarely used in hot weather conditions. However, if used from the consideration of better workability, greater proportion of air-entraining agents are required to compensate for the loss of air-entrainment due to higher temperature. The norms given for standard temperature with respect to the per cent air-entrainment cannot be taken as guide.*

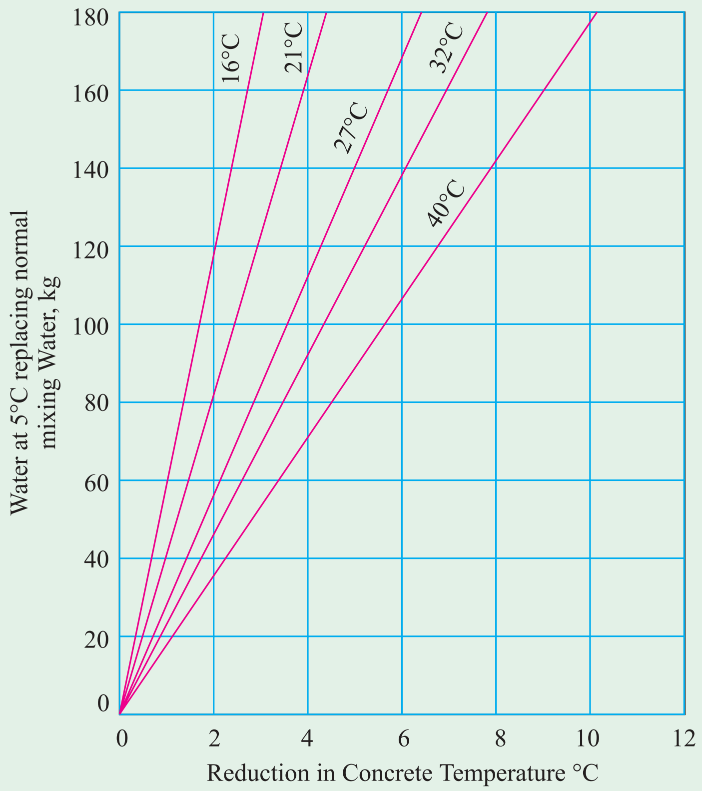
(h) Ready Mixed Concrete: *Conveyance of concrete over long distance in case of Ready Mixed Concrete is likely to pose a serious problem on account of faster loss of slump. The transit mixer drum may be covered with insulating material.*

Precautions Taken

To improve the quality of concrete it is necessary that the temperature of the concrete should be as low as possible. To obtain such a condition attempts should be made to keep the temperature of the ingredients of concrete as low as possible. The following precautions could be taken.

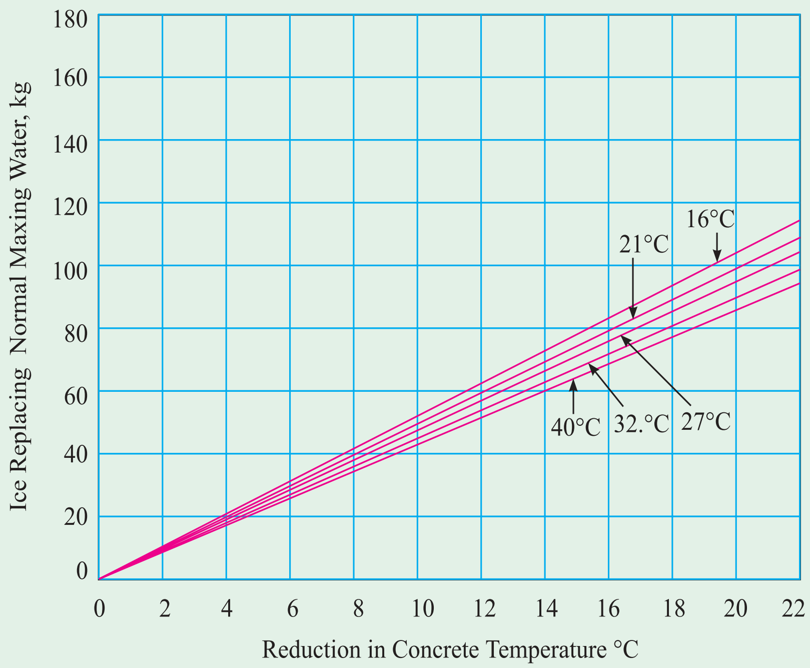
Aggregates

Aggregates should be stockpiled in shade. Sprinkling of water over the stockpile and the evaporation of this water will result in lowering the temperature of the aggregate. If possible heavy spraying of cold air over the aggregate just before it is batched is desirable.



Water

The temperature of the mixing water has the greatest effect on the temperature of concrete. In practice the temperature of water is easier to control than that of the other



ingredients. Even though the weight of water used is lesser than the other ingredients, the use of cold mixing water will effect good reduction of concrete temperature. Fig. 12.13 shows the effect of cold water at 5°C on concrete temperature.[12.15]

If the ambient temperature is very high, the use of cooled water may not be fully effective. Use of ice may be made as a part of mixing water. Crushed ice can be incorporated directly into the mixer. It shall be ensured that ice crystals should be completely melted by the time mixing is completed. Fig. 12.14 shows the possible reduction in concrete temperature by the substitution of ice as part of mixing water.

Production and Delivery

Temperature of aggregates, water and cement shall be maintained at the lowest practical level so that the temperature of concrete is below 40°C at the time of placement. Some works demand the maximum placement temperature to be much less than 40°C. The concrete is mixed to the minimum required time. When ice is used it must be mixed to such an extent that all the ice gets melted. The concrete mixer must be positioned as close to the final place of deposition to reduce the length of delivery to the minimum.

Reinforcement, formwork and subgrade should be sprinkled with cooled water just prior to placing the concrete. Reinforcement projecting out of the concrete should be covered or kept cooled by any practical means. More number of masons are required to be employed to finish the concrete at the same rate as the placing of concrete.

The concrete is placed in comparatively thin layers so that the time interval between the successive lifts is reduced. It should be noted that the layer should not be so thin as to get dried up very early. Concrete on finishing must be covered effectively to prevent loss of moisture from the concrete. Covering the top of concrete by wet gunny bag or hessain cloth is desirable. Precautions should be taken to squeeze the gunny bag fully so that water does not drip into the fresh concrete. Covering of finished floor by wet gunny bags may not be very suitable for flooring where surface finish is of primary importance. Wet curing must be commenced at the earliest possible time. If the concrete is effectively moist covered, the ponding may be commenced after 24 hours in case of floor, roof or pavements.

It must be remembered that concrete should not be allowed to become dry. At the same time, application of water should not be commenced before the final setting of cement also. Appearance of some dry particles on the surface of concrete does not mean the final setting has taken place. As said above, the best practice is to cover the concrete with moist covering for about 24 hours and then apply water by spraying, or by ponding., When the day temperature is very high, it is better to do the concreting operation during the evening time, leaving the young concrete to undergo early hydration during relatively cooler night. A temperature record of the air, the concrete that comes from the mixer, the concrete placed and the temperature of the concrete during the early period of hydration will be of help.

Pre-Packed Concrete

Generally concrete is made by mixing all the ingredients in a mixer. Then the mixed concrete is placed in a formwork. Concrete member may also be constructed by first placing the coarse aggregates in the mould and then grouted with a specially prepared mortar. This process can be employed for both plain concrete or reinforced concrete. This method of concrete construction is employed where the reinforcement is very complicated or where certain arrangements like pipes, conduits, openings and such other arrangements are required to be incorporated in the concrete. The normal method of concreting may disturb the *preplanned fitments. This method is also employed in mass concreting, in bridge abutments and piers, well steining etc. This is one of the practicable methods of concreting under water, wherein aggregates are placed in water and subsequently mortar is grouted in, to displace the water.*

There are many proprietary methods in vogue. They are called, intrusion grouting, grouted concrete, pre-packed concrete colcrete process etc.

The advantages of pre-packed concrete are that it undergoes little drying shrinkage. As the aggregates are in point contact with each other and the grout only fills the voids, the concrete as a whole does not undergo much drying shrinkage. Vibrating the aggregate before grouting makes the quality of concrete better. Both single sized or graded aggregates can be used without much difficulty.

The essential requirement is that the grout should fill the voids fully and develop full bond with the aggregate. The right extent of pressure is applied so that the grout, just fills the aggregate, but does not disturb or lift up the aggregate. Sometimes, the workability agent or expanding admixture such as aluminium powder are also added. The grouting pressure is changed depending upon the depth at which the injection of grout is done. The grout mixture should be sufficiently fluid for pumping. The fairly thick grout, well mixed in high speed machine, which has got a pumpable consistancy is referred to as colloidal grout. Such grout can travel uniformly into the aggregate voids. The fluidity of grout and keeping its identity while pushing the water out in case of underwater grouting, is the property to be looked for in the grout.

In the Colcrete process, the mortar grout is made in a special high speed, double drum type of mixer in which cement and water are mixed in one drum and the sand is added and mixed with the cement slurry in the second drum. The high speed action of the mixers produce a very intimate mix, which is more fluid than a normal grout and is comparatively immiscible with water. The ratio of the grout may range from 1 : $1^1/_4$ to 1 : 4, the rich being used for underwater work or for grouting prestressed concrete members.

Grouting is done by there methods:

(a) Grout mixture is poured on the packed aggregate and allowed to penetrate downwards. This method is normally adopted for thin concrete members, such as, road pavement slabs and floor slabs. If the depth of the aggregate bed is thicker, it cannot be assumed that the grout has completely traversed through the entire thickness.

(b) The mould is partially filled up with grout over which the aggregates are deposited. Vibration at this stage would help distributing sinking and smearing of paste over the aggregate.

(c) The grout is pumped into the prepacked aggregate at the bottom of the mould. The injection pipe full of perforations, one or more in number distribute the grout into the concrete. This injection pipe is extracted upwards by a certain distance and again the grout mixture is sent. In this way the entire depth of the concrete member is concreted. It should be noted that less pressure is to be used to inject the grout into the top layers of concrete.

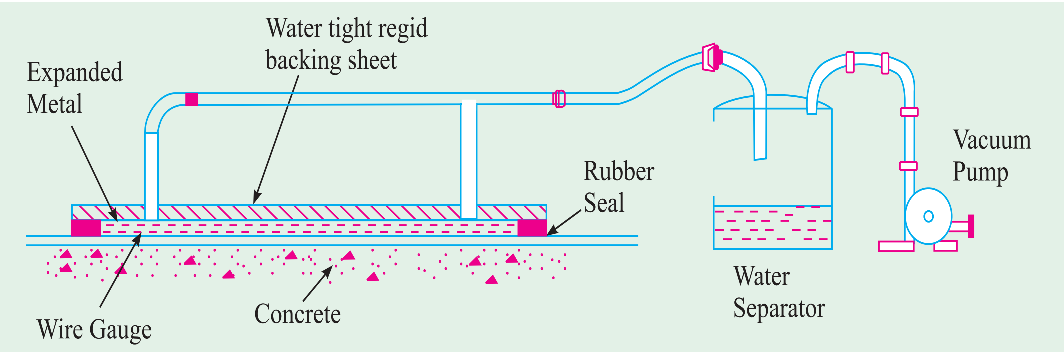
Alternatively perforated horizontal pipes are embedded in the prepacked aggregate at different levels. Grout may be sent through these pipes. Finally, it is possible to withdraw the pipe or the pipe may be left in the concrete.

Sometimes, if the grout is forced at a high pressure without any regard to the over burden pressure of packed aggregate, the pressure may cause dislodging of the aggregate with the result that excess of grout may be consumed. Therefore, the pressure at which the intrusion of grouting is to be used, will be decided carefully. This aspect needs particular care when grouting near the top surface. Sometimes, a plywood covering is fixed to the top to obviate the floating effect of the aggregate in the event of high pressure and low viscosity of the grout.

Vacuum Concrete

It has been amply brought out in the earlier discussion that high water/cement ratio is harmful to the overall quality of concrete, whereas low water/cement ratio does not give enough workability for concrete to be compacted hundred per cent. Generally, higher workability and higher strength or very low workability and higher strength do not go hand in hand. Vacuum process of concreting enables to meet this conflicting demand. This process helps a high workable concrete to get high strength.

In this process, excess water used for higher workability, not required for hydration, and harmful in many ways to the hardened concrete is withdrawn by means of vacuum pump, subsequent to the placing of the concrete. The process when properly applied, produces concrete of quality. It also permits removal of formwork at an early age to be used in other repetitive work.



The equipment is shown in Figure 12.15. It essentially consists of a vacuum pump, water separator and filtering mat. The filtering consists of a backing piece with a rubber seal all round the periphery. A sheet of expanded metal and then a sheet of wire gauge also forms part of the filtering mat. The top of the suction mat is connected to the vacuum pump. When the vacuum pump operates, suction is created within the boundary of the suction mat and the excess of water is sucked from the concrete through the fine wire gauge or muslin cloth. At least one face of the concrete must be open to the atmosphere to create difference of pressure. The contraction of concrete caused by loss of water must be vibrated.

The vacuum processing can be carried out either from the top surface or from the side surface. There will be only nominal difference in the efficiency of top processing or side processing. It has been seen that the size of the mat should not be less than 90 cm x 60 cm. Smaller mat was not found to be effective.

Rate of Extraction of Water

The rate of extraction of water is dependent upon the workability of mix, maximum size of aggregate, proportion of fines and aggregate cement ratio. In general, the following general tendencies are observed:

(*a*) The amount of water which may be withdrawn is governed by the initial workability or the amount of free water. A great reduction in the water/cement ratio can, therefore, be obtained with higher initial water/cement ratio.

(*b*) If the initial water / cement ratio is kept the same the amount of water which can be extracted is increased by increasing the maximum aggregate size or reducing the amount of fines in the mix.

(*c*) Although the depression of the water/cement ratio is less, the lower the initial water/ cement ratio, the final water/cement ratio is also less, the lower the initial value.

(*d*) The reduction in the water/cement ratio is very slightly less with mixes leaner than 6 to 1, but little advantage is gained with mixes richer than this.

(*e*) The greater the depth of concrete processed the smaller is the depression of the average water/cement ratio.

(*f*) The ability of the concrete to stand up immediately after processing is improved if a fair amount of fine material is present, if the maximum aggregate size is restricted to 19 mm and if a continuous grading is employed.

(*g*) Little advantage is gained by prolonging the period of treatment beyond 15 to 20 minutes and a period of 30 minutes is the maximum that should be used.

It is found that there is a general tendency for the mix to be richer in cement near the processing face. This may be due to the fact that along with water, some cement gets sucked and deposited near the surface. It is also found that the water/cement ratio near the surface will be lower in value, anything from 0.16 to 0.30, than the original water/cement ratio. Because of the above reasons the vacuum processed concrete will not be of uniform strength. The simultaneous vibrations or the subsequent vibrations will reduce this shortcoming to some extent and also increase the strength of the concrete. If vibration is not done, the continuous capillary channels may not get disturbed and the strength would not be improved in relation to decreased water/cement ratio. Table 12.15 shows the comparisons of strength of processed and unprocessed cubes.

Table 12.15. Comparison of Strength of Processed and unprocessed cubes having the same water/cement ratio

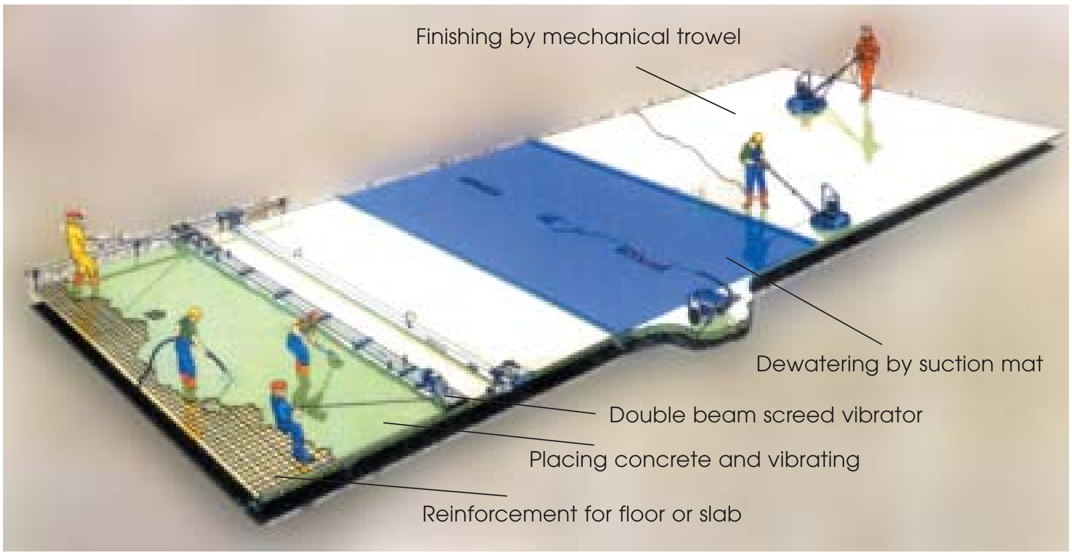
Initial water/cement ratio of processed cubes	0.74	0.71	0.65	0.60
Average final water/cement ratio of processed cubes	0.68	0.59	0.57	0.55
Strength of unprocessed cubes of the same water/cement ratio as the initial water/ cement ratio of the processed cubes MPa	18.0	15.3	19.1	30.1
Strength of fully vibrated processed cubes and increase of strength due to processing (per cent) : MPa	23.3 30	22.6 48	27.5 43	33.4 11
Strength of unprocessed cubes of the same water/cement ratio as the average final water/ cement ratio of the processed cubes and in-				

crease of strength due to the reduction in water/cement ratio				
MPa	*24.9*	*33.7*	*36.5*	*39.4*
(per cent):	*38*	*74*	*91*	*30*
Increase in strength due to the reduction of water/cement ratio according to Road Note No. 4				
(per cent):	*20*	*44*	*27*	*16*

Vacuum Dewatered Concrete

It has been stressed time and again that adoption of low water cement ratio will give alround improvement in the quality of concrete, but satisfactory workability is the essential requirement for placing concrete. One solution to this problem is the use of superplasticizer and the other solution is the adoption of vacuum dewatering of concrete. For the last about ten years vacuum dewatering technique is fairly widely used in the construction of factory floors. The techniques have been adopted in a big way for the construction of DCM Daewoo Motors at Delhi, Whirpool factory construction near Pune, Tata Cummins at Jamshedpur, Fiat Ltd. etc. amongst hundreds of other factory floors.

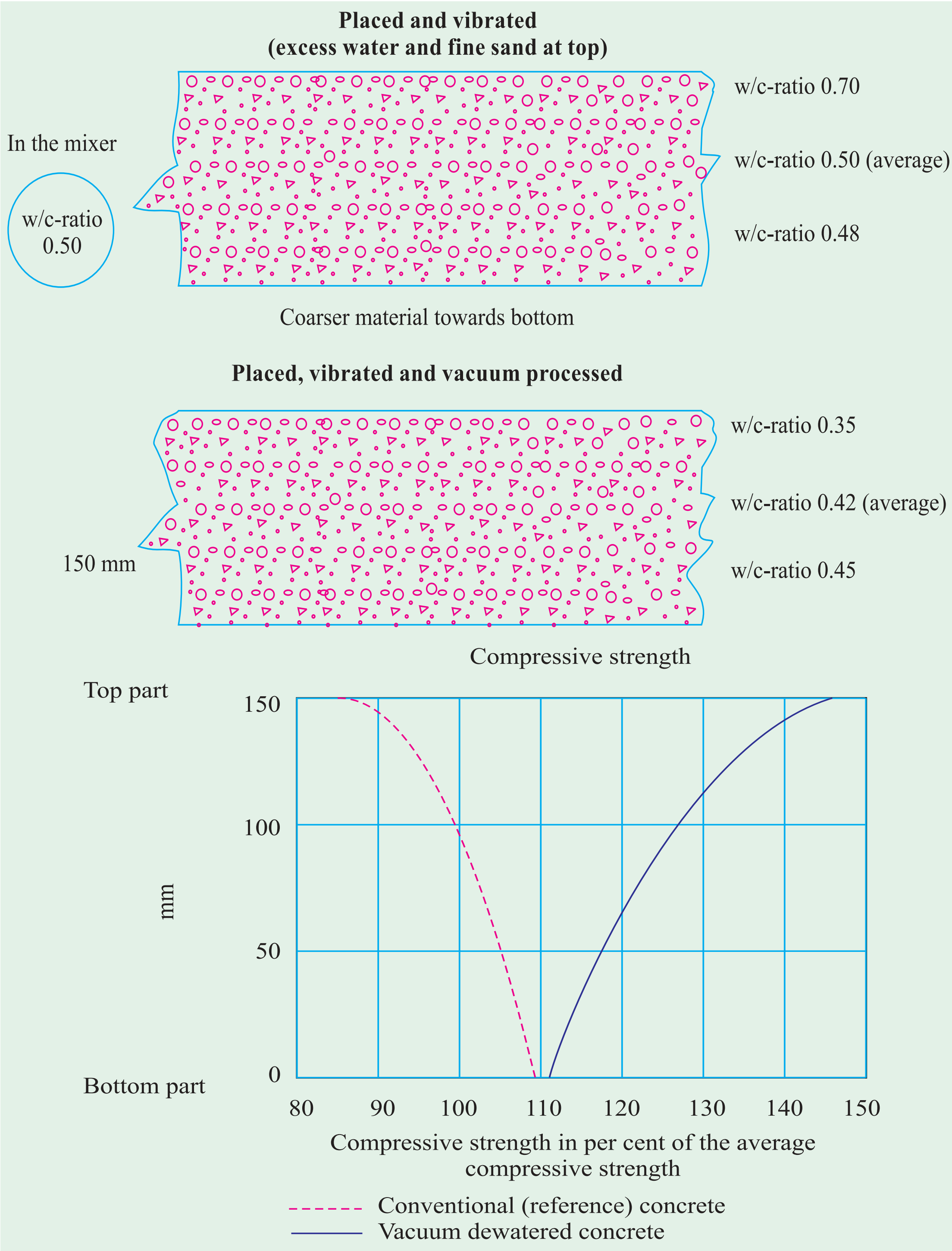
The process is equipment oriented. It requires formwork in the form of channels, internal vibrators, double beam screed board vibrator for the full width, bull float, filter pads, vacuum pump, disc floater, and power trowel.



Schematic sketch showing method of vacuum dewatering system.

First, concrete with relatively higher w/c to facilitate full compaction with needle vibrator, is poured. Then the concrete is further compacted by double beam screed vibrator. This makes the surface smooth. Filter mat is placed and it is pressed on all the four sides and effectively sealed. Within about 30 minutes, the vacuum pump is started which sucks the unwanted water, what could be termed as "water of workability" from the concrete and is thrown out.

Vacuum pump is run for about 20 to 30 minutes depending upon the thickness of concrete floor. Vacuum dewatered concrete becomes stiff and walkable. The top surface may undergo a depression of about 3 per cent, with loss of about 20% of original water. Then the concrete is skimfloated and further power trowled and finished. Often surface hardners are used in



conjunction with dewatering process. After vacuum dewatering, it gives the ideal condition for application of surface hardners in powder form. With the combined effect of vacuum dewatering and application of floor hardners a very good abrasion resistant factory floor may be constructed. The application of disc float and power trowelling may act like revibration of concrete to eliminate or segment the continuous capillaries or channels formed in the suction of water. As the effective w/c is comparatively lower at the top surface, the quality of concrete with respect to strength and abrasion resistance will be better. Fig. 12.16 and Fig. 12.17 show the result of the test carried out at the Cement and Concrete Institute, Stockholm, Sweeden, who is the supplier of vacuum dewatering equipment by trade name "Tremix".

The Gunite or Shotcrete

Gunite can be defined as mortar conveyed through a hose and pneumatically projected at a high velocity on to a surface. Recently the method has been further developed by the introduction of small sized coarse aggregate into the mix deposited to obtain considerably greater thickness in one operation and also to make the process economical by reducing the cement content. Normally fresh material with zero slump can support itself without sagging or peeling off. The force of the jet impacting on the surface compact the material. Sometimes use of set accelerators to assist overhead placing is practised. The newly developed "Redi-set cement" can also be used for shotcreting process.

There is not much difference between guniting and shotcreting. Gunite was first used in the early 1900 and this process is mostly used for pneumatical application of mortar of less thickness, whereas shotcrete is a recent development on the similar principle of guniting for achieving greater thickness with small coarse aggregates.

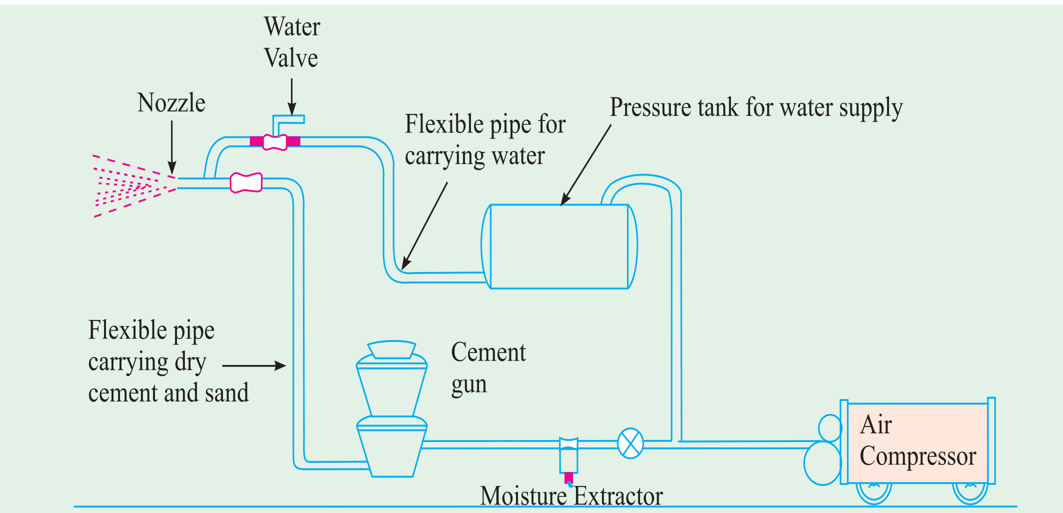
There are two different processes in use, namely the "Wet-mix" process and the "dry-mix" process. The dry mix process is more successful and generally used.

Dry-mix Process

The dry mix process consists of a number of stages and calls for some specialised plant. A typical small plant set-up is shown in Fig. 12.18.

The stages involved in the dry mix process is given below:

(a) Cement and sand are thoroughly mixed.



(*b*) *The cement/sand mixture is fed into a special air-pressurised mechanical feeder termed as 'gun'.*

(*c*) *The mixture is metered into the delivery hose by a feed wheel or distributor within the gun.*

(*d*) *This material is carried by compressed air through the delivery hose to a special nozzle. The nozzle is fitted inside with a perforated manifold through which water is sprayed under pressure and intimately mixed with the sand/cement jet.*

(*e*) *The wet mortar is jetted from the nozzle at high velocity onto the surface to be gunited.*

The Wet-mix Process

In the wet-mix process the concrete is mixed with water as for ordinary concrete before conveying through the delivery pipe line to the nozzle, at which point it is jetted by compressed air, onto the work in the same way, as that of dry mix process.

The wet-mix process has been generally discarded in favour of the dry-mix process, owing to the greater success of the latter.

The dry-mix methods makes use of high velocity or low velocity system. The high velocity gunite is produced by using a small nozzle and a high air pressure to produce a high nozzle velocity of about 90 to 120 metres per second. This results in exceptional good compaction. The lower velocity gunite is produced using large diameter hose for large output. The compaction will not be very high.

Advantages of Wet and Dry Process

Some of the advantages and disadvantages of the wet and dry processes is discussed below. Although it is possible to obtain more accurate control of the water/cement ratio with the wet process the fact that this ratio can be kept very low with the dry process largely overcomes the objection of the lack of accurate control. The difficulty of pumping light-weight aggregate concrete makes the dry process more suitable when this type of aggregate is used. The dry process on the other hand, is very sensitive to the water content of the sand, too wet a sand causes difficulties through blockade of the delivery pipeline, a difficulty which does not arise with the wet process. The lower water/cement ratio obtained with the dry process probably accounts for the lesser creep and greater durability of concrete produced in this way compared with concrete deposited by the wet process, but air-entraining agents can be use to improve the durability of concrete deposited by the latter means. Admixtures generally can be used more easily with the wet process except for accelerators. Pockets of lean mix and of rebound can occur with the dry process. It is necessary for the nozzelman to have an area where he can dump unsatisfactory shotcrete obtained when he is adjusting the water supply or when he is having trouble with the equipment. These troubles and the dust hazard are less with the wet process, but wet process does not normally give such a dense concrete as the dry process. Work can be continued in more windly weather with the wet process than with the dry process, Owing to the high capacities obtainable with concrete pumps, a higher rate of laying of concrete can probably be achieved in the wet process than with the dry process.

General Use of Shotcrete

The high cost of shotcrete limits its application to certain special circumstances where considerable savings are accrued and where its peculiar adaptability and technical advantages render it more suitable than conventional placing methods. Shuttering and formwork need be erected only on one side of the work and it does not have to be so strong as the shuttering for poured concrete. The saving in shuttering costs makes it particularly applicable for thin sections and although there is no technical reason why unlimited thicknesses cannot be deposited in horizontal and vertical work. The cost generally limits it to a thickness of 200 mm. The possible rate of application is low particularly with the dry process. Normally not more than 80 mm thickness can be deposited in overhead work in one day and the possibility of this will depend on the use of a suitable accelerator.

The fact that it can be conveyed over a considerable distance in a small diameter pipe makes this process suitable for sites where access is difficult. The other method that can be adopted in such situation is pumping techniques. It cannot, however, be used in confined spaces as the expansion of the compressed air will cause air turbulences which make accurate placing difficult. Sufficient room is required to hold the nozzle, say 1 m from the work. To accommodate a large radius bend of the delivery hose also requires considerable space. It will bond extremely well to the existing concrete, to masonry and to exposed rock. Suitably prepared steel surface also can be covered with gunited concrete.

The quality of the finished product is liable to be variable and particularly in the dry process the quality is very much dependent on the skill of the nozzleman. Quality control is very difficult and it is not possible to cast reliable test cubes or cylinders. The only way of testing the strength of the work deposited is by taking drill cores or by making a parallel slab by guniting with identical mix. It is difficult to remove rebound material as this tends to collect inside corners and behind reinforcing bars or other obstructions. Pockets of rebound formed as above and due to lack of skill of the nozzleman form weak and porous patches in the finished work. The proportions of the concrete deposited are affected by variation of the water supply and variations in the amount of rebound caused by this and other reasons. Too low an air pressure and surges in the air and water supply also can cause patches of relatively dry material. Defects of this type can result in porous concrete and also contribute to high permeability.

The amount of rebound greatly affects the economics of the shotcrete process as it has all to be discarded and involves labour in collection and disposal. The area surrounding the work will be heavily coated with mortar particularly in windy weather.

It is difficult to obtain a satisfactory surface finish with Shotcrete, particularly with the dry process, because it is almost impossible to trowel due to the low water content. Often it becomes necessary to apply a screed of about 2 cm over the gunited surface.

The application of the shotcrete process is limited to exceptional areas and that too when good nozzleman having the required skill are available. The nozzleman's job is a very strenuous one. It is, therefore, necessary to have relief nozzelmen and for high rates of application some mechanical means of holding the nozzle is required.

The maximum rate of deposition is about 15 m^3. hr for the dry process but this can be exceeded with the wet process.

The low water/cement ratio, the thinness of the section deposited and the fact that normally only one side of the concrete is covered, necessitates careful attention to curing more than with normal concrete.

The normal specifications with respect to cement, aggregate and water, also apply for shotcrete but it is desirable that the aggregate should be rather harder than normal to allow for attrition due to the action of the process. Any cement, provided it does not set too quickly, can be used.

Admixtures can be used in shotcrete to produce the same effects as in ordinary concrete. They should be added to the water in the dry process, but some difficulty may be experienced in obtaining correct proportioning due to variations in the rate of feed of the dry materials. On account of the difficulty of precise control, admixtures whose effects are very sensitive to the proportion added should not be used. Great caution should be exercised in using accelerators in the wet process but accelerators causing an initial set within 30 seconds are used in the dry process. This enable the process to be used in very wet conditions and for sealing leakages. But deficulties have sometime been experienced in obtaining adhesion of the concrete to very set surfaces and these very rapid accelerators are very expensive.

There is not much information on the drying shrinkage and creep of shotcrete. The drying shrinkage will depend on the water content and may, therefore, be expected to be fairly low for the dry process. The creep of dry shotcrete is similar to that of high quality normally placed concrete. But shrinkage and creep of wet shotcrete is likely to be high.

The durability or resistance to frost action and other agencies of dry shotcrete is good. It is not so good for wet shotcrete but can be improved to a satisfactory degree by the use of air-entraining agents. About half of the entrained air is likely to be lost while spraying.

Concluding Remarks on Shotcrete

There has been considerable increase in the use of shotcrete in Europe and U.S.A. during the last 15 years because of the good performance of many shotcrete applications. (Strictly speaking, guniting applications). Stiff, well-compacted concrete of the type used in shotcrete is a good structural material. A well designed and well executed job makes a satisfactory work.

It has been well established that the strength and other properties of shotcrete are the same as those of conventional mortar or concrete of the same proportion and water content. Shotcrete is a mix with high cement content and very low water/cement ratio. Normal shotcrete mixes applied by qualified personnel under favourable conditions are capable of strengths above 35 MPa. One of the strong points of shotcrete is its excellent bond with old concrete, rock face and even with metal sheet. The shotcrete applied as overlay to old concrete slab is found to have good bond strength at the interface. The shotcrete applied as ground support worked very well with or without rock bolting as additional support. The use of shotcreting is very frequently adopted for tunnelling operations.

Shotcreting with steel reinforcement for slope protection.

Shotcrete for ground support generally should have quick setting properties in order to permit a rapid build up of the shotcrete section, develop very early strength and seal off seepage where existing. These properties are usually obtained by the use of powerful accelerators in the mix. These accelerators should be compatible with the cement and concrete with respect to durability and stability.

It has been reported by Corps of Engineers, USA, that in one of the recently completed large shotcrete tunnel support job in California, there was an apparent saving of about two million dollars by using shotcrete in lieu of steel supports. They also reported that obtaining

Shotcreting for slope protection by Robot Jet Machine at central secretariat, Delhi Metro.

strength more than 28 MPa requires very rigid quality control at great cost and as such, strength exceeding 28 MPa should not be specified.

Recent Studies

Use of fibre reinforced shotcrete is one of the recent innovations. In this, steel fibres of about 30 gauge and 20 mm long is mixed with the shotcrete and then pneumatically applied in the usual manner. It is found that such a fibre reinforced shotcrete process increases the tensile strength of the shotcrete considerably.

Another important innovation made is the polymer shotcrete. In this, aggregate and monomer are mixed together and then this mixture is pneumatically applied in the same manner as shotcrete. The principal difference between Polymer Shotcrete and Conventional shotcrete is that a polymeric binder is used in lieu of Portland cement and water. The developmental results of polymer shotcrete indicate a potential use of this material because of its high strength and excellent durability.

Ferrocement

Ferrocement techniques though of recent origin, have been extensively used in many countries, notably in U.K., New Zealand and China. There is a growing awareness of the advantages of this technique of construction all over the world. It is well known that conventional reinforced concrete members are too heavy, brittle, cannot be satisfactorily repaired if damaged, develop cracks and reinforcements are liable to be corroded. The above disadvantages of normal concrete make it inefficient for certain types of work.

Ferrocement is a relatively new material consisting of wire meshes and cement mortar. This material was developed by P.L. Nervi, an Italian architect and engineer, in 1940. It consists of closely spaced wire meshes which are impregnated with rich cement mortar mix. The wire mesh is usually of 0.5 to 1.0 mm dia wire at 5 mm to 10 mm spacing and cement mortar is

Small diameter wires and chickenwire mesh reinforcement used in casting ferrocement water tank

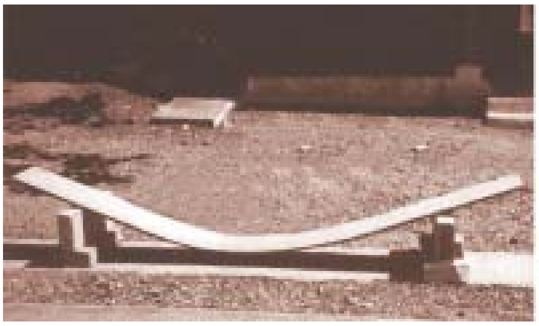
Ferrocement water tank 1000 litre capacity — thickness 15 mm.

Ferrocement boat floating on water— thickness 25 mm.

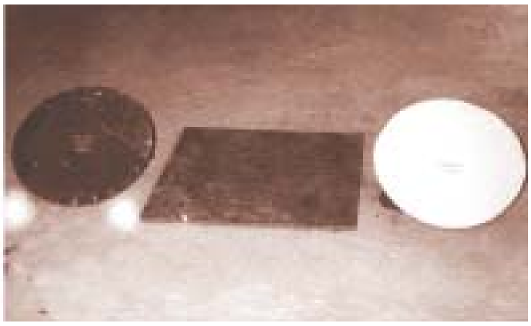
of cement sand ratio of 1 : 2 or 1 : 3 with water/cement ratio of 0.4 to 0.45. The ferrocement elements are usually of the order of 2 to 3 cm. in thickness with 2 to 3 mm external cover to the reinforcement. The steel content varies between 300 kg to 500 kg per cubic metre of mortar. The basic idea behind this material is that concrete can undergo large strains in the neighbourhood of the reinforcement and the magnitude of strains depends on the distribution and subdivision of reinforcement throughout of the mass of concrete.

Ferrocement is widely accepted in U.K, New Zealand and U.S. as a boat building material. It has also found various other interesting civil engineering applications. The main advantages are simplicity of its construction, lesser dead weight of the elements due to their small thickness, its high tensile strength, less crack widths compared to conventional concrete, easy repairability, noncorrosive nature and easier mouldability to any required shape. There is also saving in basic materials namely, cement and steel. This material is more suitable to special structures like shells which have strength through forms and structures like roofs, silos, water tanks and pipelines.

The material is under active research in various countries and attempts are being made to give a sound theoretical backing to establish the material behaviour. This is a highly suitable material for precast products, because of its easy adaptability to prefabrication and lesser dead weight of the units cast. The development of ferrocement depends on suitable casting techniques for the required shape. Development of proper prefabrication techniques for ferrocement is still not a widely explored area and gap needs to be filled.



Ferrocement plank 3000 x 300 x 25 mm, bends like a bow when supported as shown above



Sample of ferrocement manhole covers

Casting Techniques

There are four methods of casting. They are:

(*a*) *Hand plastering,*

(*b*) *Semi-mechanised process (using hand plastering),*

(*c*) *Centrifuging and*

(*e*) *Guniting.*

(a) Hand plastering (without using any formwork): *In this system a reinforcement cage is made using small diameter steel rod reinforcement bent to the required shape, say cylindrical in shape. Usually this frame provides the rigidity for the whole structure before plastering. Then the required number of wire mesh layers are securely tied to the reinforcement cage, the mortar is dashed from outside against a plain curved G.I. sheet held on the other side. The flexible curved G.I. sheet moved allround and from outside the mortar is dashed. Continuing this procedure the whole cylindrical tank is built-up. Closely spaced wire mesh helps adhering of mortar when dashed. The whole thickness is built-up gradually in two or three consecutive dashing of mortar and then both inside and outside are rubbed smooth. Hand plastering results in slightly increased thickness of ferrocement member.*

For thin cylindrical units of about I metre diameter, 6 mm diameter mild steel rods at 15 cms spacing are used to make a cage of cylindrical shape and then chicken mesh or woven mesh is tied to the cage and plastered. Use of chicken mesh in this type of construction may not be advisable as it is very flexible and plastering over chicken mesh (without inner mould) may not be satisfactory. Woven mesh and welded mesh are superior and more suitable than chicken mesh. In this method the control of thickness is difficult and the minimum thickness of section that can be cast works out to about 2 cms. Because of lesser control, the thickness of units cast by this method becomes more. The greater thickness not only makes it uneconomical but also makes it lose some of the technical advantages. The strength obtained by this system will be lower compared to other methods as the compaction is by hand and since no inner form or mould is used, the hand pressure applied is relatively less. Less pressure is required to be applied to prevent the distortion of the shape of cage. However, the units can be cast by this process and used in situations where the facilities for other improved methods do not exist. These units can be used for pipes, storage structures and gas holder units. This type of casting suits cylindrical units of size approximately 60 cms in diameter and above and also for other irregular shapes for which mould is difficult to make. Only the engineer's imagination is the limit to cast sections of any given shape by this process. It is advisable to give a water proof coating on the surfaces, as hand plastering is unlikely to result in a water tight structure.

(b) Semi-mechanised process (using hand plastering over formwork): *A semi-mechanised process has been developed at SERC, Roorkee, for casting thin ferrocement cylindrical units. In this system an inner cylindrical mould is provided over which one layer of wire mesh is wound. Over this layer, 4 mm wire is tied at a spacing of 15 cm in both the directions. Over this one more layer of chicken wire mesh is wound. This forms the complete wire mesh system of reinforcement. The cement plastering is then done layer by layer. As the mesh is tightly wound round the formwork the thickness of unit is reduced. With this system, units with thickness upto a minimum of one cm. can be cast containing two layers of wire mesh in that thickness. This system is termed as semi-mechanised because the mould can be rotated to facilitate dashing of mortar.*

Ferrocement garden umbrella
thickness 20 mm.

Ferrocement, "W" shapped folded
plate roof for span 3.5 m.
Thickness of plate is 20mm.

This system is better than the earlier system as better compaction could be obtained by means of a straight edge pressed against inner mould. The uniformity of thickness obtained in this system is also better than of the earlier system. The wire mesh can be tightly wound over the mould and can be tightened during the casting process. This helps in avoiding any looseness in the mesh and uneven thickness.

The advantages of this system are that it does not require any sophisticated enquipment or electricity, the skill can be easily acquired by local people, and it can be adopted at rural areas with ease. This system is convenient for cylindrical units of size about 1.0 m and above.

This system can be further improved by mechanising the rotation of mould and using a spray technique for mortar application. This requires synchronisation between the speed of the mould and rate of spray. Mortar spray guns of lower pressure of application of mortar than the guniting equipment may be better suited for this purpose.

(c) Centrifuging: *The centrifuging process is commonly adopted for the fabrication of concrete cylindrical units. Because of the high first crack strength of ferrocement compared to reinforced concrete, the pipe thickness can be reduced thus, resulting in lesser dead weight. In the existing centrifuging process, the mild steel reinforcement cage is replaced by wire mesh layers cage. The trial casting of pipes by centrifuging done at SERC Roorkee has indicated that this method could well be adopted for casting ferrocement units. Because of good compaction, the ferrocement pipe cast by centrifuging can be used as pressure pipes.*

Outer shell of this car is made up of ferrocement.

(d) **Guniting:** The process of guniting can be adopted for applying the mortar to the wire mesh system. This process, applied properly with experienced gunman can give good compact and uniform surface. This appears to be suitable process for mass production of ferrocement prefabricated units. A continuous process of layer guniting with an interval of about an hour will yield good results.

Application

Ferrocement has been successfully used for casting domestic over-head water tanks. The tank being light and flexible can be transported and hoisted without much difficulty. Inlet and outlet connections can also be easily done with the help of a modern adhesive like "m-seal". The ferrocement tank will be cheaper than any other competitive materials

Similar tanks or slightly modified tanks can be used as grain silos in villages. The tank can be made with hopper shaped bottom with simple arrangements for drawing the grains. The ferrocement tank will help in preserving the grain uneffected by moisture and rodents.

Similar ferrocement container can be used as gas holder unit in 'Gobbar gas" plants With a few modifications, ferrocement tanks can also be used as septic tank units.

The properties of ferrocement make it an ideal material for boat building. It has been reported that ferrocement boats 14 metres long weighs only 10 per cent more than wooden boats and the same is 300 per cent cheaper than fibre reinforced concrete boats, 200 per cent cheaper than steel boats and 35 per cent cheaper than timber boats. Many countries notably China are manufacturing ferrocement boats and fishing trawlers in large scale.

Ferrocement manhole cover is becoming very popular to replace cast iron manhole cover over sewers around domestic building where they are not subjected to heavy vehicular traffic. Owing to the reason that the cost of ferrocement manhole cover is only about 1/10 of the cost of cast iron manhole cover, and that it can be manufactured readily, it makes a good substitute for cast iron manhole cover.

Ferrocement is becoming a popular material for prefabricated roof units. Ferrocement folded plate being light, could be used advantageously as prefabricated roof units for garrages and storage sheds. A 3 cm thick ferrocement folded plate with two layers of chicken wire mesh can be used over a span of 3.5 metres. It can also be used for prefabricated channel units for roof construction.

Ferrocement is a suitable material for pressure pipes. It will be much lighter compared to normal reinforced concrete pipes. Suitable techniques like centrifuging and guniting can be used for mass production in a factory.

Ferrocement is found to be a suitable material for casting curved benches for parks, garden and open-air cinema theatre.

It is also an ideal material for making tree guards which can be cast in two parts to facilitate its removal at a later date.*

Roller Compacted Concrete

Roller Compacted Concrete (RCC) is a recent development particularly in the field of dam construction. Roller compacted concrete is a lean no slump, almost dry concrete that is compacted by Vibratory Roller. A mixture of aggregates, cement and water are mixed in a conventional batch mixer or in other suitable mixers. Supplementary cementing material, such as fly ash can also be used. In some cases high volume fly ash to the extent of 60% by weight of cement has been used. The cement content ranges from 60 to 360 kg/m^3.

Roller compacted concrete is placed in layers thin enough to allow complete compaction. The optimum layer thickness ranges from 20 to 30 cm. To ensure adequate bonding between the new and old layer or at cold joint, segregation must be prevented and a high plasticity bedding mix must be used at the start of the placement. A compressive strength of about 7 MPa to 30 MPa have been obtained.

For effective consolidation, roller compacted concrete must be dry enough to support the mass of the vibrating equipment, but wet enough to allow the cement paste to be evenly distributed throughout the mass during mixing and consolidation process.

The first RCC dam was taken up during 1978 and completed during 1980 in Japan. A number of other dams quickly followed. By end of 1985, seven RCC dams have been completed, and this method of construction technology has been accepted. In the next seven years (1992) the number of dams constructed by this techniques rose to 96 in 17 different countries mainly in USA, Japan, Spain etc.

In India Roller Compacted Concrete has been used as a base concrete in the construction of Delhi-Mathura concrete road construction project. Similarly RCC has been used as base course concrete in Pune - Mumbai express highway construction. In both the projects the RCC was referred as "Dry Lean Concrete. The grade of concrete was M 10, thickness 15 cm. Such a concrete was thoroughly compacted by vibratory roller over which Pavement Quality Concrete (PQC) of grade M 40, 35 cm thick was laid.

Self-compacting Concrete (SCC)

Self Compacting Concrete (SCC)

Making concrete structures without vibration, have been done in the past. For examples, placement of concrete under water is done by the use of tremie without vibration. Mass concrete, and shaft concrete can be successfully placed without vibration. But the above examples of concrete are generally of lower strength and difficult to obtain consistent quality. Modern application of self-compacting concrete (SCC) is focussed on high performance, better and more reliable and uniform quality.

Recognising the lack of uniformity and complete compaction of concrete by vibration, researchers at the University of Tokyo, Japan, started in late 1980's to develop SCC. By the early 1990's, Japan has developed and used SCC that does not require vibration to achieve full compaction. By the year 2000, the SCC has become popular in Japan for prefabricated products and ready mixed concrete. The Fig. 12.19 shows the amount of SCC used in Japan 12.17.

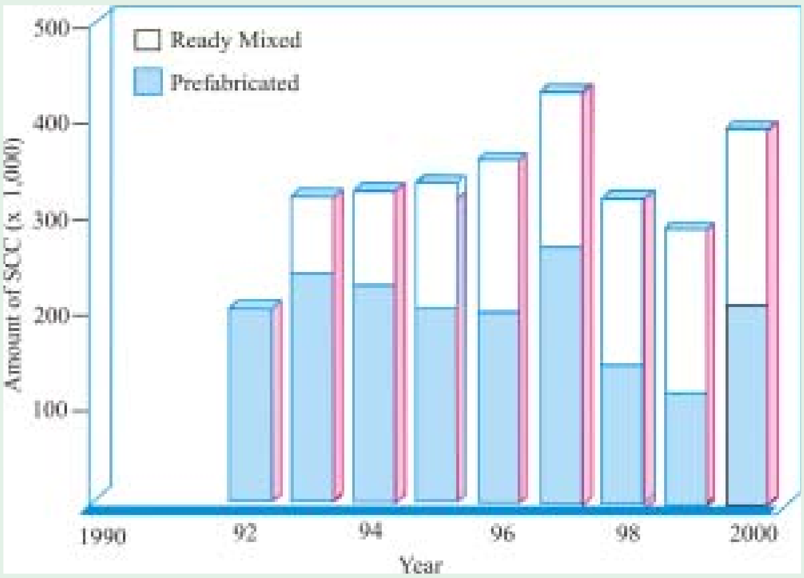


Fig. 12.19. Show the quantity of self compacting concrete used in Japan

Several European countries recognised the significance and potentials of SCC developed in Japan. During 1989, they founded European federation of natural trade associations representing producers and applicators of specialist building products (EFNARC) 12.18.

The utilisation of self-compacting concrete started growing rapidly. EFNARC, making use of broad practical experiences of all members of European federation with SCC, has drawn up specification and guidelines to provide a framework for design and use of high quality SCC, during 2001. Most of the information particularly test methods given in this chapter is based on specification and guidelines for self-compacting concrete given by EFNARC.

Self-compacting concrete has been described as ***"the most revolutionary development in concrete construction for several decades".*** *Originally developed in Japan to offset a growing shortage of skilled labour, it has proved to be beneficial from the following points.*

- *Faster construction*
- *Reduction in site manpower*
- *Better surface finish*
- *Easier placing*
- *Improved durability*
- *Greater freedom in design*
- *Thinner concrete sections*
- *Reduced noise level*
- *Safer working environment*

Material for SCC

Cement : *Ordinary Portland Cement, 43 or 53 grade can be used.*

Aggregates : *The maximum size of aggregate is generally limited to 20 mm. Aggregate of size 10 to 12mm is desirable for structures having congested reinforcement. Wherever possible size of aggregate higher than 20mm could aslo be used. Well graded cubical or rounded aggregates are desirable. Aggregates should be of uniform quality with respect to shape and grading.*

Fine aggregates can be natural or manufactured. The grading must be uniform throughout the work. The moisture content or absorption characteristics must be closely monitored as quality of SCC will be sensitive to such changes.

Particles smaller than 0.125 mm i.e. 125 micron size are considered as FINES which contribute to the powder content.

Mixing Water : *Water quality must be established on the same line as that for using reinforced concrete or prestressed concrete.*

Chemical Admixtures : *Superplaseizers are an essential component of SCC to provide necessary workability. The new generation superplasticizers termed poly-carboxylated ethers (PCE) is particularly useful for SCC.*

Other types may be incorporated as necessary, such as Viscosity Modifying Agents (VMA) for stability, air entraining agents (AEA) to improve freeze-thaw resistance, and retarders for Control of Setting.

Mineral Admixtures:

Fly ash: *Fly ash in appropriate quantity may be added to improve the quality and durability of SCC.*

Ground Granulated Blast Furnace Slag *(GGBFS) : GGBFS which is both cementitious and pozzolanic material may be added to improve rheological properties.*

Silica Fume : Silica fume may be added to improve the mechanical properties of SCC.

Stone Powder : Finely crushed lime stone, dolomite or granite may be added to increase the powder content. The fraction should be less than 125 micron.

Fibres : Fibres may be used to enhance the properties of SCC in the same way as for normal concrete.

The approximate compositions of traditional concrete and SCC are shown below.

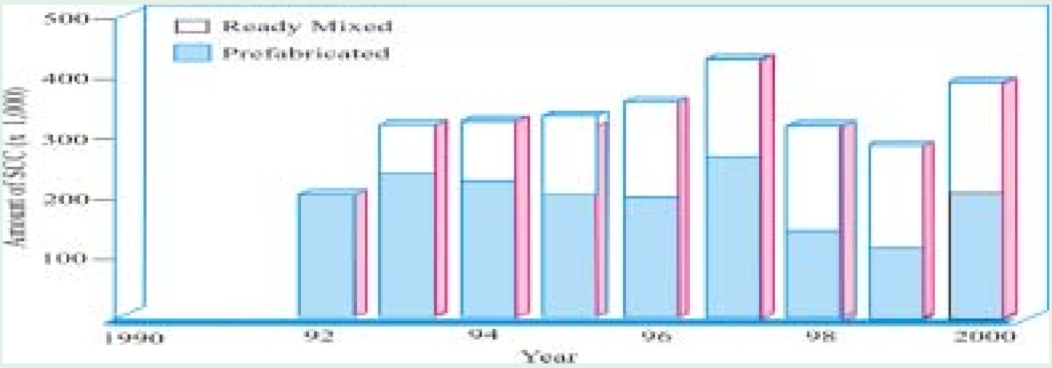


Fig. 12.20. Comparison of Traditional and SCC constituents.

The SCC mixes are designed and tested to meet the demands of the projects. It is reported that SCC for mass concrete was designed for pumping and depositing at a fairly high rate in the construction of the anchorages of the Akashi-Kaikyo batching plant and pumped through a pipe line to the location of anchorages 200 m away. The SCC was dropped from a height of 5 m without segregation. For mass concrete, the maximum size of coarse aggregate was as large as 50 mm. The SCC construction reduced the construction time for the anchorages from 2.5 years to 2 years. The coarse aggregate size for reinforced concrete generally varies from 10 mm to 20 mm.

Examples of SCC Mixes

There are three ways in which SCC can be made

(*i*) Powder Type

(*ii*) VMA Type

(*iii*) Combined type

In powder type SCC is made by increasing the powder content. In VMA type it is made by using viscosity modifying admixture. In combined type it is made by increasing powder content and using VMA. The above three methods are made depending upon the structural conditions, constructional conditions, available material and restrictions in concrete production plant etc. The following table gives an idea about the three methods and a feel for how SCC mixes differ from normal concrete mixes and from each other mixes.

Table 12.16. Shows Typical SCC Mixes in Japan 12.17

Ingredient	Powder Type	VMA Type	Combined Type
Water kg/m^3	175	165	175
Cement kg/m^3	530	220	298
Fly ash kg/m^3	70	0	206
GGBFS kg/m^3	0	220	0
Silica Fume kg/m^3	0	0	0
F.A. kg/m^3	751	870	702
C.A. kg/m^3	789	825	871
High, Range Water reducing admixtures kg/m^3	9.0	4.4	10.6
VMA kg/m^3	0	4.1	0.0875
Slump flow test dia. of spread mm	625	600	660

Requirements for self-compacting concrete

The main characteristics of SCC are the properties in the fresh state. The mix design is focussed on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to retain homogeneity without segregation. The workability of SCC is higher than "very high" degree of workability mentioned in 15 456 : 2000.

A concrete mix can only be classified as self-complicating if it has the following characteristics.

- *Filling ability*
- *Passing ability*
- *Segregation resistance*

Several test methods have been developed in attempts to characterise the properties of SCC. So far no single method or combination of methods has achieved universal approval to include in national or international organisations. However, the Table 12.17 gives the list of test methods for workability properties of SCC based on EFNARC specification and guidelines.

Table 12.17. List of test methods for workability properties of SCC

Srl No.	Method	Property
1.	Slump flow by Abrams cone.	Filling ability
2.	$T_{50\ cm}$ Slump flow	Filling ability
3.	J-ring	Passing ability
4.	V-funnel	Filling ability
5.	V-funnel at T_5 minutes	Segregation resistance
6.	L-box	Passing ability
7.	U-box	Passing ability
8.	Fill-box	Passing ability
9.	GTM Screen Stability Test	Segregation resistance
10.	Orimet	Filling ability

For the initial mix design of SCC all the three workability parameters need to be assessed.

Table 12.18. The workability properties of SCC and alternative test methods.

Property	Test Methods Lab mix. design	Field quality control	Modification of test according to max. size agg.
Filling ability	slump flow T_{50} cm slump flow V-funnel orimet Orimet	slump flow $T_{50\ cm}$ slump flow V-funnel Orimet	None None Max. 16 mm
Passsing ability	L-box, U-box Fill-box	J-ring	Different opennings in L-box and J-ring
Segregation resistance	GTM test V-funnel at T_5 min.	G.T. test V-funnel at T_5 minutes	None

For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are slump-flow and V-funnel or slump-flow and J-ring. With consistent raw material, even a single test method carried out by trained and experienced technician may be sufficient.

Workability Requirement for the fresh SCC

The following requirements are to be fulfilled at the time of placing. Any changes in workability during transport and other delay should be taken into account in production.

Table 12.19. The typical acceptance criteria for SCC 12.18.

Srl No.	Method	Unit	Typical ranges of values Minimum	Maximum
1.	Slump flow by Abrams cone.	mm	650	800
2.	$T_{50\ cm}$ Slump flow	sec	2	5
3.	J-ring	mm	0	10
4.	V-funnel	sec	8	12
5.	V-funnel at T_5 minutes	sec	0	+3
6.	L-box	(h_2/h_1)	0.8	1.0
7.	U-box	$(h_2 - h_1)$mm	0	30
8.	Fill-box	%	90	100
9.	GTM Screen Stability Test	%	0	15
10.	Orimet	sec	0	5

Initial Mix composition

In the design of mix, the relative proportions of the key components may be considered by volume rather than by mass. Indicative proportions of materials are shown below for self compactability.

- Water/powder ratio by volume is to be 0.80 to 1.00
- Total power content to be 160 to 240 litres (400-600 kg) per m^3
- The sand content may be more than 38% of the mortar volume
- Coarse aggregate content should normally be 28 to 35% by volume of the mix
- Water/cement ratio is selected based on strength. In any case water content should not exceed 200 litres/m^3.

One must bear in mind that there is going to be some variation in raw material quality and variation in moisture content in aggregates.

After laboratory trials, the mix should be tested at full scale at the concrete plant or site. In the event of not getting satisfactory performance, the mix should be readjusted in respect of type and quantity of filler material, proportions of F.A. or C.A., dosage of superplasticizer and VMA. Try also alternative type of superplaticizer which may be more compatible.

Production and Placing

Aggregates : *Aggregate should come from same source. There should not be much variations in size, shape and moisture content.*

Mixing : *Any suitable mixer could be used - Generally, mixing time need to be longer than for conventional concrete. Time of addition of admixture is important. A system should be established for optimum benefit during trial itself.*

In the beginning there may be fluctuations in the quality of freshly mixed concrete. It is recommended that every batch must be tested until consistent and compliant results are obtained. Subsequently, checking could be done "by the eye" and routine testing is sufficient.

Placing: *Formwork must be in good conditions to prevent leakage. Though it is easier to place SCC than ordinary concrete, the following rules are to be followed to minimise the risk of segregation.*

- *limit of vertical free fall distance to 5 meter.*
- *limit the height of pour lifts (layers) to 500 mm*
- *limit of permissible distance of horizontal flow from point of discharge to 10 meters.*

Curing: *On account of no bleeding or very little bleeding, SCC tends to dry faster and may cause more plastic shrinkage cracking. Therefore, initial curing should be commenced as soon as practicable. Alternatively the SCC must be effectively covered by polyethylene sheet. Due to the high content of powder, SCC can show more plastic shrinkage or creep than ordinary concrete mixes. There are disagreements on the above statement. These aspects should be considered during designing and specifying SCC. It should also be noted that early curing is necessary for SCC.*

Mix Design

Procedure : *The following sequence is followed*

- *Determine the desired air content*
- *Determine the coarse aggregate volume*
- *Determine the sand content*
- *Design the paste composition*
- *Determine the optimum water to powder ratio and superplasticizer dosage in mortar*
- *Finally the concrete properties are assessed by standard tests.*

Air Content: *Generally air content may be assumed to be 2%. In case of freeze-thaw conditions in cold weather concreting higher per cent of air content may be specified.*

Determination of Coarse Aggregate Volume : *Coarse aggregate volume is defined by bulk density. Generally coarse aggregate (D > 4.75) should be between 50% and 60%. Optimum coarse aggregate content depends on the following parameters.*

- *The lower the maximum aggregate size, the higher the proportion.*
- *The rounded aggregate can be used at higher percentage than crushed aggregates.*

Determination of Sand Content: *Sand, in the context of mix design procedure is defined as all particles bigger than 125 micron and smaller than 4.75 mm. Sand content is defined by bulk* *density. The optimum volume content of sand in the mortar varies between 40-50% depending on paste properties.*

Design of paste composition: *Initially the water/powder ratio for zero flow (β_p) is determined in the paste; with chosen proportion of cement and additions. Flow cone tests with water/powder ratios by volume of e.g. 1.1, 1.2, 1.3 and 1.4 are performed with the selected powder composition. Fig. 12.21 shows the typical results. The point of intersection with "Y" axis is the β_p value. This β_p value is used mainly for quality control of water demand for new batches of cement and fillers.*

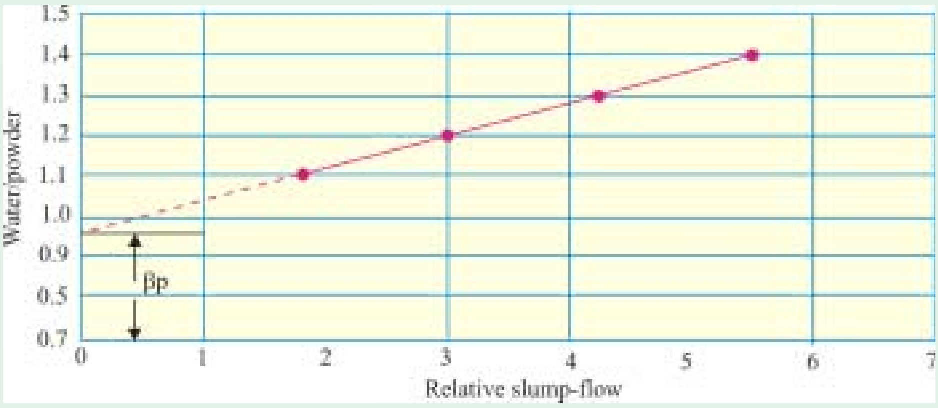


Fig. 12.21. Determination of water/powder ratio b_p for zero slump flow.

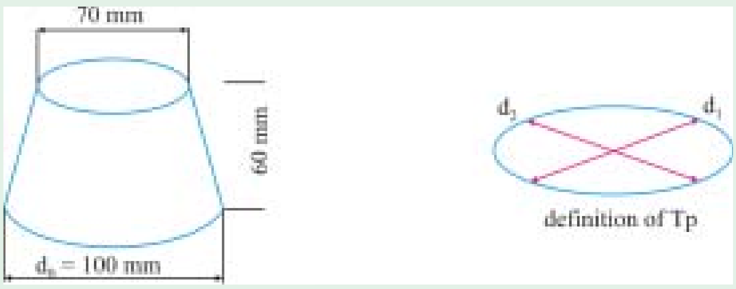
Determination of Optimum Volumetric Water/powder ratio and Superplasticizer dosage in mortar :

Tests with flow cone and V-Funnel for mortar are performed at varying water/powder ratios in the range of (0.8 to 0.9) β_p and dosages of superplasticizer. The superplasticizer is used to balance the rheology of the paste. The volume content of sand in the mortar remains the same as determined above.

The target values are slump flow of 24 to 26 cm and V-funnel time of 7 to 11 seconds.

At target slump flow, where V-funnel time is lower than 7 secs, then decrease the water/powder ratio. For largest slump flow and V-funnel time in excess of 11 seconds water/powder ratio should be increased.

If these criteria cannot be fulfilled, then the particular combination of materials is inadequate. One can also change the type of superplasticizer. Another alternative is a new additive, and as a last resort is to change the cement.



$$T_p = \left(\frac{d}{d_0}\right)^2 - 1 \quad \text{where} \quad d = \left(\frac{d_1 + d_2}{2}\right)$$

Fig. 12.22. Flow cone and Table to determine the relative slump-flow Tp

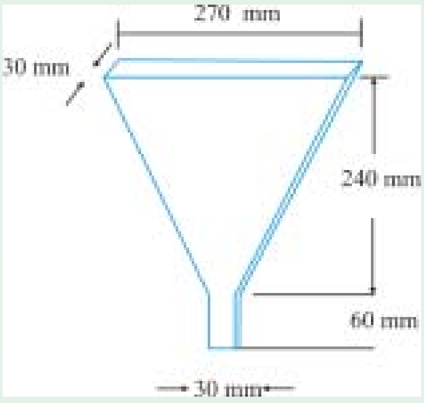


Fig. 12.23. V-funnel to determine the flow time of mortar

Tests on Concrete: The concrete composition is now determined and the superplasticizer dosage is finally selected on the bases of tests on concrete.

Guideline for mix composition

Coarse aggregate < 50%
Water/powder ratio = 0.8 to 1.0
Total powder content = 400–600 kg/m^3
Sand Content = < 40% of the mortar (by volume)
Sand = < 50% of paste volume
Sand = > 50% by weight of total aggregate
Free water < 200 litre.
Paste > 40% of the volume of the mix

With the above parameters conduct the workability tests and see whether you get the following results. If not adjust the parameters to get the following test results.

Slump flow by Abrams cone.	650 to 80 mm
$T_{50\ cm}$ Slump flow	2 to 5 sec
J-ring	0 – 10 mm
V-funnel	8 – 12 sec
V-funnel at T_5 minutes	+3 sec
L-box	H_2/H_1 = 0.8 to 1.0
U-box	$H_2 - H_1$ = 30 mm (Max.)
Fill-box	90 to 100%
Screen Stability	0 – 15%
Orimet	0 – 5 sec

Test Methods :

It is important to mention that none of the test methods for SCC has yet been standardised and the tests mentioned below are not yet perfected. They are mainly adhoc method which have been devised for SCC.

Slump flow Test

The slump flow test is done to assess the horizontal flow of concrete in the absence of obstructions. It is a most commonly used test and gives good assessment of filling ability. It can be used at site. The test also indicates the resistance to segregation.

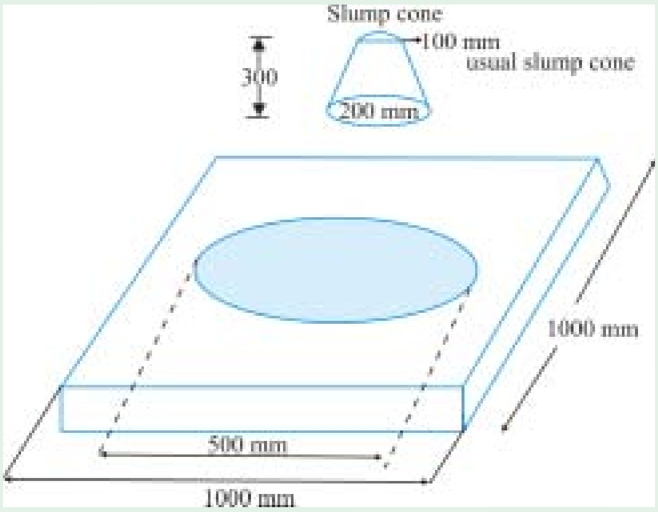


Fig. 12.24. Slump flow test

Equipments : *The usual slump cone having base diameter of 200 mm, top diameter 100mm and height 300mm is used.*

- *A stiff base plate square in shape having at least 700 mm side. Concentric circles are marked around the centre point where the slump cone is to placed. A firm circle is drawn at 500 mm diameter*
- *A trowel*
- *Scoop*
- *Measuring tape*
- *Stop watch*

Procedure : *About 6 litre of concrete is needed for this test. Place the baseplate on level ground. Keep the slump cone centrally on the base plate. Fill the cone with the scoop. Do not tamp. Simply strike off the concrete level with the trowel. Remove the surplus concrete lying on base place. Raise the cone vertically and allow the concrete to flow freely. Measure the final diameter of the concrete in two perpendicular directions and calculate the average of the two diameters. This is the slump flow in mm. Note that there is no water or cement paste or mortar without coarse aggregate is seen at the edge of the spread concrete.*

Interpretation: *The higher the flow value, the greater its ability to fill formwork under its own weight. A value of at least 650 mm is required for SCC. In case of severe segregation, most coarse aggregate will remain in the centre of the pool of concrete and mortar and paste at the periphery of concrete.*

T_{50} Slump Flow Test : *The procedure for this test is same as for slump flow test. When the slump cone is lifted, start the stop watch and find the time taken for the concrete to reach 500 mm mark. This time is called T_{50} time. This is an indication of rate of spread of concrete. A lower time indicates greater flowability. It is suggested that T_{50} time may be 2 to 5 secs.*

J-Ring Test : *J-ring test denotes the passing ability of the concrete. The equipment consists of rectangular section of 30 mm x 25 mm open steel ring drilled vertically with holes to accept threaded sections of reinforcing bars 10 mm diameter 100 mm in length. The bars and sections can be placed at different distance apart to simulate the conjestion of reinforcement at the site. Generally these sections are placed 3 x maximum size of aggregate. The diameter* *of the ring formed by vertical sections is 300 mm and height 100 mm.*

Equipment :

- *slump cone without foot pieces.*
- *Base plate at least 700 mm square*
- *Trowel*
- *Scoop*
- *Tape*
- *J-ring-rectangular section 30mm x 25mm planted vertically to form a ring 300 mm dia generally at a spacing of 48 ± 2mm.*

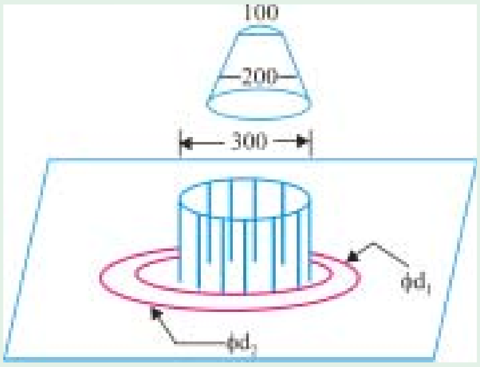


Fig. 12.25. J-ring apparatus

Procedure : *About 6 litres of concrete is needed for the test. Moisten the inside of the slump cone and base plate. Place the J-Ring centrally on the base plate and the slump cone centrally inside the J-ring. Fill the slump cone with scoop. Do not tamp. Simply strike off the concrete level with trowel. Remove all surplus concrete. Raise the cone vertically and allow the concrete to flow out through the J-ring. Measure the final diameter in two perpendicular directions. Calculate the average diameter. Measure the difference in height between the concrete just inside J-Ring bars and just outside the J Ring bars. Calculate the average of the difference in height at four locations in mms. Note any border of mortar or cement paste without coarse aggregate at the edge of the concrete. The acceptable difference in height between inside and outside should be between 0 and 10 mm.*

You can see unsegregated and cohesive concrete coming out of J-ring.

Courtesy : Hindustan Construction Company

V-Funnel test and V-Funnel test at T_5 min.

This test was developed in Japan. The equipment consists of a V-shaped funnel shown in Fig. 12.26. The V- Funnel test is used to determine the filling ability (flowability) of the concrete with a maximum size of aggregate 20 mm size. The funnel is filled with about 12 litre of concrete. Find the time taken for it to flow down.

After this the funnel can be filled with concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

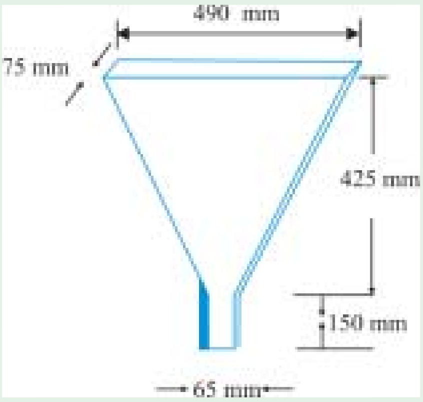


Fig. 12.26. V-Funnel Test Equipment

Equipment

- *V-funnel*
- *Bucket 12 litres*
- *Trowel*
- *Scoop*
- *Stopwatch*

Procedure : *About 12 litre of concrete is needed for the test. Set the V-funnel on firm ground. Moisten inside of the funnel. Keep the trap door open to remove any surplus water. Close the trap door and place a bucket underneath. Fill the applaratus completely with concrete – No compaction or tamping is done. Strike off the concrete level.*

Open within 10 seconds the trap door and record the time taken for the concrete to flow down. Record the time for empltying. This can be judged when the light is seen when viewed from top. The whole test is to be performed within 5 min.

Observing the time of emptying of concrete from V-funnel.

Procedure for flow time at T_5 mm : *Do not clean or moisten the inside surface of the funnel. Close the trap door and refill the V-funnel immediately after measuring the flow time. Place the bucket underneath. Fill the apparatus completely with concrete without tamping or tapping. Strike off the concrete level with the top by trowel. Open the trap door after 5 minutes after the second fill of the funnel and allow the concrete to flow. Calculate the time taken for complete discharge. It is called the flow time at T_5 min. For V-funnel test the flow time should be between 8 and 12 secfonds. for V-funnel flow time at T_5 min. + 3 seconds is allowed.*

L box test method. *This test is developed in Japan. The test assesses the flow of concrete, and also the extent to which the concrete is subjected to blocking by reinforcement. The apparatus is shown in Fig. 12.27.*

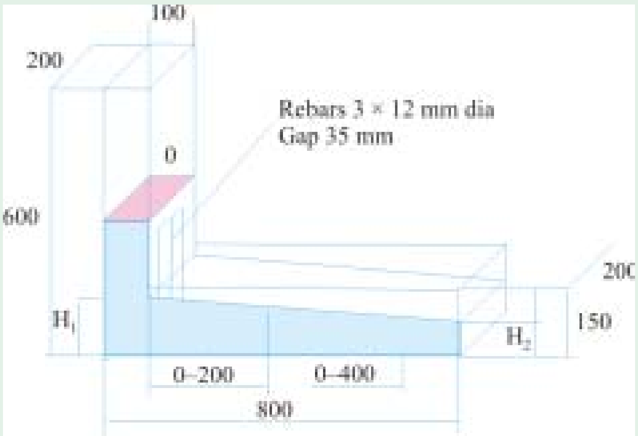


Fig. 12.27. L-Box

Concrete flowing through L-Box

Courtesy : Hindustan Construction Company

Procedure : *About 14 litres of concrete is required for this test. Ensure that sliding gate can open freely and then close it. Moisten the inside surface, remove all surplus water. Fill the vertical section of the apparatus with concrete. Leave it standing for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously start the stopwatch and record the time taken for the concrete to reach 200 and 400 mm marks. When the concrete stops flowing, the height H_1 and H_2 are measured. Calculate, H_2/H_1 , the blocking ratio. The whole test has to be performed within 5 minutes.*

Interpretation of result: *If the concrete flows as freely as water, at rest it will be horizontal. Therefore H_2/H_1 will be equal to 1. Therefore nearer the test values, the blocking ratio, is to unity, the better the flow of concrete. The European union research team suggested a minimum acceptable value of 0.8. T_{20} and T_{40} time can give some indication of ease of flow, but no suitable values have been suggested.*

U-box test method:

Introduction. *The test was developed in Japan The test is used to measure the filling ability of self com,pacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments shown by R_1 and R_2 in Fig.12.28.*

An opening with a sliding gate is fillted between the two compartments. Reinforcing bars with nominal diameter of 13 mm are installed at the gate with centre to centre distance of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litres of concrete. The gate is then lifted and the concrete flows to the other section. The height of concrete in both the sections is measured.

Asessment of test: This test provides a good direct measurement of filling ability.

Equipment

- U-box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure : About 20 litre of concrete is needed for this test. Ensure that sliding gate can open freely and then close it. Moisten the inside surface and remove any surplus water. Fill the one compartment of the apparatus with about 20 litre concrete. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow to the other compartment. Once the concrete has come to rest, measure the height of the concrete in the second compartment in two places. Calculate the mean. Let it be H_2. The height of concrete in the 1st compartment be H_1.

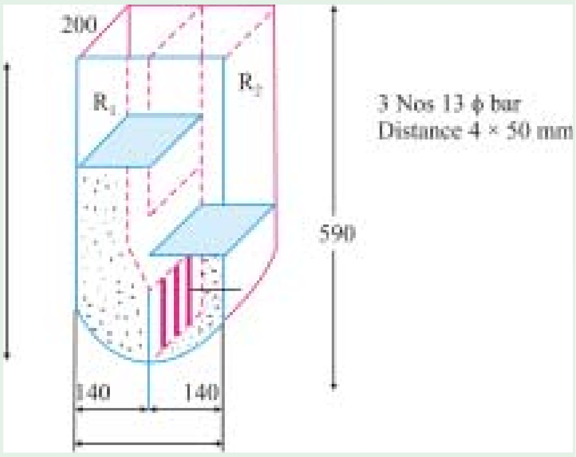


Fig. 12.28. U-box

Concrete passing through U-Box

Courtesy : Hindustan Construction Company

Calculate $H_1 - H_2$ the filling height. The whole test has to be completed within 5 minutes.

Interpretation of result : If the concrete flows as freely as water, at rest it will be horizontal, so $H_1 - H_2 = 0$. Therefore the nearer the test value, the filling height, is to zero, the better the flow and passing ability of the concrete. The acceptable value of filling height is 30mm maximum.

Fill box test

Introduction : This test is also called "Kajima test". The test is used to measure the filling ability of self compacting concrete with the maximum aggregate size of 20 mm. The appara-

tus consists of a container (transparent) with a flat and smooth surface. In the container there are 35 obstacles made of PVC with a diameter of 20mm, placed at centre to centre distances of 50 mm. At the top side is put a filling pipe 100 mm diameter 500 mm high with a funel 100 mm high. The container is filled with concrete through the filling pipe and the difference in height between two sides of the container is a measure for the filling ability.

Assessment of test : *This is basically a laboratory test. It gives a good impression of the self compacting characteristics of the concrete. The apparatus is shown in Fig. 12.29.*

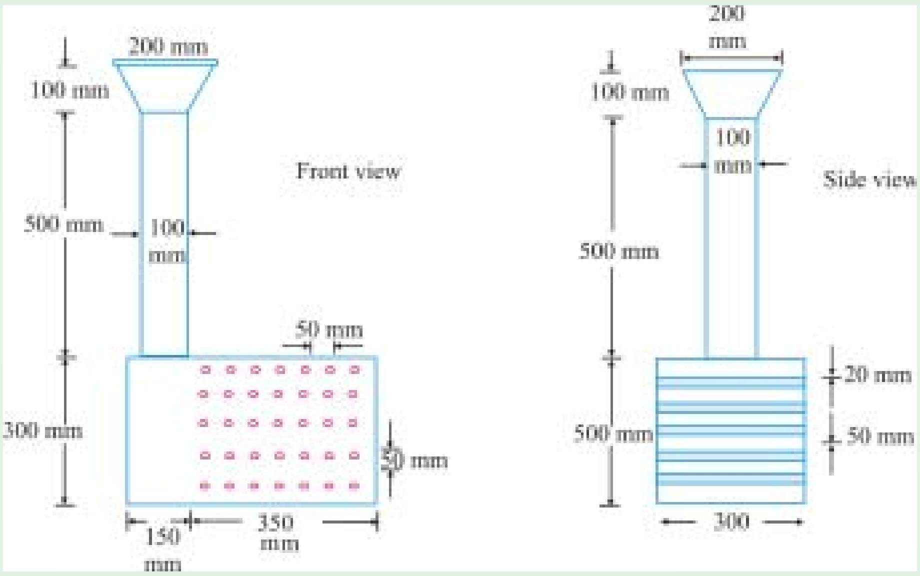


Fig. 12.29. Fill-box

Detail of the Fill-Box empty and filled with concrete.
Courtesy : Hindustan Construction Company

Equipment :

Fill box of a stiff transparent, non-absorbing material
Scoop 1.5 to 2 litre capacity
Ruler
Stop watch

Procedure

About 45 litre of concrete is required for this test. Set the apparatus on a firm ground. Moisten inside. Remove any surplus water. Fill the apparatus by pouring 1.5 to 2 litres concrete taken in the scoop into the filling pipe at every 5 secs until the concrete has just covered the first top obstacle,. After the concrete has come to rest measure the height at the side at which the container is filled on two places and calculate the average (h_1). Carryout the same on the opposite side (h_2).

Calculate the average filling percentage.

Average filling percentage $F = \frac{h_1 + h_2}{2h_1} \times 100$

Interpretation of result :

*If the concrete flows as freely as water, at rest, it will be horizontal, and so the average filling percentage = 100%. Therefore the nearer the test value, the "**filling height**" is to 100%, the better the self compacting characteristics of the concrete. A value of 90 to 100% is generally prescribed.*

GTM Screen Stability test:

***Introduction:** This test was developed by the French Contractor GTM, to assess segregation resistance (stability). It consists of taking a sample of 10 litre of concrete allowing it to stand for a period to allow any internal segregation to occur, then pouring half of it on to a 5mm sieve of 350 mm diameter, which stands, on a sieve pan on a weigh scale. After two minutes, the mortar which passed through 5 mm sieve is weighted; and expressed as a percentage of the weight of the original sample on the 5mm sieve.*

Assessment of the test:

Practising engineers who have used this test method are of the opinion that it is an effective method for assessing the stability of SCC. Though simple, it is not a rapid test and needs accurate weighing which may make it difficult to adopt at the site.

Equipments

- *10 litre bucket with lid*
- *5 mm seieve 350 mm diameter*
- *Seive pan*
- *Balance, accuracy 20 gm minimum capacity 20 kg*
- *Stop watch*

Procedure:

About 10 litre of concrete is needed. Allow the concrete to stand in a bucket for 15 minutes. Cover the concrete with the lid. Determine the weight of empty seive pan. Inspect the surface of concrete if there is any bleeding water and note it. Pour the top 2 litre or approximately 4.8 ± 0.2 kg of concrete into a pouring container. Determine the weight of the filled pouring container. Determine the weight of the empty seive pan. Pour all the concrete from the pouring container on to the seive from a height of 500 mm in one smooth continuous movement. Weigh the empty pouring container. Calculate the weight of concrete poured *onto seive, Ma (i.e. the difference between the weight full and empty). Allow the mortar fraction of the sample to flow through the seive into the seive pan for a period of 2 minutes. Remove the seive and determine the weight of filled seive pan. Calculate the weight of sample passing seive, M_b, by substracting the empty seive pan weight from the filled seive pan weight.*

Calculate the percentage of the sample passing seive, the segregation ratio is $\frac{M_b}{M_a} \times 100$

Interpretation of result:

Empirical observation suggest that if the percentage of mortar which has passed through the seive, the segregation ratio, is between 5 and 15% of the weight of the sample, the segregation resistance is considered statisfactory. Below 5% the resistance is excessive, and likely to affect the surface finish. Above 15% and particularly above 30% there is strong likelyhood of segregation. The suggested value is 0–15%.

Orimet test

Introduction:

Orimet test was developed at the University of Paisley as a method for assessment of highly workable, flowing fresh concrete mixes on construction sites. The orimet consists of a vertical casting pipe filled with a changeable inverted cone shaped orifice at its lower end, with a quick release trap door to close the orifice. Usually the orifice has 80 mm internal diameter for 20 mm maximum size of aggregate. Orifices of other sizes, usually from 70 mm to 90mm can be fitted instead.

Operation consists simply of filling the orimet with concrete, then opening the trap door and measuring the time taken for emptying it.

Assessment of test:

This test is able to simulate the fresh of fresh concrete during actual placing at site. It is a rapid test. This test has the useful characteristics of being capable of differentiation between

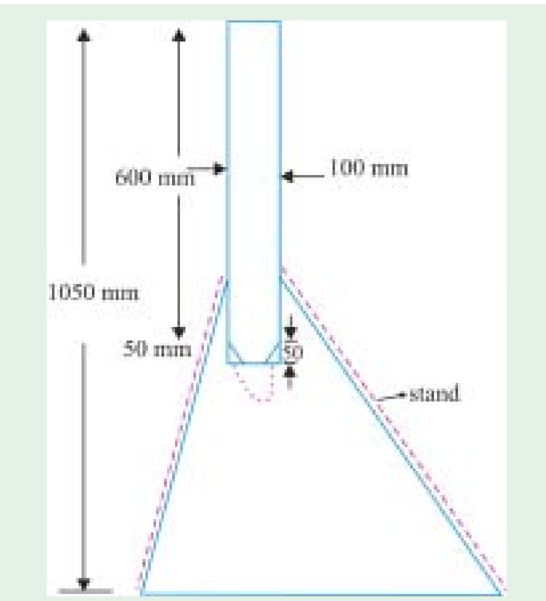


Fig. 12.30. Orimet device

Concrete flowing through Orimet device

highly workable, flowing mixes, and might therefore useful for compliance testing of successive loads on site. Orimet device is shown in Fig. 12.30.

Equipment:

- *Orimet device of a stiff non-abosrbing material*
- *Bucket Appx. 10 litre*
- *Trowel*
- *Scoops*
- *Stopwatch*

Procedure:

About 8 litre of concrete is needed for the test.
Set the orimet on a firm ground
Moisten the inside of pipe and the orifice
Keep the trap door open to drain of surplus water
Close the trap door and place a bucket underneath

Fill the apparatus completely. Do not compact or tap the pipe. Strike off the concrete level with the top by trowel. Open the trap door within 10 seconds after filling and allow the concrete to flow out. Find the time taken for complete discharge (Flow time). The whole test has to completed within 5 minutes.

Interpretation of Result

This test measures the ease of flow. Shorter duration indicate greater flowability. For SCC a flow time of 5 seconds or less is considered apporpriate. The inverted cone shape of the orifice restricts the flow, and prolonged flow time may give some indication of the susceptibility of the mix to blocking and/or segregation.

Complexities Involved in Making SCC:

Normal strength concrete itself is a complex material. High strength and high performance concrete with low water/binder ratio adds to the complexity. Making self compacting concrete, particularly of high strength, adds further to the complexity.

Generally self compacting concrete is used in situations for concrete requiring high strength say over 40 MPa upto 100 MPa or more. Production of such high strength concrete would require the use of relatively low water/binder ratio. Binder generally includes silica fume also. Use of silica fume while increasing the strength reduces the workability to an unacceptable level for self compacting requirements. To restore the workability or even to have much higher level of workability needed for SCC, a higher dose of superplaticizer is needed. Very high dosage of superplasticizer could lead to two major problems. Firstly, all the superplasticizers available in the market are not suitable for application at high dosage. Therefore it is important to choose the one that could be used without causing adverse side effect such as excessive retardation, at the sametime the one that could retain the slump for sufficiently long time. The superplasticizers based on Naphthalene or Melamine are generally not suitable for self compacting concrete requiring very high strength.

Initial trial for finding the compatibility between superplasticizer and cement, at very low water/binder ratio is also required to be ascertained.

Another point for consideration is that, there is a tendency for using relatively large binder paste volume in order to achieve both high strength and self compacting properties. From all round performance point of view, the use of a large binder paste volume is undesirable as it would lead to higher heat of hydration, greater shrinkage and creep.

EFNARC specification and Guideleines recommend the paste volume to be more than 40% of the volume of the mix. But other authorities have recommended that the paste vol-

ume not to be more than 35% for concrete to be considered as high performing. The above brings more complexities. It is to be pointed out that although, on the face of it, higher paste volume may result in higher shrinkage and creep in SCC, the comparativestudy conducted by Persson B. as reported in Cement and concrete Research vol 31, 2001, the mechanical properties such as strength, elastic modulus, creep and shrinkage of SCC and conventional concrete did nto show significant difference, when the strength was kept the same.

New Generation Plasticizers :

From various studies for production of SCC it was found better to use poly-carboxylate based superplasticizer (PC). This next generation superplasticizer or what is sometimes called hyperplasticizer is more efficient than naphthalene or melamine based superplasticizer with respect to plasticizing property and slump retention property. They cause dispersion of fine particles more by steric hindrance of many side long chain of PC than only by Zeha potential of naphthalene based or melamine based plasticizers. Such polycarboxylate based (PC), Multicarboxylatethers (MCE) or carboxylic acrylic ester (CAE) etc. are avaialble in India.

Viscosity Modifying Agent:

Another important material required for production of SCC. is Viscosity Modifying Agent (VMA). One of the methods of improving the stability of flowing SCC is to increase the paste content by using large amount of filler active or insert. Of late, however attempts are being made to reduce the fines content (the paste content) with a view to reduce shrinkage and creep by using VMA for stability.

VMAs have been in use for long time for under water concreting in the past. Now their use is extended to SCC. Most VMAs contain polysaccharides as active ingredient. Some starches could also be used for control of viscosity. ***Diutan gum and welan gum*** *are often become part of certain viscosity modifying admixture. It is claimed that such VMA becomes compatible with all superplasticizers.*

One must be careful about the sequence of addition of VMA and superplasticizer into SCC. VMA should be added after superplasticizer is added and mixed with cement particles. If VMA is added before superplasticizer, it swells in water and dispersion of superplasticizer in concrete becomes difficult. Usually VMA is added in a small dose of 0.2 to 0.5 per cent by weight of the binder content.

Availability of New generation Superplasticizer and VMA in India for SCC

The following table gives the brand names of new generation superplasticizer and VMA available in India.

Table 12.20 Brand names of new generation plasticizers and VM^{3}A

S.No.	Names of chemical admixtures manufacturing Companies	New Generation Superplasticizers for SCC	VMA for SCC
1.	MC Bauchemie (Ind) Pvt. Ltd.	Muraplast FK 63 FK 61	Centrament Stabi 510 (non-organic base)
2.	Degussa MBT	Glenium 51 Glanium B 233	Glanium Stream - 2
3.	Fosroc	Structuro	—
4.	Sika	VISCO Crete–1	Sika Stabilizer 229
5.	Burgin And Leons Agenturen Pvt. Ltd	—	Kelco-crete 200 (containing Diutangunm)

Indian Scenario of SCC

In India, during the last few years, attempts were made in the laboratories and in the field to develop and use SCC. However, large scale uses have been rare. Some pionering efforts have been made in Delhi Metro projects in association with L&T and MBT. Nuclear Power Corporation, Gammon India, Hindustan Construction Company have made large scale laboratory trials and on the ground Moch up trials. Laboratory studies conducted at SERC Chennai, Indian Institute of Technologies at Madras, Roorkee and other places have given enough inputs and confidence to adopt SCC in India.

Experience at Delhi Metro Project

Of all the places Delhi Metro Project have used SCC in large scale for dome construction, tunnel lining, column casting etc. About 10,000 m^3 of SCC has been used in as many as forty locations during the year 2004, This is by far the biggest use of SCC in India.

Hindustan Construction Company have also carried out considerable studies on the use of High Volume Fly ash self compacting concrete for domes, walls in turbine building in Rajasthan Power Project, and Concrete for Piers in Bandra-Worli Sea Link Projects. Based on their extensive trials, they used High Volume Fly ash self compacting concrete in the above projects and in many other works.

Experiance of SCC at Delhi Metro Project. *(12.19)*

Table 12.21 gives the mix proportions adopted at Delhi Metro Project.

Table 12.21. Mix Proportions adopted at Delhi Metro Project For 35 MPa SCC

Sl.	*Materials*	*For Retardation time 90 mm*	*For Retardation time 120 mm*	*Volume litres*
1.	Water (kg)	163	163	163
2.	Cement kg	330	330	105
3.	20 mm (kg)	455	455	169
4.	10 mm (kg)	309	309	115
5.	Sand kg	917	917	354
6.	Fly ash kg	150	150	68.5
7.	Glenium 51 (litre)	2.4	3.12	–
8.	Glenium stream 2 (litre)	0.96	1.3	–
9.	Possolith 300 R(litre)	0.66	0.99	–
10.	Fresh density (kg/m^3)	2340	2337	
11.	Quantity of fines	525 kg*		
12.	Water/Powder ratio	0.85%		
13.	Paste Content by (vol)	36%		
14.	Sand Content by vol.	35%		
15.	Coarse Agg. by vol.	28%		

Note : 1. Entrapped air at 2% assumed
2. Sand contains 5% fives (< 125 micron)

SCC poured at Rotary Dome at central secretariat station – Delhi Metro Project

Table 12.22 shows the Trial Results of SCC at Delhi Metro as against EFNARC recommended values.

Table 12.22. Trial Result at Delhi Metro Project

Table 12.22 Shows the Trial Result of SCC as against EFNARC Values

Method	Property	Unit	Min	Max	Trial Result
Slump flow	Filling ability	mm	650	800	680
V-Funnel	Filling ability	Sec	8	12	8
L-Box	Passing ability	mm	8	1.0	0.91
U-Box	Passing ability	%	0	30	15
V-Funnel at 5 min	Segregation	sec	0	+3	+2

The strength of SCC poured at Delhi Metro, on the basis of Cube strength was between 44 and 49 MPa at 28 days. The target mean strength was 43 MPa for the characteristic strength of 35 MPa.

Experience of Mock-up Trials conducted at Tarapur Atomic Power Project (12.20)

Based on EFNARC guidelines, extensive trials were conducted to select the ingredients for SCC to be used in underground pump house wall. As per the designer's requirement, they used micro silica. The following are the mix proportions adopted based on laboratory trials for 40 MPa SCC

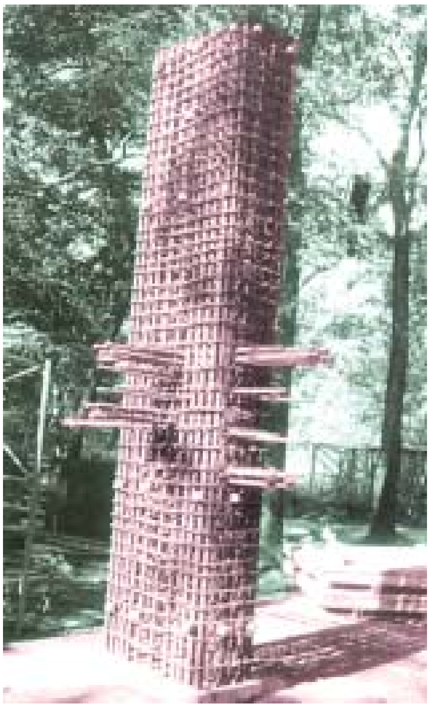
Cement	300 kg
Fly ash	200 kg
Micro silica	25 kg
Water	175 kg
Coarse aggregate	664 kg
Fine aggregate	976 kg
Superplasticizer	12.60 kg (2.4% by wt. of cementitious material)
VMA (Powder)	52.5g (0.03% by wt. of water).

The following laboratory trials were carried out for final acceptance of the three SCC mixes.

- *Slump flow by Abrams cone.*
- $T_{50\ cm}$ *Slump flow*
- *J-ring*
- *V-funnel*
- *V-funnel at* T_5 *minutes*
- *L-box*
- *U-box*
- *Fill-box*
- *GTM Screen Stability Test*
- *Orimet*
- *Unit weight*
- *Air Content*
- *Initial and Final Setting time*
- *Compressive strength of 7, 28, and 56 days.*

Having successfully conducted the laboratory trials, they used the selected SCC mix for the mock–up trials for the construction of 12 m long beam with two column junctions. The width of beam was 300 mm and the depth was 750 mm. The beam had highly conjected reinforcements, especially at the column junctions.

At Tarapur, they have also used SCC for construction of three walls of a pump-house. The hight of the wall was 14.4 m and it was done in 5 pours.



If this is the situation, what else is possible except self compacting concrete ? Above shows the mock-up trial of SCC at Kaiga Nuclear Power Project, (Karnataka).

Use of SCC in nuclear power plants–Laboratory and Mock-up trials at Kaiga (12.21)

Nuclear power plants are designed with higher safety factors particularly in case of seismic loadings. This results in higher percentage of steel which leads to conjestion of reinforcement, particularly at a column-beam junctions. In addition, there are number of inserts which add to the difficulties for normal method of compaction.

At Kaiga, SCC of characteristic strength 30 MPa was used in the two Mock-up structures one being heavily reinforced column with two beams passing through it and the other being a thin wall (140 mm thick). The conjested reinforcement is shown in Fig. 12.32.

The mix proportions adopted is shown in table 12.23.

Table 12.23. Mix proportions adopted at Kaiga Mock up trial

Cement kg/m^3	*Fly ash* kg/m^3	*Water* kg/m^3	*20mm* *C.A. kg/m3*	*10mm* *F.A.* kg/m^3	*River sand* kg/m^3	*Crushed sand* kg/m^3	*Super plasticizer* kg/m^3	*VMA* kg/m^3
225	225	165	354	354	288	684	1.80	1.35

The trial mix data of self compacting concrete (Seven Samples) are Shown in table 12.24

Table 12.24. Trial mix data of self compacting concrete (7 samples)

Mix identi-fication no	GTM 29	GTM 30	GTM 31	GTM 32	GTM 33	GTM 34	GTM 35
Fresh concrete properties							
Flow, mm							
"0" min	690	710	700	675	670	680	710
"60" min	640	665	680	660	650	645	690
Flow T50, s							
"0" min	2.00	2.50	2.00	2.00	2.50	2.00	2.00
"60" min	2.50	3.00	2.50	2.50	2.50	2.00	2.50
V-Funnel T '0' min,s							
"0" min	8.00	9.00	7.00	8.00	8.00	9.00	8.00
"60" min	8.50	10.00	8.00	8.00	8.50	10.00	9.00
V-Funnel T'5' min,s							
"0" min	+0	+0.5	+0	+0.5	+0.5	+0	+0
"60" min	+1.0	+0	+0.5	+1.0	+1.0	+.05	+0.5
L-Box (h2/h1)							
"0" min	1.00	0.98	1.00	1.00	0.98	0.98	1.00
"60" min	0.96	0.93	1.00	0.96	0.96	0.94	0.96
U-Box ($h_1 - h_2$)							
"0" min	2.00	3.00	3.00	5.00	2.00	5.00	3.00
"60" min	5.00	5.00	3.00	8.00	5.00	7.00	7.00
Fill box							
"0" min	100	100	100	100	100	100	100
"60" min	98	95	100	96	95	98	94
Air content, percent	1.6	1.8	1.2	1.3	1.3	1.3	1.2
Unit, weight, kg/m^3	2298	2308	2312	2332	2290	2312	2304
Setting time, h							
Initial	10.00	9.50	8.55	10:15	9:15	9:00	10:30
Final	11:35	12:00	10:05	12:50	11:55	11:05	12:20
Strength data							
Compressive strength, MPa							
3-day	12.36	14.80	12.86	13.31	11.03	11.35	13.79
7-day	18.36	20.22	22.43	19.05	22.21	20.62	23.04
28-day	43.20	49.60	39.80	40.49	38.85	37.97	40.42
56-day	54.20	52.40	49.80	55.80	50.46	48.88	53.20
90-day	58.20	57.64	53.50	61.93	54.49	54.70	58.52
Split tensile, MPa							
7-day	2.64	2.44	2.64	2.06	2.33	2.45	2.61
28-day	3.92	3.62	3.35	3.77	3.92	3.77	4.18
Flexural strength, MPa 28-day	4.44	4.85	4.48	4.35	4.55	4.12	4.33
Permeability (DIN), min	Nil	Nil	Nil	Nil	Nil	Nil	Nil

In the trial diutan gum as VMA showed excellent result but it delayed the setting time too *much. Therefore they had to go for VMA with Synthetic polymer base. VMA dose of 0.8 per cent by weight of mixing water was used. Though the dosage of VMA with synthetic polymer base in liquid form is comparatively higher than diutan gum it was preferred for the following reasons.*

- *it facilitated easy disperson of VMA during large scale production of SCC at batching plant*
- *In case of diutan gum, not only it delayed the setting time, weighing and dispersion of a very small quantity (30–35 gm/m^3) in powder form in a batching plant was found to be difficult.*

Rapid chloride penetration test (RCPT) conducted on SCC showed an average charges passed was only 599 coulombs. Whereas the RCPT test on control mix showed 5040 coulombs. The surface finish of SCC both in case of column and wall was found to be excellent.

Trials at structural engineering research centre (SERC) Chennai (12.22)

Structural Engineering Research Centre at Chennai conducted some trial on SCC regarding structural behaviour and compared the same with conventionally vibrated concrete (CVC) of same strength (70 MPa). Reinforced Concrete (RC) beams of size 150 mm x 400 mm x 3000 mm with similar concrete shrength and identical reinforcement were cast and tested in flexure. They compared the structural behaviour such as load-deflection characteristics, crack widths, spacing of cracks, number of cracks, crack pattern, ultimate load carrying capacity, moment-curvature relationship, longitudinal strain in both concrete and steel for SCC and CVC.

The mix proportions of SCC and CVC are given in table 12.25

Table 12.25. Details of SCC and CVC mixture

Mix	Cement kg/m^3	Fly ash kg/m^3	Sand kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	Water/binder ratio	Superplasticizer by weight of binder
CVC	450	50	775	950	186	0.37	0.6
SCC	490	160	790	700	220	0.34	0.4

Table No. 12.26. Shows the Mechanical properties of SCC and CVC

Properties	Age, days	SCC	CVC
Compressive Strength MPa	1	18.3	19.3
	3	39.8	37.1
	7	54.2	46.8
	28	72.1	69.4
Split tensile Strength MPa	1	1.9	2.0
	3	4.7	4.6
	7	5.5	5.2
	28	6.2	5.8
Flexural strength MPa	28	7.6	7.1
Modulus of Elasticity GPa	28	37.5	38.9
Bond Strength MPa	28	18.6	17.6

From the study at SERC it was observed that although the SCC and CVC have defferent *mode of compaction, both mixes yielded similar strength at ages 1, 3, 7 and 28 days. Besides, compressive strength, split tensile, flexural and bond stregth of both mixcs were found to be similar. In view of the assured self compactability property, SCC can be adopted for any structural applications especially when there is conjested reinforcements.*

Studies at Hong Kong

An interesting study has been conducted in Hong Kong by Albert K.H. Kwan and Ivan Y.T. NG and this has been reported in Hong Kong Institution of Engineers Transactions (12.24). The study involves self compacting concrete of grade 80 to 100 MPa.

Structural Engineering Research Centre, Chennai Study, as reported in table 12.26, indicated that the strength parameter of self compacting concrete is slightly higher than conventionally vibrated concrete (CVC), it is intended to take one more view in this respect from the study carried out at Hong Kong.

It has been realised that it is not easy to achieve both high strength, which demands a low water/binder ratio, and high workability, which demands a high water content without increasing the binder paste volume, which may lead to thermal and shrinkage cracking problems. In the study at Hong Kong they investigated the feasibility of producing high strength (80 to 100 MPa), self compacting concrete with a binder paste volume of not more than 35%. They used Poly carboxylate-based (PC) superplasticizer. A total of 18 trial mixes were made in the study. The mix proportions are shown in table 12.27.

Table 12.27. Mix Proportions of the Trial Concrete Mixes. (12.24)

Mix no.	W/B ratio	PFA %	CSF %	PC %	Weight of Material kg/m3 Cement	PFA	CSF	Water	PC
1			0		435	145	0	139	18.3
2	0.24	25	5	3	401	143	29	137	18.0
3			10		367	141	57	136	17.8
4			15		335	140	84	134	17.6
5A			0	3	421	140	0	146	17.7
5B			0	4	421	140	0	146	23.6
5C	0.26	25	0	5	421	140	0	146	29.5
6			5	3	388	139	28	144	17.5
7			10	3	356	137	55	142	17.2
8			15	3	325	135	81	141	17.0
9					408	136	0	152	17.1
10	0.28	25		3	376	134	27	150	16.9
11					345	133	53	149	16.7
12					315	131	79	147	16.5
13					395	132	0	158	16.6
14	0.30	25		3	365	130	26	156	16.4
15					335	129	52	155	16.2
16					306	127	76	153	16.0

Note : W/B ratio stands for water/binder ratio
PFA stands for pulverised fuel ash (fly ash)
CSF stands for Condensed Silica fume
PC stands for polycarboxylate based superplasticizer

Table 12.28. Shows the workability results of the Trial Concrete Mixes [12.24]

Mix no.	W/B ratio	CSF %	PC %	Slump (mm) 0 min	30 min	60 min	Flow (mm) 0 min	30 min	60 min
1		0		205	185	185	420	395	363
2	0.24	5		240	235	235	545	513	513
3		10	3	205	205	210	465	435	428
4		15		225	225	220	480	500	445
5A		0	3	220	215	215	620	585	525
5B		0	4	255	235	225	725	650	620
5C	0.26	0	5	240	230	230	770	710	660
6		5	3	220	220	205	518	495	450
7		10	3	220	220	215	525	510	425
8		15	3	230	240	230	555	560	510
9		0		235	235	220	663	640	595
10	0.28	5	3	250	240	230	660	645	620
11		10		225	185	185	580	415	400
12		15		220	185	190	530	445	410
13		0		225	215	220	670	565	505
14	0.30	5	3	235	235	240	660	600	600
15		10		225	225	225	620	585	555
16		15		230	235	230	600	540	540

Table 12.29. Shows Strength Results of the Trial Mixes [12.24]

Mix no.	W/B ratio	CSF %	PC %	Compacted Cube Strength MPa 3-day	7-day	28-day	Uncompacted Cube Strength MPa 28-day	Strength ratio
1		0		67.7	80.2	98.1	83.3	0.85
2	0.24	5	3	70.4	88.1	109.1	109.0	1.00
3		10		70.1	89.0	114.6	107.8	0.94
4		15		70.1	94.6	116.6	113.4	0.97
5A		0	3	65.9	78.2	98.0	86.0	0.88
5B		0	4	64.6	77.5	101.2	97.4	0.96
5C	0.26	0	5	51.6	65.6	84.6	80.8	0.96
6		5	3	65.1	82.6	107.9	102.4	0.95
7		10	3	60.6	85.3	107.2	105.8	0.99
8		15	3	57.2	85.0	109.0	105.4	0.97
9		0		61.7	74.6	96.1	94.1	0.98
10	0.28	5	3	58.4	74.6	101.4	99.6	0.98
11		10		57.0	81.4	108.5	102.7	0.95
12		15		55.2	84.2	109.0	101.7	0.93
13		0		50.1	63.3	81.6	81.5	1.00
14	0.30	5	3	58.6	77.1	102.7	99.1	0.96
15		10		51.1	73.1	104.8	100.4	0.96
16		15		49.8	75.8	106.0	98.8	0.93

Note : The strength ratio is the ratio of the 28 day Uncompacted Cube Strength to the corresponding 28 day Compacted Cube Strength.

The table 12.28 shows that the polycarboxylate-based (PC) superplasticizer can produce self compacting concrete of grade 80 to 100 MPa with not more than 35% binder paste volume. Not only that, the PC superplasticizer could retain the required slump for 60 minutes.

Out of 18 mixes, 11 mixes have given more than or equal strength ratio of 0.95 at 3% superplasticizer dosage. Point to note is that the study carried out at Hong Kong, the self compacting concrete did not give higher strength than conventionally compacted concrete, as reported by SERC study at Chennai.

How Economical is Self Compacting Concrete ?

There is a feeling that cost of SCC is much higher than that of the corresponding normal stregth or high stregth concrete. It is seen that the cost of materials of SCC is about 10 – 15 percent higher. If one takes the other components of costs such as cost of compaction, finishing, etc, then one would realise that SCC is certainly not a costly concrete for comparable stregth.

Table No. 12.30 and Table 12.31 give comparision of cost of SCC and control concrete of similar stregth.

Table 12.30. Cost analysis of SCC and control concrete of similar stregths (12.23)

	Control Concrete			SCC	
	Rate Rs.	Quantity/kg	Amount Rs.	Quantity kg	Amount Rs.
Cement	3000/ton	450	1350	400	1200
Fly ash	1500/ton	–	–	175	263
Natural sand	900/ton	627	564	225	203
Crushed sand	850/ton	267	227	680	578
Course Aggregate					
20 mm	370/ton	510	189	405	150
10 mm	370/ton	430	159	330	122
Water	–	–	–	–	–
PCE – based admixture	140//	–	–	5.175	725
Superplasticizer	33//	11.25	371	–	–
Retarder	50//	1.35	68	1.725	86
VMA	40//	–	–	0.575	23
Total			2928		3350
Cost over control					16.05 %

Another example of cost analysis of SCC and control concrete of approximatly 40 MPa strength is given in Table 12.31 (12.23).

Table 12.31. Cost analysis of SCC and control concrete of approximately 40 MPa strengths

Material	Control concrete		SCC		Difference
	Quantity	Rate Rs.	Quantity	Rate Rs.	Rs.
Cement kg	395	3000/ t	300	3000/ t	– 285
Fly ash kg	130	1500/ t	170	1500/ t	+ 60
20 mm aggregate kg	639	370/ t	842	370/ t	+ 75
10 mm aggregate kg	462	370/ t	0	370/ t	– 171
Crushed sand kg	0	850/ t	235	850/ t	+ 200
Natural sand kg	660	900/ t	745	900/ t	+ 76.5

Admixture PCE /	–	140/ /	4.23	140/ /	+ 592
Admixture VMA /	–	40/ /	1.41	40/ /	+ 56.4
Admixture SNF /	5.25	33/ /	–	33/ /	– 173.0
Net					+ 430.9

∴ Cost above control = 16.8%

From the abvoe two examples it can be inferred that the material cost of SCC will be about 16 to 17% higher than ordinary concrete. But if one takes into considerations like savings in labour cost, rate of pouring, savings in repair work etc, the cost of SCC will be comparable with that of conventional concrete.

Bacterial Concrete (12.25)

Natural process, mainly weathering, deteriorates concrete by creating cracks, fractures and fissures, which result in reducing service life of structures. Even historical monuments built in stone also develop cracks and fissures. Grouting with epoxy or other cementitious materials are often adopted for remediating such defects.

Ramakrishan et al of South Dakota School of Mines and Technology have experimented a novel technique for remediating cracks and fissures in concrete structures by employing a selective microbial agency. In their attempt to seal cracks in concrete they used common soil bacteria called "Bacillus pasteruii" which during the process of their metabolic activities secrete or precipitate calcite ($CaCO_3$) which is responsible for sealing the cracks. Calcium Carbonate is a natural calcareous cementing material and a bonding agent which is environmental friendly unlike other bonding materials, like epoxy or calcium silicate hydrates (C–S–H gel) resulting from hydration of cement.

The idea was taken from earlier paper on consolidation of sand by using similar bacteria. Earlier similar technique was also employed for sealing cracks and fissures in oil wells. From earlier studies it was found that an average crack width of 2.7 mm in granite rock was remedied with a mixture of sand and silica fume by using same kind of common soil bacteria.

Experimental Investigations (12.25)

In the South Dakota School of Mines, the effectiveness of microbiologically induced caleite ($CaCO_3$) precipitation in remediating cracks in concrete was evaluated by comparing the compressive strength and stiffness of cracked specimens treated with bacteria and with those of the control specimens (without bacteria).

For studying the above, cement mortar beams of size 152 x 25.4 x 25.4 mm were prepared. The specimens were cured in water for 28 days and then kept exposed to air for another 3 months. Artificial cracks were cut. The width of the cracks were 3.2 mm for all the 10 specimens and the depth of cracks were 3.2 and 9.5 mm. The first 5 specimens were used as control without any filling in the cracks and were left exposed to air. The craeks in the remaining 5 specimens were filled with a mixture of sand and B. Pasteurii Bacteria. The final concentration of bacteria in the sand is of the order of 6.2×10^{10} cells per ml. is forced into the crack by knife edge. Then the beams with bacteria in their cracks were placed in a tray containing urea – $CaCl_2$ medium as food for bacteria and cured for 28 days. The medium was replaced after 14 days. Extreme care was taken not to disturb the precipitation of the calcium carbonate during change of the medium.

The control beams and those of beams with bacteria were tested for their stiffness after 28 days. It was found that stiffness value of beams whose cracks were filled with bacteria and sand were higher than those of control specimens. This was also true for beams with both *crack depths. But the beams with deeper cuts showed comparatively lower stiffness value than the beams with shallower cuts, meaning thereby the bacterial action and precipitation did not reach to the full depth of deeper cuts. Shallow cut beams showed improvements of stiffness by 23.9% while the deep cut beams showed an improvement of 14% over control specimens.*

Appropriate and similar investigations were also conducted with respect to the following

- *The effect of microbial calcite precipitation to various depth of cracks on the compressive strength of cement mortar cubes.*
- *The effect of different concentration of bacterial cells for cracks remediation, on the compressive strength of cement mortar cubes.*
- *The effect of B. Pasturii with various concentration on the modulus of rupture of the cracked cement mortar beams.*

The experimental results showed that the microbial remediation increased the compressive strength by approximately 80%, when compared to that of control specimens.

The cracked beams with bacteria showed 57% greater modulus of rupture than that of cracked specimens without bacteria.

Investigations on Durability Characteristics

Recently Ramakrishnan et al investigated the durability aspects of cement mortar beams made with different concentration of bacteria. The main objective was to determine whether the beams with bacteria performed better, when subjected to alkaline, sulphate and freeze-thaw attack.

They used Scan Electron Microscope (SEM) which is one of the most versatile instruments available for examination and analysis of micro structural characteristics of solids.

From the detail investigations they concluded that microbial culture generated in the cracks of mortar beams increased the compressive strength, stiffness and modulus of rupture. It was also found that the durability characteristics improved with the addition of bacteria. SEM examination established the fact that the calcite precipitation inside cracks has been responsible for the improvement in mechanical properties and permeability characteristics for enhancing the durability.

When bacterial concrete is fully developed, it may become yet another alternative method to replace OPC and its hozardous effect on environmental pollution.

Zeopolymer Concrete (12.26)

The emission of CO_2 coupled with non absorption of the same on account of deforestation etc has caused tremendous environmental pollution leading to global warming and other bad effects. It is estimated that about 7% of greenhouse gas is being emitted into the atmosphere annually on account of production of OPC alone.

Therefore, it is necessary to reduce the emission of CO_2 into atmosphere by reducing the cement production and consumption.

It is suggested that consumption of cement could be reduced by three ways.

- *Through economical mix design*
- *By replacing cement with fly ash by adopting high volume fly ash concrete (HVFC) or by using other supplementary cementitious materials.*
- *By using alternate binding materials for concrete such as Bacterial concrete or Geopolymer concrete. (no cement in concrete)*

Geopolymer Concrete

The term "Geopolymer" was coined by Davidovits in 1978. Geopolymer is an inorganic alumino-silicate polymer, synthesized from predominantly silicon and aluminium material such as fly ash. Alkaline solutions are used, to induce the silicon and aluminium atoms; in the source materials (fly ash), to dissolve to form gel. The polymerisation process may be assisted by applied heat followed by drying. The Geopolymer gel binds the loose coarse and fine aggregates to form geopolymer concrete. Geopolymer gel replace the C–S–H gel in cement concrete. Chemical reaction period is substantially fast and the required curing period may be within 24 to 48 hours.

Davidovits claimed that the Egyptian pyramids were built by casting geopolymer on site. He also reported the geopolymer possesses excellent mechanical properties, does not dissolve in acidic solutions, and does not generate any deleterious alkali-aggregate reaction even in the presence of high alkalinity. Some applications of geopolymer concrete are for marine structures, precast concrete products such as railway sleepers, sewer pipes etc.

B.V. Rangan et al of Curtain University of Technology, Perth, Australia [12.25] have carried out pioneering experimental work for the production of geopolymer concrete with a view to develop optimum mix design process and to establish the engineering properties such as compressive and tensile strengths, stress-strain relations, modulus of elasticity etc. The studies undertaken by them also aimed at establishing shrinkage, creep and durability properties, in particular, the corrosion resistance. The information given under geopolymer concrete in this book is freely drawn from the article published by RV Rangan et al in the proceedings of the seminar, INCONTEST 2003 held at Coimbatore, India.

In the experimental work low calcium (Class F) fly ash has been used. Sodium hydroxide in flake form Na(OH) with 98% purity and sodium silicate solutions (Na_2O = 14.7%), SiO_2 = 29.4% and water 55.9% by mass) were used as alkaline activators. To improve the workability of fresh concrete, a commercially available naphthaline based superplasticizer was used. Four types of locally available aggregates (at Perth, Australia) were mixed together.

Aggregates and the fly ash were mixed dry in a pan mixer for 3 minutes. The alkaline solutions and the superplasticizer were mixed together, and then added to the solid particles and mixed for another 3 to 5 minutes. The fresh concrete had a stiff consistency and was glossy in appearance. The mixture was cast in 100 x 200 mm cylinder in three layers. Each layer was tamped 60 times and vibrated for 10 seconds on a vibrating table. Five cylinders were prepared for each test variable.

Immediately after casting, the samples were covered by a film to avoid the loss of water due to evaporation during curing at an elevated temperature. After being left in room temperature for 30 – 60 minutes, the specimens were cured in an oven at a specified temperature for a period of time in accordance with the test variables selected.

Numerous trial mixes of geopolymer concrete were made and tested. The data collected from these studies indicated that the salient parameter affecting the compressive strength of geopolymer concrete are listed below :

- *Silicon oxide (SiO2) to aluminum oxide (Al_2O_3) ratio by mass in fly ash should preferably be in the range of 2.0 to 3.5 to make good concrete.*
- *Activator liquid to source material (fly ash) ratio by mass*
- *Concentration of sodium hydroxide NaOH liquid measured in terms of Molarity (M) in the range of 8 to 16 M.*
- *Sodium silicate to sodium hydroxide liquid ratio by mass. The effect of the parameter depends on the composition of the sodium silicate solution.*

- *Curing temperature in the range of 30° to 90°C*
- *Curing time in the range of 6 to 48 hours.*
- *Water content in the mixture.*

Table 12.32. Effect of Parameter on Compressive strength

Mix	*Concentration of NaOH liquid in Malarity (M)*	*Sodium Silicate / (NaOH) liquid ratio by mass*	*7 day compressive strength after curing at 60°C for 24 hours MPa*
A1	*8 M*	*0.4*	*17.3*
A2	*8 M*	*2.5*	*56.8*
A3	*14 M*	*0.4*	*47.9*
A4	*14M*	*2.5*	*67.6*

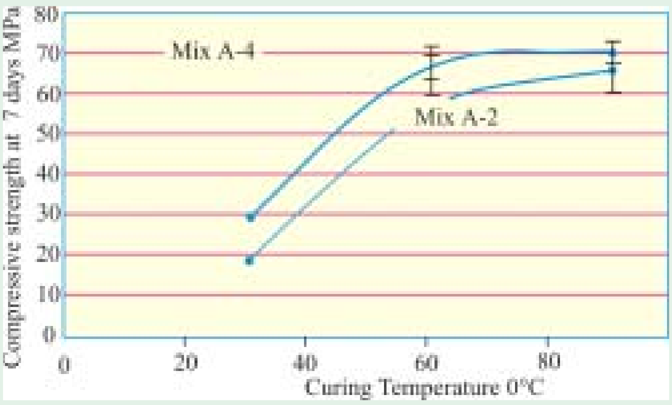


Fig. 12.33. Shows the Effect of curing temperature on compressive strength

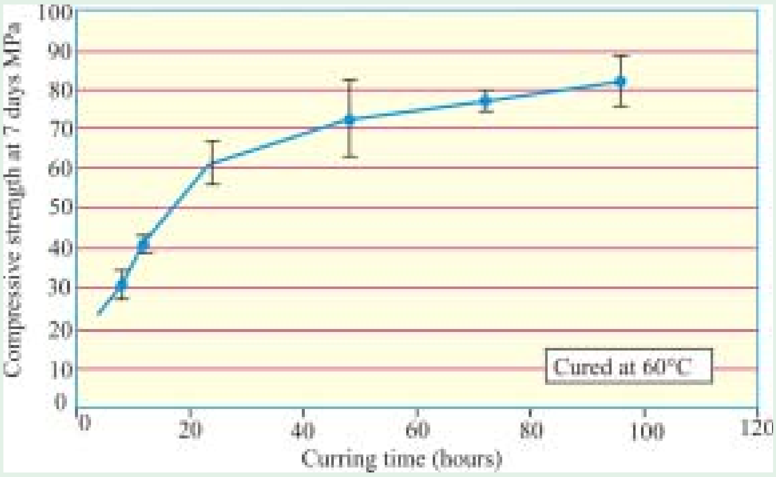
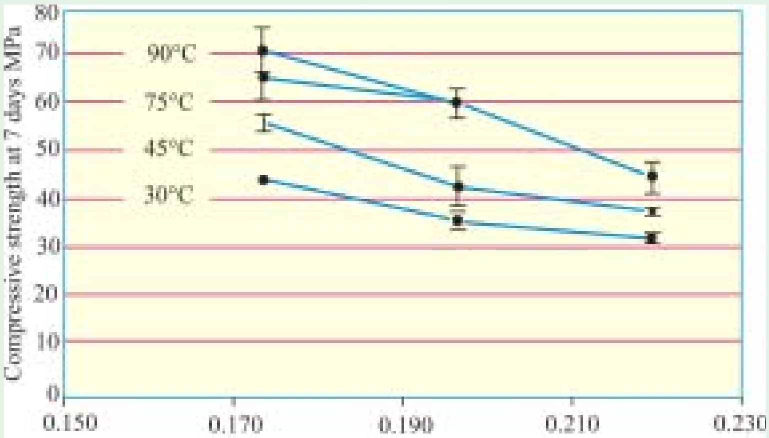


Fig. 12.34. Influence of curing time on compressive strength for Mix A2.

Effect of water contents in the Mix

In order to study the effect of water content on the compressive strength of geopolymer concrete several tests were carried out. The dose of superplasticizer to the mass of fly ash was taken as 1.5%.

The effect of water contents is shown in Fig. 12.35 by plotting the compressive strength versus water to geopolymer solid ratio by mass. For a given geopolymer concrete the total mass of water in the mix is taken as the sum of the mass of water in the sodium silicate solution plus the mass of water in sodium hydroxide solution plus the mass of extra water, if any, added to the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide flakes and the mass of sodium silicate solids.



Water/Geopolymer solids (by mass)

Fig. 12.35. Effect of water/Geopolymer solids ratio on compressive strength.

Concluding Remarks

Geopolymer concrete is a concrete made without using portland cement and as such it is environmentally friendly and energy efficient construction material with an enormous potential in many infrastrctural applications. The limited trial results show that geopolymer concrete undergoes very little drying shrinkage and moderately low creep, and possesses excellent resistance to sulphate attack.

Basalt Fibre Concrete and Concrete Reinforced with Basalt Fibre Reinforcements (12.27)

Concrete is a brittle material and possesses very low tensile strength; limited ductility and little resistance to cracking. Internal microcracks are inherently present in the concrete and its poor tensile strength propagates such microcracks and eventually leading to brittle failure of concrete.

To improve brittle behaviour, impact resistance and tensile strength, fibres of different kind such as steel fibre, glass fibres, polypropylene fibres carbon fibres etc. were used in the past. The latest fibre in the list is basalt fibre.

One of the causes of failure of reinforced concrete structures is due to corrosion of steel reinforcement. It was reported that about 40 per cent of failure of RCC structures was due to corrosion of reinforcement. Use of nonferrous fibre-reinforced polymer (FRP) reinforcement *bars making use of glass fibres or carbon fibres etc. in conjunction with suitable resins have been used to mitigate chloride induced corrosion and to impart many better mechanical properties to reinforced concrete. The latest one in this direction is the basalt fibre reinforcement bars in concrete.*

Basalt Continuous Fibers

V. Ramakrishnan and others in South Dakota school of Mines and Technology have investigated, for the first time in the world, the use of basalt fibres and use of basalt fibre reinforcement in concrete. They used both plain bars and modified bars with corrugation and indentation bars. The result of the investigations showed that the rebars made from basalt fibre is a viable alternative to the conventional steel reinforcement as it is found to be superior in many respects.

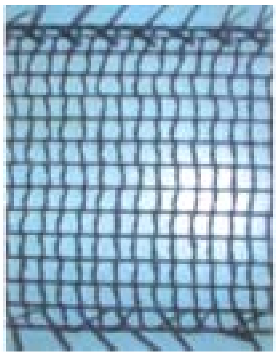
Basalt fibres are manufactured in a single-stage process by melting naturally occurring pure basalt rock. They are abundantly available, environmentally safe, nontoxic, non corrosive, non-magnatic, possess high heat stability and insulating characteristics. The tensile strength of continuous basalt fibres is about twice that of E-glass fibres and modulus of elasticity is about 15 to 30 % higher. Basalt fibres in an amorphous state exhibit higher chemical stability than glass fibres. When exposed to water at 70°C basalt fibres maintain their strength for 1200 hours, whereas the glass fibres do so only for 200 hours.

Basalt fibre concrete (12.27)

Investigations were carried by Ramakrishan et al to find out the following :

- *The properties of fresh concrete with and without basalt fibres*
- *The properties of hardened concrete such as compressive strength, static modulus,*

Basalt Fibres



Basalt Fibres Reinforcement Mesh

Woven Fabrics made from Basalt Fibres

static flexural strength, unit weight and impact strength.

- The toughness indices by ASTM method with the help of load deflection curves.
- The flexural toughness factor and equivalent flexural strength by the Japanese standard method.

The investigation involves making 5 mixes and the dosages of basalt fibres added to the concretes were 0.1, 0.25, 0.4 and 0.5 by volume. One control mix was also done. The mix proportions are given in table 12.33.

Table 12.33. Mix proportions for Basalt fibre Concrete For 0.057 cubic metre

Mix designation	Water/ Cement Ratio	Fibres		Weight in kg			
		Kg	Vol. %	Cement	coarse Agg.	Fine Agg.	Water Kg.
B1	0.5	–	–	20.85	53.1	53.1	10.25
B2	0.5	0.68	0.5	20.85	53.1	53.1	10.25
For 0.071 cubic metre							
B3	0.5	0.5	0.4	25.68	66.5	66.5	12.83
B4	0.5	0.43	0.25	25.68	66.5	66.5	12.83
B5	0.5	0.17	0.1	25.68	66.5	66.5	12.83

Basic mix proportions for 1 m3 of concrete

Cement Kg	Water Kg	Coarse Agg Kg	Fine Agg. Kg	Water/ Cement Ratio
361.9	188	937.4	937.4	0.5

Plastic Properties

The freshly mixed concrete was tested for slump, air content, unit weight, concrete temperature, Vee-Bee time etc.

In all the tests the basalt fibre reinforced concrete did not differ much from plain concrete accept that slump and Vee-Bee slump decreased with the addition of fibres, and Vee-Bee time increased with the addition of fibres.

Test for hardened Concrete

For hardened concrete, compressive strength test, static modulus, flexural strength test, behaviour of load-deflection and impact test by drop weight test method, were conducted. In all these tests much desirable properties were exhibited by basalt fibre concrete than the plain concrete.

Conclusions.

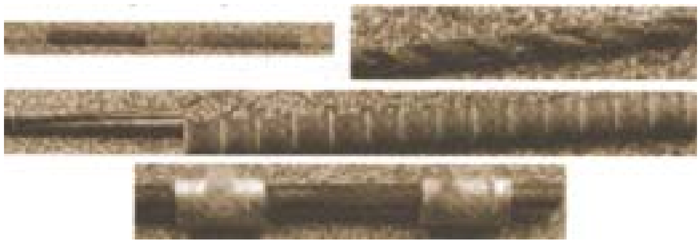
- Satisfactory workability can be maintained with the addition of basalt fibres up to 0.5 % by volume. A higher % of fibres could be used without causing any balling or segregation.
- Compared to the control concrete, there was considerable increase to the toughness and impact strength for the basalt fibre concrete.
- The most important contribution due to the addition of basalt fibre in concrete is the

change of mode of failure from a brittle to ductile failure, when subjected to compression, bending and impact.

- *Based on earlier research conducted with other fibers in concrete, it is suggested that the length of the fibres could be increased from 25 mm to 50 mm for better performance.*

Concrete Reinforced with basalt fibre reinforcement

Basalt composite rebars are made by utilising basalt fibres and epoxy resin binder. They are non corrosive and consist of 80% fibres. They have tensile strength three times that of the steel rebars. Wherever the corrosion problem exists, basalt fibre composite rebars have the potential to replace steel bars in reinforced concrete structures. Currently the FRP rebars available in the market are made of E-glass fibre and they suffer from lack of durability under extreme alkaline environments and are costly.



Modified basalt fibre reinforcement

Other advantages are that the basalt rebars weighs only one-third of the steel rebars. Thermal coefficient of expansion is very close to that of concrete. The high mechanical performance to price ratio of basalt bars, combined with corrosion resistance to alkaline attack are further justification for the use of basalt bar in place of steel bars.

To evaluate the properties of concrete reinforced with basalt fibre reinforcements, studies were conducted by Ramakrishan et al at South Dakota school of Mines and Technology in five phases.

In phase I they directed their studies to flexure test using plain basalt bars as reinforcement in concrete beams. In phase II they conducted flexure test of plain basalt bar reinforced concrete beam, concrete 3-dimensionally reinforced with basalt fibres. In phase III they conducted bond test on basalt rebars and cables. In phase IV they conducted investigation for determination of cracking and ultimate loads for extremely under-reinforced beams and in phase V the trials were conducted to determine cracking and ultimate loads for five under-reinforced beams.

The results obtained from Phase I and II revealed that the actual ultimate failure moments of basalt rebar reinforced concrete beams were less than the theoretically calculated ultimate moments. This was due to bond failure between rebars and concrete. To avoid this type of failure, they developed basalt cable with corrugations and rods with slots, barriers and anchors; for improving the bond between the bars and the concrete. In phase III to V, they studied the bond between modified basalt rebars and concrete. The photographs of the modified basalt rebars are shown in fig. 12.36.

Results of the investigations

Phase I

- *The beams reinforced with plain basalt bars failed in flexure, due to inadequate bond between the rod and the concrete. All the actual ultimate moments were much less than the calculated ultimate moments due to the bar pullout failure.*

Phase II

- *The beams with 3D-fibres and rebars exhibited a primary failure in flexure and shear followed by a secondary failure on splitting.*
- *The 3D-fibres caused a ductile failure of the beam and also increased the actual cracking moment capacity of the beam.*
- *All the actual ultimate moments were much less than the calculated ultimate moments due to bar pullout failure.*

Phase III to V

- *The bond between all the modified basalt rebars and concrete was extremely good*
- *The experimental ultimate moments nearly matched or exceeded the calculated moments for all the beams tested.*
- *The experimental ultimate moment was much higher than the first crack moment in all the beams tested, indicating a good bond between rebar and concrete.*
- *The deflections were considerable, indicating adequate ductility.*
- *All the beams had primary flexural failure and a few beams had secondary shear failure.*
- *There was no slip of the rebars in any of the beams tested and there was no evidence of bond failure between the concrete and the modified basalt rebars and twisted cables.*
- *In general, the basalt rebars are suitable for use in reinforced concrete structures.*

Basalt continuous fibres are manufactured, apart from other places, at kottingbrunn, Austria, in the patented name of BaXalt Technologie GmbH, established during 2003. A cooperative union has been formed with the South Dakota School of Mines (Prof Ramakrishnan) and with the Vienna Technical University for process engineering (Prof Marini) BaXalt Technologie, by way of passionate innovative strategies will revolutionize the fibre industries.

The market has not seen this magnitude of cutting edge technology since 1940's when fibre glass was first invented.

Basalt continuous fibres will fill the niche between fibre glass and carbon fibres. Subsequently basalt exhibits a vital competitive edge due to higher Modulus of elasticity, chemical consistency, temperature stability and low cost raw material.

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