A

Major Project

On

Strength and Durability Aspects of Silica Fume Blended Concrete in Acidic Environment

Submitted in Partial fulfilment of the requirement
for the award of the degree of

MASTER OF ENGINEERING
(Structural Engineering)

Submitted by
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Under the Guidance of
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2009-2010

CANDIDATE DECLARATION AND CERTIFICATE

This is to declare that the major project on **"Strength and Durability aspects of Silica Fume Blended Concrete in Acidic Environment"** is a bonafide record of work done by me for partially fulfillment of requirement for the degree of M.E., Civil Engineering (Structural Engineering) from Delhi College of Engineering, Delhi.

This project has been carried out under the supervision of **Dr. A.K. Sahu, Assistant Professor**, Delhi College of Engineering, Delhi.

I have not submitted the matter embodied in this report to any other University or Institution for the award of any Degree or Diploma.

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This is to certify that the above statement laid by the candidate is correct to best of my knowledge.

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ABSTRACT

Acidic environment represents one of the most severe conditions to which structures may be subjected and it is found due to sub soil, industrial waste disposal, housing waste disposal, ground water, rainy water. Acidic environment is harmful to concrete as they can lead to increase in concrete volume and consequent cracking. Concrete structures are also used for storing liquids, some of which are harmful for concrete. In industrial plants, concrete floors come in contact with liquids which damage the floor. In damp conditions SO_2 and CO_2 and other acidic fumes present in the atmosphere affect concrete by dissolving and removing part of the set cement. In fact, no Portland cement is acidic resistant. Concrete is also attacked by water containing free CO_2. Sewerage water also very slowly causes deterioration of concrete.

Sulphates are generally found in ground water and sub-soil. Sea water also contains large quantity of sulphates. Sulphates can be naturally occurring or could be as a consequence of industrial waste disposal. Calcium, sodium, magnesium and ammonium sulphates (increasing order of hazard) are harmful to concrete as they can lead to increase in the concrete volume and consequent cracking. Calcium sulphate reacts with calcium aluminate present in cement hydrates forming an expansive ettringite. Sodium sulphate reacts with calcium hydroxide and forms expansive gympsum in presence of aluminates and may turn lead to formation of ettringite. Magnesium sulphate reacts with cement compounds decomposing the cement itself and subsequently producing gypsum and ettringite.

For minimizing the danger of sulphate attack, low C_3A content are recommended. Sulphate resisting cement with very low C_3A is most suitable. However, if chlorides are also present in the ground water and sub soil in addition to sulphate then it is not recommended for the use in view of the vulnerability of low C_3A cement to chloride ion diffusion. Blended cements are

most preferred when both sulphates and chlorides are present in an environment at the same time.

Blended cements have low C3A content and also enable production of pastes containing small amount of calcium hydroxide. The pozzolana cements have also shown high sulphate resistance which is probably due to the composition and the structure of the pores in hydrated pastes. The resistance of concrete to sulphate attack can be tested by storing the specimens in a solution of sodium or magnesium sulphate or in a mixture of these two.

Using of silicafume in concrete it improves very high strength and durability characteristic of hardened concrete.

In the present study the influence of acidic environment with time on the mechanical behaviour of concrete has been investigated. The cement concrete produced with silicafume replaced with 5% and 15% of cement quantity of grade M-35 and M-45 concrete. Super plasticizer is used in concrete mix to make high workability of slump (100-120 mm). These mixes are used to prepare specimens of cube of size 150 x 150 x 150 mm, cylinders 150 mm diameter and 300 mm height, beams 100 x 100 x 500 mm Half nos. of specimens are cured in potable water and half nos. of specimens are cured in 0.2 N H_2SO_4 Acidic water for 7 days, 28 days and 90 days. Then the mechanical properties are determined which includes compressive strength, flexural strength, split tensile strength, loss in mass, rebound number and ultrasonic pulse velocity test. It is concluded that compressive split tensile strength and flexural strength of the specimen are reduced after acidic environment exposure.

CHAPTER 1

INTRODUCITON – I

Cement concrete is by far the most widely used construction material today. The versatility and mouldability of this material is high compressive strength, high durability and less detoriation against environmental effects. It is obtained by mixing cement, water and stone aggregates and admixtures.

The strength, durability and other characteristics of concrete depend upon the properties of its ingredients on the proportions of mix, the method of compaction and other controls during placing, compaction and curing. The popularity of the concrete is due to the fact that from the common ingredients it is possible to tailor the properties of concretes to meet the demands of any particular situation.

A pozzolana is a finely ground siliceous glassy material which as such does not possess cementing property in itself but reacts in the presence of water with lime at normal temperature to form compounds of low solubility having cementing properties. This action is called pozzolanic action. This improves the strength, permeability and durability of concrete. The pozzolanic material silica fume is a waste by product of the manufacture of silicon or ferro silicon alloys. It is produced from high purity quartz and coal in a submerged arct electric furnace. The silica fume is particularly valued in making high performance concrete. Silica in the form of amorphous structure is highly reactive and the smallness of the particles speeds up the reaction with calcium hydroxide produced by the hydration of Portland cement in concrete. The very small particles of silica fume can enter the space between the particles of cement and thus improve the strength and durability requirements etc. i.e. high strength concrete. Additional benefits of replacing cement by silica fume are reduced bleeding and improved cohesion of the concrete mix.

Though concrete is quite strong, mechanically it is highly susceptible to chemical attack, and thus concrete structures get damaged and even fail unless some measures are adopted to counteract deterioration of concrete and thereby increasing the durability of the concrete structure.

The durability of concrete can be defined as its resistance to the deteriorating influence of both external and internal agencies. The external or environmental agencies causing the loss of durability include weathering, attack by the natural or industrial liquids and gases, etc. Whereas the internal agencies responsible for the lowering of durability are harmful alkali aggregate reactions, volume changes due to non-compatible thermal and mechanical properties of aggregate and cement paste, presence of sulphates and chlorides from the ingredients of concrete etc. In the case of reinforced concrete the ingress of moisture or air may lead to corrosion of steel and cracking and spalling of concrete cover.

A durable concrete is dense, workable having as low as permeability as possible under the given situation. The recommendations for making durable concrete usually envisage limits for maximum water-cement ratio, thickness of cover, type of cement and the amount of chlorides and sulphates in the concrete.

The gradual deterioration of concrete by chemically aggressive agents is called concrete corrosion. Basically corrosion of concrete is a physico-chemical process and the extent of deterioration caused to it by the aggressive agents is dependent upon the properties of the constituents of concrete and the corrosive media. Any factor which may help in the development of cracks in concrete will promote the penetration of the aggressive solution and gases, and will lead to the faster deterioration of concrete structure.

As a structural engineer we are supposed to make our structures perform better against Acidic Environment, Concrete elements such as columns, slab and walls may be subjected to extreme acidic conditions. In order to assess the performance of reinforced concrete members it is important to understand the changes in the concrete properties due to acidic environment exposure. Since the high strength concrete produced may contain Pozolanic materials silica fume in addition to cement, it is also becoming necessary to investigate the influence of the binder material type on the concrete properties under acidic environment.

OBJECTIVE :

The main objective of this project is to study the mechanical properties of high strength silica fume blended cement concrete subjected to acid curing. It consists of following point

1) Procurement of material in the lab.
2) To prepare the design mix.
3) To make the specimens of silicafume blended cement concrete cubes cylinders and beams.
4) To place the specimens in the acidic water for curing for various span of time.
5) To perform the destructive and Non-destructive tests on the concrete specimens.
6) To observe the change in mechanical behaviour of concrete.

With this objective, literature has been reviewed which is depicted in the successive chapters.

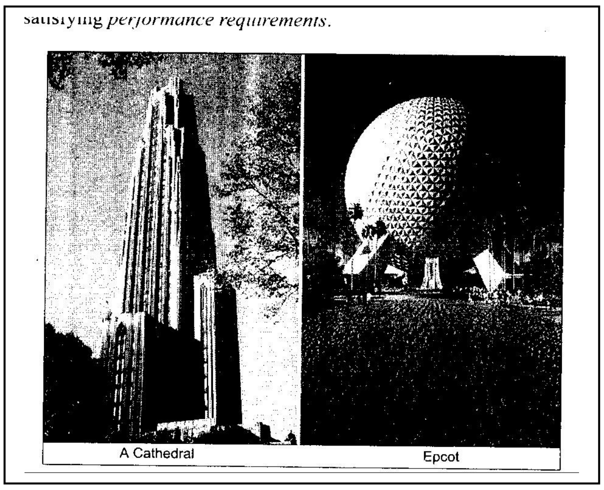
CHAPTER - 2

LITERATURE REVIEW

CONCRETE

2.1 Construction Material

Concrete is the most widely used man-made construction material in the world, and is second only to water as the most utilized substance on the planet. It is obtained by mixing cementing materials, water and aggregates, and sometimes admixtures in required proportions. The mixture when placed in forms and allowed in cure, hardens into a rock like mass known as concrete. The hardening is caused by chemical reaction between water and cement and it continues for a long time, and consequently the concrete grows stronger with age. The hardened concrete may also be considered as an artificial stone in which the voids of larger particles (coarse aggregate) are filled by the smaller particles (fine aggregates) and the voids of fine aggregates are filled with cement. In a concrete mix the cementing material and water form a paste called cement water paste which in addition to filling the voids of the fine aggregate, coats and surface of fine and coarse aggregates and binds them together as it cures, thereby cementing the particles of the aggregates together in a compact mass



A Cathedral Epcot

Fig. (2.1) Architectural use of concrete

The strength, durability and other characteristics of concrete depend upon the properties of its ingredients on the proportions of mix, the method of compaction and other controls during placing, compaction and curing. The popularity of the concrete is due to the fact that from the common ingredients, it is possible to tailor the properties of concrete to meet the demands of any particular situation. The images in Fig. (2.1) illustrate the mouldability of concrete in architectural forms. The advances in concrete technology have paved the way to make the best use of locally available materials by judicious mix proportioning and proper workmanship, so as to produce concrete satisfying performance requirements.

2.2 Ingredients

The key to producing a strong, durable and uniform concrete i.e. high performance concrete lies in the careful control of its basic and process components. These are the following :

Cement : Portland cement, the most widely used in cementing ingredients in present day concrete comprises phases that consist of compounds of calcium, silicon, aluminum, iron and oxygen.

Aggregate : These are primarily naturally occurring inert granular materials such as sand, gravel or crushed stone. However technology is broadening to include the use of recycled materials and synthetic products.

Water : The water content and the minerals and chemicals dissolved in it are crucial to achieving quality concrete.

Chemical admixtures : These are the ingredients in concrete other than Portland cement, water, and aggregates that are added to the mixture immediately before or during mixing to reduce the water requirements, accelerate/retard setting, or improve specific durability characteristics.

Supplementary cementing materials : Supplementary cementing materials, also called mineral additives, contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are natural Pozzolanas fly ash, ground granulated blast-furnace slag, and silica fume. After concrete is placed, these components must be cured as a satisfactory moisture content and temperature must be carefully maintained for a sufficiently long time to allow adequate development of the strength of the concrete.

2.3 Ready Mix Concrete

The concept of treating concrete in its entity as a building material rather than its ingredients is gaining popularity. The user is now interested in the concrete having the desired properties without bothering about the ingredients. This concept is symbolized with the progress of ready mixed concrete industry where the consumer can specify the concrete of his needs, and further in the pre-caste concrete industry where the consumer obtains finished structured components satisfying the performance requirements.

2.4 Reinforced Cement Concrete

Concrete has high compressive strength, but its tensile strength is very low. In situations where tensile stresses are developed, the concrete is strengthed by steel bars or shorts randomly distributed fibres forming a composite construction called reinforced cement concrete (RCC).

2.5 Pre stressed Cement Concrete

Sometimes the tensile stresses are taken care of by making compressive stresses in the concrete so that the initial compression neutralizes the tensile stresses. Such a construction is known as prestressed cement concrete construction.

2.6 Concrete Mix Proportioning Classification

2.6.1 Nominal Mix Concrete

The main ingredients of concrete are cement, fine aggregate (sand) and coarse aggregates (gravel or crushed rock). It is usual to specify a particular concrete by the proportions (by weight) of these constituents and their characteristics e.g. (a) 1:2:4 concrete refers to a particular concrete manufactured by mixing cement, sand and broken stone in a 1:2:4 ration (with a specified type of cement, water-cement ratio, maximum size of aggregate, etc.) This classification specifying the proportions of constituents and their characteristics is termed as prescriptive specifications and is based on the hope that the adherence to such prescriptive specifications will result in satisfactory performance.

2.6.2 Design Mix Concrete

The concrete making materials being essentially variable result in the production of mixes of variable quality. In such a situation, for high performance concrete, the most rational approach of mix proportioning is to select proportion with specific materials in a mind which possess more or less unique characteristics. This will ensure the concrete with the appropriate properties to be produced, most economically. Other factors like workability, durability, compatibility, equipment available, curing methods adopted, etc. also influences the choice of the mix proportions. The mix proportion so arrived is called the designed mix.

2.7 Properties of Concrete

Concrete making is not just a matter of mixing ingredients to produce a plastic mass, but good concrete has to satisfy performance requirements in the plastic or green state and also the hardened state. In the plastic state the concrete should be workable and free from segregation and bleeding. Segregation is the separation of coarse aggregate and bleeding is the separation of concrete at paste from the main mass. The segregation and bleeding results in poor quality of concrete. In its hardened state concrete should be strong, durable and impermeable, and it should have minimum dimensional changes.

2.8 Grades of Concrete

Concrete is generally graded according to its compressive strength. The various grades of concrete as stipulated in IS:456-2000 and IS:1343-1980 are given in Table 2.1. In the designation of concrete mix, the letter M refers to the mix and the numbers to the specified characteristics strength of 150 mm work cubes at 28 days, expressed in MPa (N/mm^2). The concrete of grades M5 and M7.5 is suitable for lean concrete bases, simple foundations, foundations for masonry walls and other simple or temporary reinforced concrete constructions. These need not be designed. The concrete of grades lower than M15 is not suitable for reinforcement works and grades of concrete lower than M30are not to be used in the prestressed concrete works.

Table 2.1

Group	**Ordinary Concrete**			**Standard concrete**							**High Strength concrete**				
Grade Designation	M10	M15	M20	M25	M30	M35	M40	M45	M50	M55	M60	M65	M70	5	0
Specified Characteristic Strength at	10	15	20	25	30	35	40	45	50	55	60	65	70	5	0

28 days, MPa															

2.9. Water Cement Ratio

In engineering practice, the strength of concrete at a given age and curved in water at a prescribed temperature is assumed to depend primarily on two factors only : the water / cement ratio and the degree of compaction.

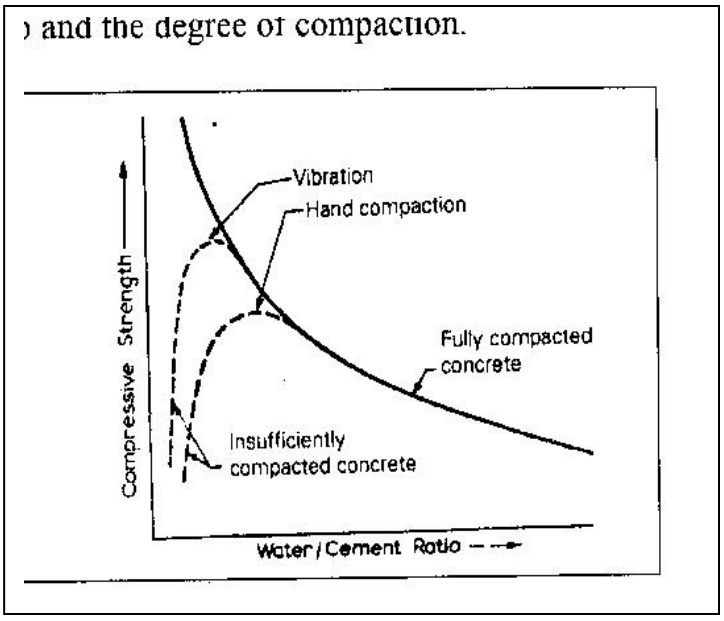


Fig. (2.2) The relation between strength and water/cement ratio of concrete

When a concrete is fully compacted, its strength is taken to be inversely proportional to the water/cement ratio. This relation was preceded by a so-called 'law', but really a rule, established by Duff Abrams in the year 1919. He found strength to be equal to :

$$f_c = \frac{K_1}{K_2^{w/c}}$$

where w/c represents the water/cement ratio of the mix (originally taken by volume), and K_1 and K_2 are empirical constants.

Abram’s rule, although established independently, is similar to a general rule formulated by Rene Feret in 1896 in that they both relate strength of concrete to the volumes of water and cement. Feret’s rule was in the form :

$$f_c = K\left(\frac{c}{c+w+a}\right)^2$$

Where f_c is the strength of concrete, c, w and a are the absolute volumetric proportions of cement, water, and air, respectively, and K is constant.

It may be recalled that the water/cement/ratio determines the porosity of the hardened cement paste at any stage of hydration. Thus the water/cement ratio and the degree of compaction both affect the volume of voids in concrete, and this why the volume of air in concrete is included in Feret's expression.

Nevertheless in practice the water/cement ratio is the largest single factor in the strength of fully compacted concrete. Perhaps the best statement of the situation is that by Gilkey.

"For a given cement and acceptable aggregates, the strength that may be developed by a workable, properly placed mixture of cement, aggregate, and water (under the same mixing, curing, and testing conditions) is influenced by the :

a) ratio of cement in mixing water
b) ratio of cement to aggregate
c) grading, surface texture, shape, strength, and stiffness of aggregate particles
d) maximum size of the aggregate."

2.10. Gel / Space Ratio

The influence of the water/cement ratio on strength does not truly constitute a law because the water/cement ratio rule does not include many qualifications necessary for its validity. Strength on any water/cement ratio depends on : the degree of hydration of cement and its chemical and physical properties; the temperature at which hydration takes place; the air content of the concrete; and also the change in the effective water/cement ratio and the formation of cracks due to bleeding. The cement content of the mix and the properties of the aggregate cement paste interface are also relevant.

It is more correct, therefore, to relate strength to the concentration of the solid products of hydration of cement in the space available for these products. Powers had determined the relation between the strength development and the gel/space ratio. The ratio is defined as the ratio of the volume of the hydrated cement paste to the sum of the volumes of the hydrated cement and of the capillary pores.

In the following calculations the products of hydration of 1 ml of cement will be assumed to occupy 2.06 ml ; not all the hydrated material is gel, but as an approximation we can consider it as such. Let

c= mass of cement

v_c = specific volume of cement, that is volume of unit mass

w_0 = volume of mixing water, and

α = the fraction of cement that has hydrated

Then, the volume of gel is 2.06 $v_c\alpha$, and the total space available to the gel is $c\ v_c\alpha + w_0$. Hence, the gel / space ratio is

$$r = \frac{2.06 v_c \alpha}{v_c \alpha + \frac{w_0}{c}}$$

The actual relation between the compressive strength of mortar and the gel/space ratio is shown in fig. (3) it can be seen that strength is approximately proportional to the cube of the gel/space ratio. The volume of air present in the cement paste is A, the ratio w_0/c in the above expression is replaced by (w_0+A)

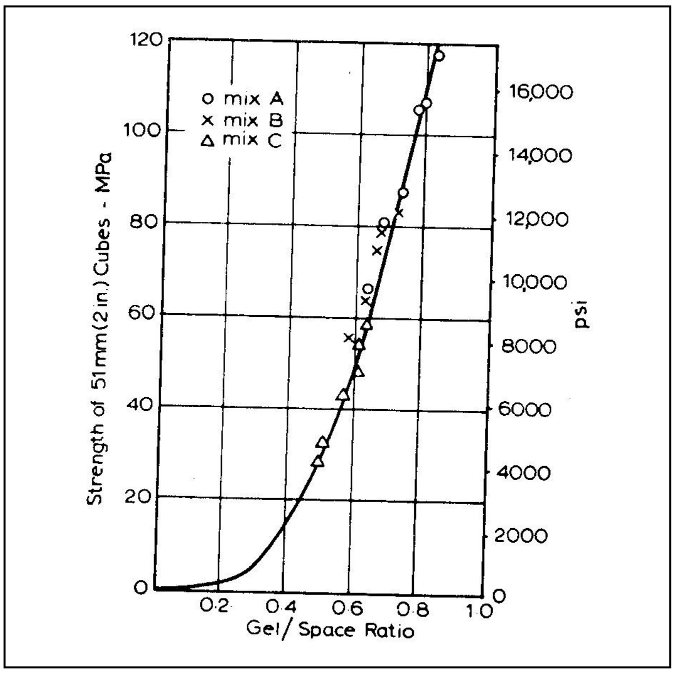


Fig. (2.3) Relation between the compressive strength of mortar and gel/space ratio

The resulting expression for strength is similar to that of Feret but the ratio used here involves a quantity proportional to the volume of hydrated cement instead of the total volume of content, and is thus applicable at any stage.

2.11. Porosity

The strength of concrete is fundamentally a function of the volume of voids in it. The relation between strength and the total volume of voids is not a unique property of concrete but is found also in other brittle materials in which water leaves behind pores. If the strengths of different materials are expressed as a fraction of their respective strengths at a zero porosity, a wide range of materials conform to the same relation between relative strength and porosity, as shown in Fig. (2.4) for plaster, steel, iron, alumina and zirconia. This general pattern is of interest in understanding the role of voids in the strength of concrete. Moreover, the relation of Fig. (2.4) makes it clear why cement compacts which have a very low porosity, have a very high strength.

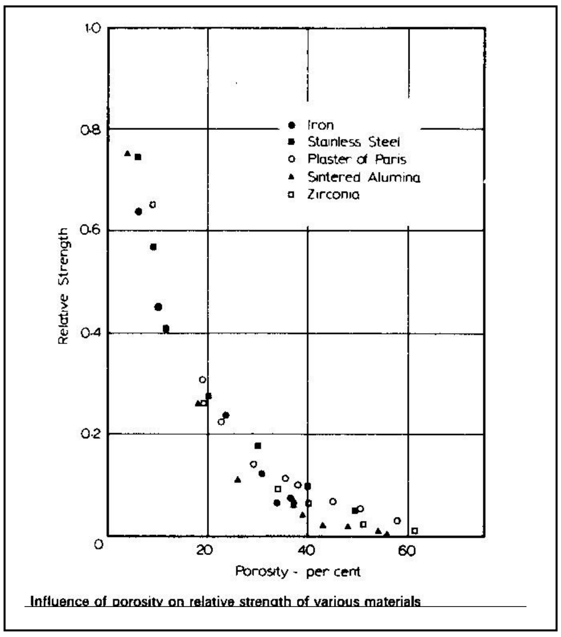


Fig. (2.4) Influence of porosity on relative strength of various materials

Strictly speaking, strength of concrete is influenced by the volume of all voids in concrete; entrapped air, capillary pores, gel pores, and entrained air.

The influence of the volume of pores on strength can be expressed by a power function of the type :

$$f_c = f_{c,0}\,(1-p)^n$$

where , p = porosity, that is, the volume of voids expressed as a fraction of the total volume of concrete.

f_c = strength of concrete with porosity p

$f_{c,0}$ = strength at zero porosity, and

n = a coefficient, which need not to be constant.

The effect of pores smaller than 20 nm in diameter was found to be negligible. The relation between the strength of mortar and porosity based on volume of pores larger than 20 nm in diameter is shown in fig. (2.5). Consequently, in addition to total porosity, the effect of pore size distribution on strength must be considered . Generally at a given porosity, smaller pores lead to a higher strength of the cement paste.

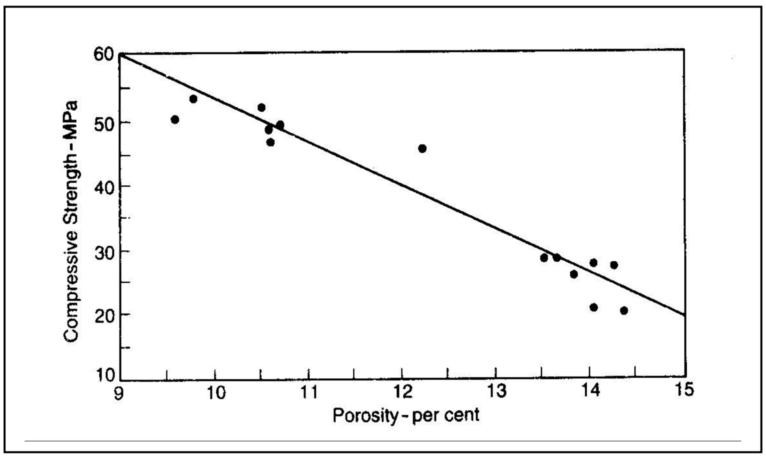


Fig. (2.5) Relation between compressive strength of mortar and porosity calculated from the volume of pores larger than 20 nm in diameter.

Although the pore size is, for convenience, expressed as a diameter, all the pores are by no means cylindrical or spherical in shape; the 'diameter' represents a sphere with the same ratio of volume to surface area as the totality of pores. It is only macropores, that is those whose diameter is larger than about 100 nm, that are approximately spherical. Figure (2.6) shows a diagrammatic representation of the various pores. The spherical pores originate from residual air bubbles or from imperfect cement particle packing but are not readily detected in porosimetry measurements because they are accessible only through connecting pores which have a narrow entrance.

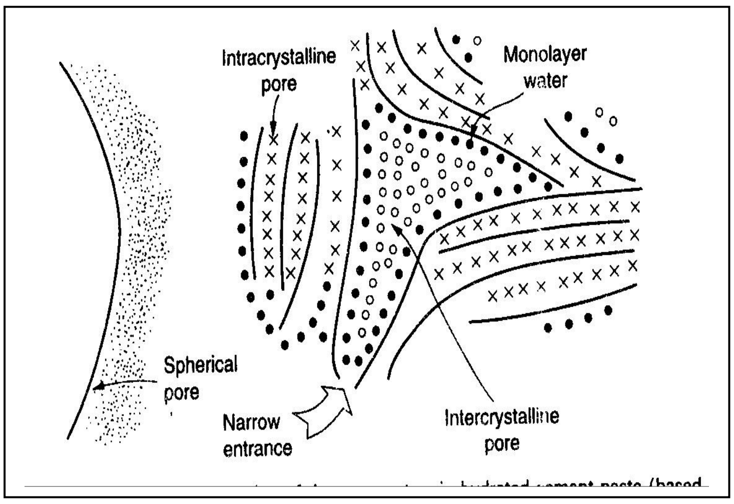


Fig. (2.6) Diagrammatic representation of the pore system in hydrated cement paste.

In concrete, the pore characteristics of the hydrated cement are somewhat different because of the influence of coarse aggregate particles on the cement paste in their neighbourhood. Winslow and Liu found that, with the same paste composition and at the same degree of hydration, the presence of coarse aggregate results in an increased porosity; even the presence of fine aggregate has a similar, but smaller, effect. The difference in porosity between concrete and neat cement paste, at the same water/cement ratio, increases with the progress of hydration and arises from the presence in concrete of some pores larger than those which can exist in neat cement paste.

2.12 Influence of properties of coarse aggregate on strength

The stress at which the cracks develop depends largely on the properties of the coarse aggregate; smooth gravel leads to cracking at lower stress than rough and angular crushed rock, probably because mechanical bond is influenced by the surface properties and, to a certain degree, by the shape of the coarse aggregate.

The properties of aggregate affect thus the cracking load, as distinct from the ultimate load, in compression and the flexural strength in the same manner, so that the relation between the two quantities is independent of the type of aggregate used. Fig. (2.7) shows Jones and Kaplan's results, each symbol representing a different tpe of coarse aggregate. On the other hand, the relation between the flexural and compressive strengths depends on the type of coarse aggregate used because (except in high strength concrete) the properties of aggregate especially its shape and surface texture, affect the ultimate strength in compression very much less than the strength in tension or the cracking load in compression. This behaviour was confirmed by Knab. In experimental concrete entirely smooth coarse aggregate led to a lower compressive strength, typically by 10 percent, than when roughened.

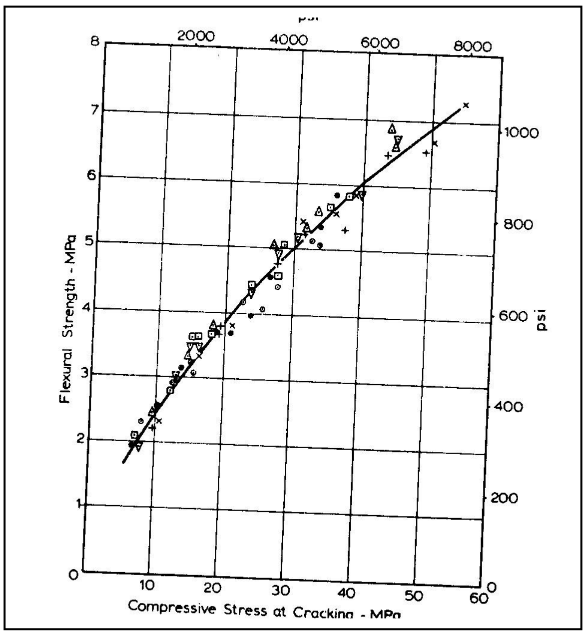


Fig. (2.7) Relation between flexural strength and compressive stress at cracking for concrete made with different coarse aggregates.

The influence of the type of coarse aggregate on the strength of concrete varies in magnitude and depends on the water/cement ratio of the mix. For water / cement ratios below 0.4, the use of crushed aggregate has resulted in strengths up to 38 percent higher than when gravel is used. With an increase in the water/cement ratio,t he influence of aggregate falls off, presumably because the strength of the hydrated cement paste itself becomes paramount and, at a water/cement ratio of 0.65, no difference in the strengths of concretes made with crushed rock and gravel has been observed.

2.13 Influence of aggregate/cement ratio on strength

There is no doubt that the aggregate /cement ratio, is only a secondary factor in the strength of concrete but it has been found that, for a constant water/cement ratio, a leaner mix leads to a higher strength.

The reasons for this behaviour are not clear. In certain cases, some water may be absorbed by the aggregate; a large amount of aggregate absorbs a greater quantity of water, the effective water/cement ratio being thus reduced. In other cases, a higher aggregate content would lead to lower shrinkage and lower bleeding, and therefore to less damage to the bond between the aggregate and the cement paste; likewise, the thermal changes caused by the heat of hydration of cement would be smaller. The most likely explanation, however, lies in the fact that the total water content per cubic meter of concrete is lower in a leaner mix than in a rich one. As a result, in a leaner mix, the voids form a smaller fraction of the total volume of concrete, and it is these voids that have an adverse effect on the strength.

Studies on the influence of aggregate content on the strength of concrete with a given quantity of concrete paste indicate that, when the volume of aggregate (as a percentage of the total volume) is increased from zero to 20, there is a gradual decrease in compressive strength, but between 40 and 80 percent there is an increase. The pattern of behaviour is shown in fig. (2.8). The reasons for this effect are not clear, but it is the same at various water/cement ratios. The influence of the volume of aggregate on tensile strength is broadly similar.

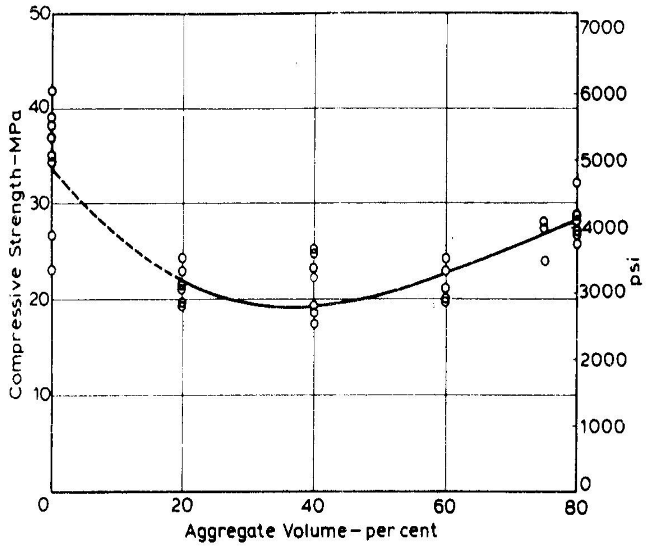


Fig. (2.8) Relation between the compressive strength of cylinders (100 mm diameter, 300 mm in length) and volume of aggregate at a constant water/cement ratio of 0.50

2.14 Nature of strength of concrete

The paramount influence of voids in concrete on its strength has been repeatedly mentioned, and it should be possible to relate this factor to the actual mechanism of failure. For this purpose, concrete is considered to be a brittle material, even though it exhibits a small amount of plastic action, as fracture under static loading takes place at a moderately low total strain; a strain of 0.001 to 0.005 at failure has been suggested as the limit of brittle behaviour. High strength concrete is more brittle than normal strength concrete.

2.15 Strength of concrete

The compressive strength of concrete is one of the most important and useful properties of concrete. In most structural applications concrete is employed primarily to resist compressive stresses. In those cases where strength in tension or in shear is of primary importance, the compressive strength is frequently used as a measure of these properties. Therefore, the concrete making properties of various ingredients of mix are usually measured in terms of the compressive strength. Compressive strength is also used as a qualitiative measure for other properties of hardened concrete.

When concrete fails under a compressive load the failure is essentially a mixture of crushing and shear failure. The mechanic of failure is a complex phenomena. It can be assumed that the concrete in resisting failure, generates both cohesion and internal friction. The cohesion and internal friction developed by concrete in resisting failure is related to more or less a single parameter i.e. w/c ratio.

The compressive strength given by different specimens for the same concrete mix are different. The cylinders and prisms of a ratio of height or length to the lateral dimension of 2 may give a strength of about 75- 85 percent of the cube strength of normal strength concrete. The effect of height/lateral dimension ratio of specimen on compressive strength is given in fig. (2.9).

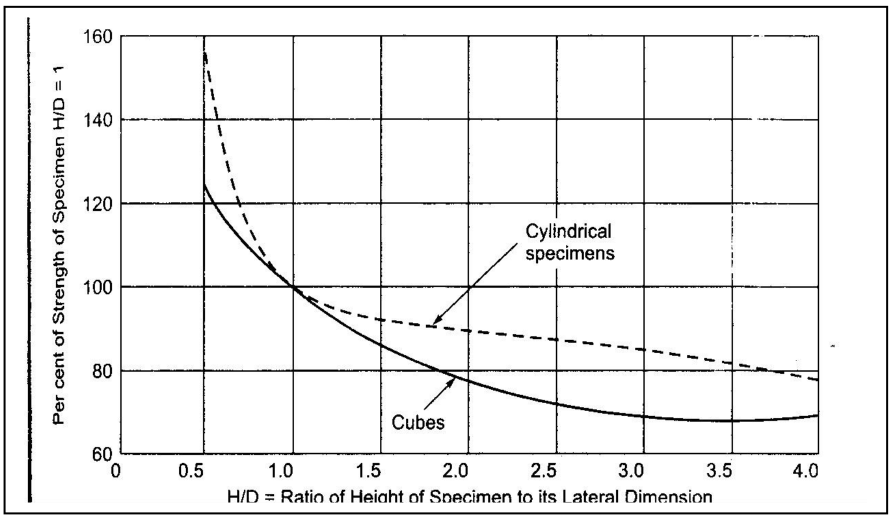


Fig. (2.9) Effect of ratio of height/lateral dimension of specimen on the compressive strength

2.16 Flexural Strength

The determination of flexural tensile strength is essential to estimate the load at which the concrete members may crack. As it is difficult to determine the tensile strength of concrete by conducting a direct tension test, it is computed by flexure testing. The flexural tensile strength at failure or the modulus of rupture is thus determined and used when necessary. Its knowledge is useful in the design of pavement slabs and airfield runway as flexural tension is critical in these cases.

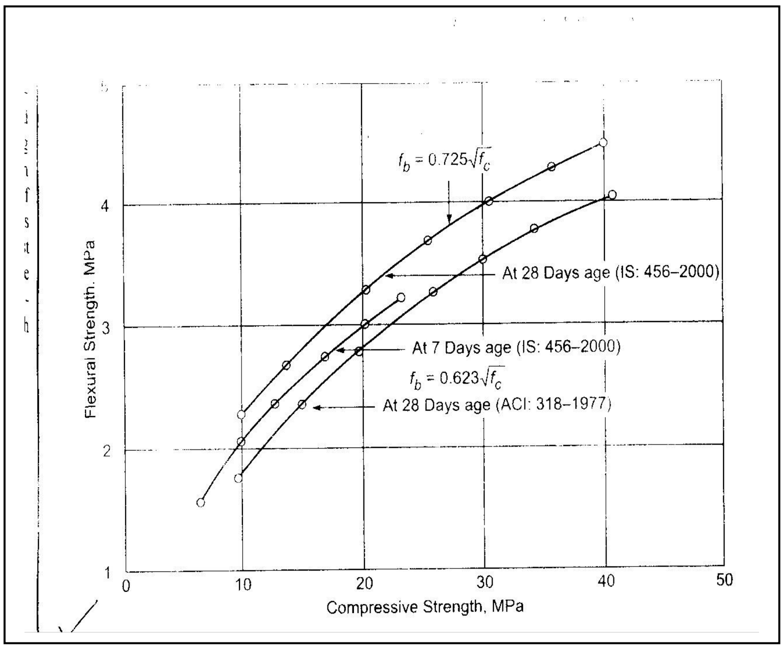


Fig. (2.10) Relationship between flexural strength and compressive strength at various ages

2.17 ensile Strength of Concrete

A compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses induced in the specimen. The tensile stress at which failure occur is the tensile strength of concrete. The splitting test are well known indirect tests used for determining the tensile strength of concrete, sometimes referred as the splitting tensile strength of concrete.

2.18 Stress and Strain Characteristic of Concrete

A typical stress and strain curve of concrete in compression is shown in Fig. (2.11) The relation is fairly linear in the initial stages but subsequently becomes non-linear reaching a maximum value and then a descending portion is obtained before concrete finally fails. The curve is usually obtained by testing a cylinder with a height-to-lateral dimension ratio of at least 2, the test being conducted under uniform rate of strain. If a uniform rate of stress is adopted, it will not be possible to obtain the descending portion of stress and strain curve beyond the maximum stress.

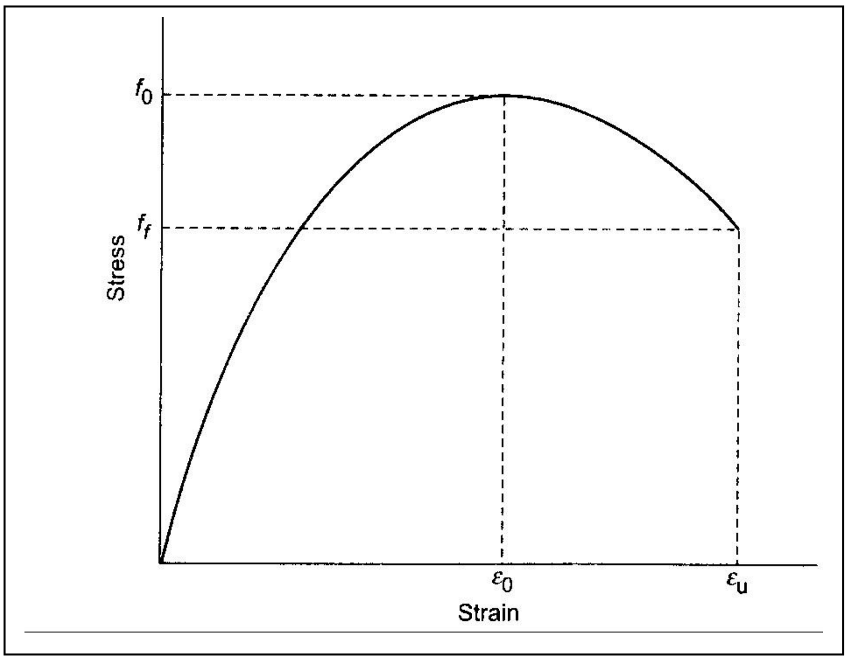


Fig. (2.11) Stress-strain relationship for concrete

2.19 High Performance Concrete

A performance enhanced concrete or high performance concrete (HPC) is a specialized series of concrete designed to provide several benefits in the construction of concrete structure that cannot always be achieved routinely using conventional ingredients, normal mixing and curing practices.

In the other words a high performance concrete is a concrete in which certain characteristics are developed for a particular application and environment, so that it will give excellent performance in the structure in which it will be placed, in the environment to which it will be exposed, and with the loads to which it will be subjected during its design life. It includes concrete that provides either substaintially improved resistance to environment influences (durability in service) or substantially increased structural capacity while maintaining adequate durability). It may also include concrete, which significantly reduces construction time without compromising long-term serviceability. It is, therefore, not possible to provide a unique definition of HPC without considering the performance requirements of the intended use of the concrete. Examples of characteristics that may be considered critical in an application requiring performance enhancement are : ease of placement and compaction without segretation, early-age strength, long-term mechanical properties, permeability, density, heat of hydration, toughness, volume stability, and long life in severe environments, i.e. durability.

Concretes possessing many of these characteristics often achieve higher strength. Therefore HPC is often of high strength, but high strength concrete may not necessarily be of high performance. Thus, in practical application of this type of concrete, the emphasis has in many cases gradually shited from the compressive strength to other properties of the material, such as a high modulus of elasticity, high density, low permeability, and high resistance to some forms of attacks. The cost and other benefits derived may include less material, light and fewer structural elements, reduced maintenance, extended life cycle and aesthetics.

2.19.1 **High Strength Concretes**

This class is further divided into two sub classes according to whether or not they contain ultrafine material additive. They need high strength or high grade Portland cement with its content in the range of 400 to 450 kg/m^3. High range water reducing (HRWR) admixtures must be added in order to maintain the water-cementing ratio between 0.35 to 0.40 wihtout impairing the concrete workability. No special aggregates are required.

2.19.2 Very High Strength Concretes

These are obtained by providing a further reduced water cementing ratio between 0.20 to 0.35 with high doses of HRWR admixtures. All the concrete components should be of high quality. It is necessary to use ultrafines such as silica fume or/and rice husk ash. They generally need water reducing superplasticizers admixtures must have strength and Young's modulus not too different from that of hardened cement paste in order to minimize differential deformations beween the aggregates and the matrix. Generally, the use of aggregates with a maximum nominal size of 10 to 12 mm is recommended.

2.20 Durability of Concrete

A durable concrete is one that performs satisfactorily under anticipated exposure (working) conditions during the service life span. The materials and mix proportions used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion. Even though concrete is a durable material requiring a little or no maintenance in normal environment but when subjected to highly aggressive or hostile environments it has been found to deteriorate resulting in premature failure of structures or reach a state requiring costly repairs.

One of the main characteridics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potentially deleterious substances. The permeability of the concrete depends upon micro and macro-cracks, and voids developed during production and service.

Most of the durability problems in the concrete can be attributed to the volume change in concrete. Volume change in concrete is caused by many factors. The entire hydration process is nothing but an internal volume change, the effect of heat of hydration, the pozzolanic action, the sulphate attack, the carbonation, the moisture movement, all types of other aspects come under the preview of volume change in concrete. The internal or external restraints to volume change in concrete results in the cracks. It is te crack that promotes permeability and thus it becomes a part of cycle action, till such time that concrete deteriorates, degrades, disrupts and eventually fails.

2.21 Role of Water-Cement Ratio

As discussed above the volume change in concrete in cracks and the cracks are responsible for disintegration of concrete. It may now be added that permeability is the contributory factor to the volume change with higher water-cement ratio being the fundamental cause of higher permeability. Therfore, use of higher water-cement ratio → permeability → volume change → cracks → disintegration → failure of concrete is a cyclic process in the concrete. Therefore, for a durable concrete, use of lowest possible water-cement ratio is the fundamental requirement to produce dense and impermeable concrete.

The advent and use of superplsticizers have revolutionized the technology of making durable concrete by drastically reducing water-cement ratio of concrete. Presently the flowing or self leveling concrete are being produced with a water-cement ratio as low as 0.25 or even 0.20. This technology breakthrough, in conjunction with the use of cementing minerals additives, has enable the production of highly durable high performance concrete.

2.22 Role of Permeability

The capillary pores in concrete serve as a conduit or provide transport system for deteriorating agents. However, it may be mentioned that the micro-cracks in initial stage are so fine that they may not increase the permeability. But propagation of micro-cracks with time due to drying shrinkage, thermal shrinkage and externally applied loads will increase the permeability of the system.

2.22.1 Permeability of cement :

Cement paste consists of C-S-H (gel), $Ca\ (OH)_2$ and both water filled and empty capillary cavities. The gel has porosity to the extent of 28 percent with permeability of the order 7.5×10^{-16} which is about one-thousandth of that of the cement paste. Therefore, contribution of gel pores to the permeability of concrete paste is minimal. The extent and size of capillary cavities or pores depend upon water-cement ratio. At low water-cement ratio the extent of capillary cavities is less and cavities are very fine which are easily filled up within few days by hydration products of cement. Only unduly large cavities resulting from high water cement ratio (of the order of 0.7) will not get filled up by the product of hydration and will remain un-segmented and are responsible for the permeability of the paste.

2.22.2 Permeability of concrete :

Introduction of aggregate, particularly larger size of aggregate, increase the permeability considerably. As explained above, the increase in the permeability is due to the development of micro-cracks in the weak transition zone at early age. The size of the cracks in the transition zone is reported to be much bigger than that of capillary cavities present in the cement paste.

2.23 Effect of mineral additives :

Permeability of pozzolanic cement paste which is initially higher as compared to OPC tends to become lower as the curing proceeds. For the first 7 to 15 days cement hydration involves only the clinker fraction. Pozzolanic materials or fly ash converts $Ca(OH)_2$ which is otherwise soluble and leach able into cementing product later on at a slower rate and within an already rigid pore structure. The resulting precipitation of cementing product into the pores previously formed by hydration of the clinker fraction is not able to fill the larger pores completely but blocks smaller capillaries connecting larger pores or at least reduce their openings considerably. As a consequence, porosity of pozzolanic cement pastes remains higher than or at the most becomes the same as OPC, but the permeability becomes lower. Concrete containing cements with 35 percent fly ash has been found to be 2 to 5 times less permeable than concrete manufactured with OPC or blast-furnace-slag cements. Moreover, concretes made using pozzolanic cements have a better flexural compressive strength ratio and reduced tendency to cracking than concrete made using OPC.

2.24 Effect of air-entrainment :

An air-entrainment up to 6 percent make the concrete more impervious. The steam curing of concrete using pozzolanic has been reported to decrease the permeability due to formation of coarser C-S-H gel, lower drying shrinkage and accelerated conversion of $Ca(OH)_2$ into cementing product.

2.25 Causes of Lack of Durability

The factors affecting the durability may be external or internal causes. The external causes may be physical, chemical and mechanical which are grouped in the following categories :-

(i) Environmental, such as occurrence of extreme temperatures, abrasion and electrostatic actions.

(ii) Chemical attack by natural or industrial liquids and gasses.

The internal causes include the following :

(i) Alkali-aggregate reaction.

(ii) Volume change due to difference in thermal properties of the aggregate and cement paste.

2.26 CHEMICAL REACTIONS ON CONCRETE

2.26.1 Chloride –ion Penetration

The chloride ion present in the concrete can have harmful effect on concrete as well as on the reinforcement. In the first case, chloride ion penetration results in concrete swelling of 2 to 2.5 times larger than that observed with water penetration This causes slight reduction of concrete strength. In the second case presence of chloride ions near the reinforcement steel makes it vulnerable to corrosion. If the hydroxide to chloride ratio near the reinforcement steel drops below 0.3, the passivation is destroyed and corrosion is inevitable. Chlorides have therefore to be prevented from entering into the concrete. As per IS:456-2000 the amount of chlorides in concrete so far as corrosion of reinforcements is concerned is limited to acid-soluble chloride contents of 0.4 and 0.6 kg/m^3 of concrete in pre-stressed and reinforced concrete respectively, at the time of placing concrete.

2.26.2 Carbonation

Alkalinity of Concrete :

Concrete is an alkaline substance and provides excellent protection to reinforcement embedded inside. The alkaline environment forms a protective oxide film which passivates the steel and protects it from corrosion. Concrete initially has a pH value of about 12 to 13. Due to leaching, carbonation and defective construction practices the pH value drops rapidly. Once pH value of concrete drops below 10, corrosion of steel reinforcement is inevitable and therefore concrete durability is at stake. This is however dependent on the quality of concrete and its porosity mainly in the cover area. A dense good quality concrete offers good protection to steel embedded in it. It is also essential to produce concrete using low water-cement ratio so that it has minimum unblocked capillary pores. Since the concrete of higher strength have lower water-cement ratio they are preferred.

Process of carbonation :

Carbon dioxide present in the atmosphere reacts in presence of water with the concrete surface and concrete gets carbonated or in other words turns acidic. This chemical reaction starts at the surface and gradually proceeds inside the concrete mass and is generally measured as depth of carbonation. As hydrated calciu silicate and aluminates are less stable than calcium carbonate, concrete carbonation be avoided. In the cracked portion, carbonation penetrates inside along the cracks.

On carbonation the concrete loses its pH value from around 13.5 to 8.3. Therefore steel is no longer passivated by the alkaline concrete around it. Oxidation of reinforcement steel therefore takes place in the presence of moisture and oxygen, and corrosion (rusting) occurs. The concrete increases the volume of steel and ultimately results in cracking and spalling concrete.

2.27 Sulphate Attack

Sulphates are generally found in ground water and sub-soil. Sea water also contains large quantity of sulphates. Sulphates can be naturally occurring or could be as a consequence of industrial waste disposal. Calcium, sodium, magnesium and ammonium sulphates (increasing order of hazard) are harmful to concrete as they can lead to increase in the concrete volume and consequent cracking. Calcium sulphate reacts with calcium aluminates present in cement hydrates forming an expansive ettringite. Sodium sulphate reacts with calcium hydroxide and forms expansive gympusm in presence of aluminates and may in turn lead to the formation of ettringite. Mangesium sulphate reacts with cement compounds decomposing the cement itself and subsequently producing gypsum and ettringite.

For minimizing the danger of sulphate attack, low C_3A content are recommended. Sulphate resisting cement with very low C_3A content is most suitable. However, if chlorides are also present in the ground water and sub soil, in addition to sulphates then it is not recommended for the use in view of the vulnerability of low C_3A cement pastes to chloride ion diffusion. Blended cements are most preferred when both sulphates and chlorides are present in an environment at the same time.

Table (2.2) sulphate resisting cement – classification and composition

Type of cement	**Chemical resistance to sulphates**		
	Moderate	**High**	**Very high**
	Limits of compounds per cent		
Ordinary Portland Cement	$C_3A < 8$	$C_3A < 5$ $(2\ C_3A + C_4AF) < 25$ or $(C_4AF + C_2F) < 25$	$C_3A = 0$ $C_4AF < 20$ Or $(C_4AF + C_2F) < 20$
Pozzolana Cement	No special Prescription	$C_3A < 6$	$C_3A < 3.5$
Slag Cement	Slag > 36	Slage > 70	Slag > 70 and $C_3A < 2$

The reactions of the various sulfates with hardened cement paste are as follows :

Sodium sulphate attack Ca $(OH)_2$

Ca $(OH)_2 + Na_2SO_4 . 10H_2O \rightarrow CaSO_4 . 2 H_2O + 2 NaOH + 8H_2O$

This is an acid type attack. In following water, Ca $(OH)_2$ can be completely leached out but if NaOH accumulates, equilibrium is reached, only a part of the SO3 being deposited as gypsum.

The reaction with calcium aluminate hydrate can be formulated as follows :

$2 (3CaO. Al_2O_3. 12H_2O) + 3(Na_2SO_4 . 10H_2O) \rightarrow$

$3CaO. Al_2O_3. 3CaSO_4. 32H_2O + 2Al (OH)_3 +6NaOH + 17 H_2O$

Calcium sulfate attacks only calcium aluminate hydrate, forming calcium sulfoaluminate ($3CaO. Al_2O_3. 3CaSO_4. 32H_2O$), known as ettringite. The number of molecules of water may be 32 or 31 depending upon the ambient vapour pressure.

On the other hand, magnesium sulfate attacks calcium silicate hydrates as well as $Ca(OH)_2$ and calcium aluminate hydrate. The pattern of reaction is

$3CaO. 2 SiO_2.aq + MgSO_4 .7 H_2O \quad CaSO_4 . 2H_2O + Mg (OH)_2 + SiO_2.aq.$

Because of the very low solubility of $Mg(OH)_2$, this relation proceeds to completion so that under certain conditions, the attack by magnesium sulfate is more severe than by other sulfates. A further reaction between Mg $(OH)_2$ and silica gel is possible and may also cause deterioration. The critical consequence of the attack by magnesium sulfate is the destruction of C-S-H.

2.28 Acid Reactions :

Deterioration may be caused by the chemical reaction between the hardended cement constituents of concrete and the chemical of a solution. The reaction products formed may be either water soluble and may get removed from the internal structure of concrete by a diffusion process, or the reaction products if insoluble in water may get deposited on the surface of concrete as an amorphous mass.

Acid attack on concrete :

Concrete can be attacked by liquids with a pH value below 6.5 but the attack is severe only at a pH below 5.5; below 4.5, the attack is very severe. A concentration of CO_2 of 30 to 60 ppm results in a severe attack, and above 60 ppm results in a very severe attack.

The attack progresses at a rate approximately proportional to the square root of time because the attacking substance has to travel through the residual layer of the low solubility products of reaction which remain after $Ca(OH)_2$ has been dissolved. Thus it is not only pH but also the ability of aggressive ions to be transported that influence the progress of the attack. Also, the rate of attack decreases when aggregate has become exposed because the vulnerable surface is smaller and the attacking medium has to travel around the particles of aggregate.

Table : (2.3) A list of some substances which cause severe chemical attack on concrete

Acids	
Inorganic	1. Organic
1. Carbonic	2. Acetic
2. Hydrochloric	3. Citric
3. Hydrofluoric	4. Formic
4. Nitric	5. Humic
5. Phosporic	6. Lectic
6. Sulfuric	7. Tannic
Other substances	
1. Aluminium chloride animal fats	4. Vegetables and
2. Ammonium salts	5. Vegetable oils
3. Hydrogen sulfide	6. Sulfates

Acid rain which consists mainly of sulfuric acid and nitric acid and has a pH value between 4.0 and 4.5 may cause surface weathering of exposed concrete.

Although domestic sewage by itself is alkaline and does not attack concrete, severe damage of sewere has been observed in many cases, especially at fairly high temperatures, when sulphur compounds become reduced by anaerobic bacteria to H_2S. This is not a destructing agent in itself, but it is dissolved in moisture films on the exposed surface of the concrete and undergoes oxidation by aerobic bacteria, finally producing sulfuric acid. The attack occurs, therefore, above the level of flow of the sewage. The hardened cement paste is gradually dissolved, and progressive deterioration of concrete takes place. A somewhat similar form of attack can occur in offshore oil storage tanks.

Sulphuric acid is particulally aggressive because, in addition to the sulphate attack of the aluminate phase, acid attack on $Ca(OH)_2$ and C-S-H takes place Reduction in the cement content on the concrete is therefore beneficial, provided of course, that the density of the concrete is unimpaired.

2.29 SULPHURIC ACID ($H2SO_4$)

Sulfuric (or sulphuric) acid, H2SO4, is a strong mineral acid. It is soluble in water at all concentrations. Sulfuric acid has many applications, and is one of the top products of the chemical industry. World production in 2001 was 165 million tonnes, with an pproximate value of US$8 billion. Principal uses include lead-acid batteries for cars and other vehicles, ore processing, fertilizer manufacturing, oil refining, wastewater processing, and chemical synthesis.

2.29.1 Occurrence

Pure (undiluted) sulfuric acid is not encountered naturally on Earth, due to its great affinity for water. Apart from that, sulfuric acid is a constituent of acid rain, which is formed by atmospheric oxidation of sulfur dioxide in the presence of water - i.e., oxidation of sulfurous acid. Sulfur dioxide is the main byproduct produced when sulfur-containing fuels such as coal or oil are burned.

Sulfuric acid is formed naturally by the oxidation of sulfide minerals, such as iron sulfide. The resulting water can be highly acidic and is called acid mine drainage (AMD) or acid rock drainage (ARD). This acidic water is capable of dissolving metals present in sulfide ores, which results in brightly-colored, toxic streams. The oxidation of iron sulfide pyrite by molecular oxygen produces iron(II), or

Fe2+:2 FeS2 + 7 O2 + 2 H2O → 2 Fe2+ + 4 SO42− + The Fe2+ can be further oxidiz 4 Fe2+ + O2 + 4 H+ → 4 Fe3+ + 2 H2O

The Fe3+ produced can be precipitated as the hydroxide or hydrous oxide:

Fe3+ + 3 H2O → Fe(OH)3 + 3 H+

The iron(III) ion ("ferric iron") can also oxidize pyrite. When iron(III) oxidation of pyrite occurs, the process can become rapid. pH values below zero have been measured in ARD produced by this process.

ARD can also produce sulfuric acid at a slower rate, so that the Acid Neutralization Capacity (ANC) of the aquifer can neutralize the produced acid. In such cases, the Total dissolved solids (TDS) concentration of the water can be increased from the dissolution of minerals from the acid-neutralization reaction with the minerals.

2.29.2 PHYSICAL PROPERTIES

Forms of sulfuric acid

Although nearly 100% sulfuric acid can be made, this loses SO3 at the boiling point to produce 98.3% acid. The 98% grade is more stable in storage, and is the usual form of what is described as concentrated sulfuric acid. Other concentrations are used for different purposes. Some common concentrations are 10%, dilute sulfuric acid for laboratory use, 33.53%, battery acid (used in lead-acid batterie 62.18%, chamber or fertilizer acid, 73.61%, tower or Glover acid, 97%, concentrated acid.

Different purities are also available. Technical grade H2SO4 is impure and often colored, but is suitable for making fertilizer. Pure grades such as United

States Pharmacopoeia (USP) grade are used for making pharmaceuticals and dyestuffs.

When high concentrations of SO3(g) are added to sulfuric acid, H2S2O7, called pyrosulfuric acid, fuming sulfuric acid or oleum or, less commonly, Nordhausen acid, is formed. Concentrations of oleum are either expressed in terms of% SO3 (called% oleum) or as% H2SO4 (the amount made if H2O were added); common concentrations are 40% oleum (109% H2SO4) and 65% oleum (114.6% H2SO4). Pure H2S2O7 is a solid with melting point 36°C.

Pure sulphuric acid is an oily clear liquid and this explains the old name of the acid ('oil of vitriol').

2.29.3 Polarity and conductivity

Anhydrous H2SO4 is a very polar liquid, having a dielectric constant of around 100. It has a high electrical conductivity, caused by dissociation through protonating itself, a process known as autoprotolysis.[3] 2 H2SO4 H3SO4+ + HSO4−

The equilibrium constant for the autoprotolysis is[3]

Kap(25°C)= [H3SO4+][HSO4−] = 2.7 × 10−4.

The comparable equilibrium constant for water, Kw is 10−14, a factor of 1010 (10 billion) smaller. In spite of the viscosity of the acid, the effective conductivities of the H3SO4+ and HSO4− ions are high due to an intra-molecular proton-switch mechanism (analogous to the Grotthuss mechanism in water), making sulfuric acid a good conductor. It is also an excellent solvent for many reactions. The equilibrium is actually more complex than shown above; 100% H2SO4 contains the following species at equilibrium (figures shown as millimol per kg solvent): HSO4− (15.0), H3SO4+ (11.3), H3O+ (8.0), HS2O7− (4.4), H2S2O7 (3.6), H2O (0.1).[3]

2.29.4 Chemical properties

Reaction with water

The hydration reaction of sulfuric acid is highly exothermic. One should always add the acid to the water rather than the water to the acid, because of the relative densities of these two liquids. Water is less dense than sulfuric acid, and will tend to float on top of it. Thus, if water is added to the concentrated sulfuric acid, it can boil and splatter dangerously. This reaction is best thought of as the formation of hydronium ions:

$H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$

$HSO_4^- + H_2O \rightarrow H_3O^+ + SO_4^{2-}$

Because the hydration of sulfuric acid is thermodynamically favorable, sulfuric acid is an excellent dehydrating agent, and is used to prepare many dried fruits. The affinity of sulfuric acid for water is sufficiently strong that it will remove hydrogen and oxygen atoms from other compounds; for example, mixing starch $(C_6H_{12}O_6)_n$ and concentrated sulfuric acid will give elemental carbon and water which is absorbed by the sulfuric acid (which becomes slightly diluted):

$(C_6H_{12}O_6)_n \rightarrow 6n\ C + 6n\ H_2O$

The effect of this can be seen when concentrated sulfuric acid is spilled on paper; the cellulose reacts to give a burnt appearance, the carbon appears much as soot would in a fire. A more dramatic reaction occurs when sulfuric acid is added to a tablespoon of white sugar; a rigid column of black, porous carbon will quickly emerge. The carbon will smell strongly of caramel.

2.30 CEMENTITIOUS MATERIALS

The cementitious materials are those materials which may or may not be cementitious in themselves, have latent cementitious properties and which contribute to strength of concrete primarily through their physical behaviour. All these cementitious materials have one property in common that they are atleast as fine as particles of Portland cement and sometimes much finer. The supplementary cementitious materials are also known as pozzolanic materials.

2.30.1 POZZOLANIC MATERIALS

These materials are siliceous or siliceous and aluminous materials, which themselves possess little or no cementitious value but when ground in very fine from then in the presence of water chemically react with calcium hydroxide which is liberated on hydration of cement, at ordinary temperature to form compounds, possessing cementitious properties. Best pozzolans in optimum proportion when mixed with Portland cement help in improving the qualities of concrete like:

Lower the rate of hydration and thermal shrinkage.
Increase water tightness.
Reduce alkali aggregate reaction.
Improve resistance to attack by sulphate soils and sea water.
Improve workability.

Lowers cost.

Pozzolan + Calcium hydroxide + water ----→ C-S-H(Gel)
At ambient temperature

The above reaction is termed as pozzolanic reaction, which is slow in the beginning result in slow hydration and slow strength development.

Pozzolanic materials can be divided into two groups:

Natural pozzolans:

Clay and shales.
Diatomaceous earth.
Opaline cherts.
Volcanic tuffs and pumicites.

These Pozzolanas need further grinding and sometimes need calcining to activate them to show pozzolanic activities.

Artificial Pozzolans :

Fly ash.
Silica fume.
Rice husk ash.
Metakaolin.
Ground granulated blast furnace slag.

2.30.2 FLY ASH (PULVERIZED FUEL ASH)

Fly ash is the ash precipitated electro statically or cyclonically from the exhaust gases of the coal fired power stations. The fly ash particles are spherical with the particle size/diameter of fly ash particles varying between 1 micron and 100 microns. There are two ways in which fly ash can be used:

One way is to inter grind certain percentage of fly ash with cement clinker at the factory to produce Portland pozzolana cement (PPC) and the second way is to use fly ash as an admixture at the time of making concrete at the site of work.

ASTM classifies fly ash into two classes:

Class C

Normally produced by burning lignite or sub bituminous coal. Class C fly ash may have CaO content in excess of 10 percent. In addition to pozzolanic properties, class C fly ash also possesses cementitious properties.

Class F

Normally produced by burning anthracite or bituminous coal which have CaO content less than 5 percent. This has only pozzolanic properties.

The use of right quality of fly ash in concrete results in reduced water demand for desired slump thereby reducing bleeding and drying shrinkage. The initial strength of fly ash concrete tends to be lower than that of concrete without fly ash. Due to continued pozzolanic reactivity concrete develops greater strength at later age which may exceed that of concrete without fly ash. Pozzolanic reaction contributes in making the texture of concrete dense resulting into decrease in waterand gas permeability. The optimum fly ash content to produce concrete with best surface absorption properties varies with the type of cement and the age of concrete, but more importantly with the curing environment.Dhir and Byars et.al reported that the absorption and permeability properties decrease with fly ash replacement up to 30 percent for concrete cured in water and air both. Rapid hardening Portland cement/fly ash blends produce better concrete than OPC concrete alone but the best quality is obtained when fly ash is blended with OPC.This effect also improves with age. The pozzolanic reaction can only proceed in the presence of water, enough moisture should be available for long time and therefore, fly ash concrete should be cured for longer period·

High volume fly ash (HVFA) concrete with replacement level of 50 to 55 percent are economical, durable·, high strength and high performance concrete. Ashraf, Sharma and Mokal et.al.·have reported that HVFA concrete does not require special effort for mixing, placing, transporting and these operations can be done by conventional means·

HVFA concrete is cohesive and can be used in under water situations. It is also good for mass concrete where control on rise of temperature is desirable. The total binder content of 450kg/m^3 and 400kg/m^3 have been used with replacement level of 50 percent and 55 percent. The minimum and the maximum 28 day compressive strength of concrete used in the studies are (40 and 26.4 N/mm^2) and (43.2 and 32.9N/mm^2) respectively for the two mixes, both using OPC 53 grade cement.

Lee, Kim and Lee et.al have reported that partial replacement of cement by fly ash effectively reduces autogeneous shrinkage stress of high performance concrete. It cannot completely eliminate early age cracking

In the concrete mix using total cementitious content of 500kg/m^3 and 550kg/m^3 with water cement ratio of 0.31 and 0.27 at 10 percent replacement level with fly ash has reported a 28 day compressive strength of 53.4N/mm^2 and 63.9Nm^2.At 20 percent replacement level with fly ash in the concrete mix using total cementitious material of 370kg/m^3, 450kg/m^3, 500kg/m^3 and 550kg/m^3 with water cement ratio of 0.5,0.35,0.31 and 0.27 have given 28 day compressive strength of 29.3N/mm^2, 45.9N/mm^2,52.6N/mm^{2}and 62.4N/mm^2 respectively. At 30 percent replacement level of cement the fly ash using total cementitious material of 500 kg/m^3 and 550 kg/m^3 with water cement ratio 0.31 and 0.27 has reported strengths of 49.3N/mm^2 and 55.83N/mm^2 respectively.

2.31 RICE HUSK ASH

Rice husk ash is obtained by burning rice husk in a controlled manner without causing environmental pollution. When burnt properly it contains high SiO_2 content (about 90 percent) and can be used as a concrete admixture. It exhibits high pozzolanic characteristics and contributes to high strength and high impermeability of concrete. The particle size is large as compared to silica fume and have complex shapes and also have high water demand unless inter ground with clinker so as to break down the porous structure. To achieve adequate workability use of super plasticizer may be necessary.

2.32 METAKAOLIN

Natural pozzolans namely kaolinite clay and thermally activated ordinary clay are often called metakaolin. They posses certain amount of pozzolanic properties and are not highly reactive. By removing unreactive impurities from these pozzolans by water processing they are made highly reactive pozzolan termed High Reactive Metakaolin (HRM). High reactive metakaolin shows high pozzolanic reactivity and reduction in $Ca(OH)_2$ even as early as at one day. The cement paste undergoes densification and as a result the strength increases and the permeability decreases[1].Basu and Kulkarni et.al.[1] reported that Indian kaolin used as High reactive meta kaolin (HRM) concrete has low penetrability which further decreases with increase in richness of the mix. The high reactive metakaolin is having the potential to compete with silica fume. Mavin kurve, Basu etc[1] reported that HRM dosage of 10 percent by weight of cement yields high 28 day compressive strength up to 82.75 mpa with reasonably high (100mm) slump using water cement ratio of 0.3.

2.33 GROUND GRANULATED BLAST FURNACE SLAG

The slag is a waste product obtained in the manufacturing of pig iron and consists of mixture of lime, silica and alumina. The Portland blast furnace slag cement can be produced either by inter grinding Portland cement clinker and dry granulated blast furnace slag (together with gypsum) or by dry blending of Portland cement powder and granulated blast furnace slag. Clinker and blast furnace slag are separately ground to give a smoother texture and thus benefiting the workability. Slag with various components like lime (40-50 percent), silica (30 -40 percent), alumina (8-18 percent) and magnesia (0-8 percent) are satisfactory for cement.

The replacement of cement with ground granulated blast furnace slag reduces the water content necessary to obtain the same slump. It reduces heat of hydration, results into refinement of pore structure, reduced permeability to the effect of external agencies and increased resistance to chemical attack.

Bala Subramanian, Krishna moorthy et.al[8]. have reported that compressive strength of concrete mixes are not affected by cement replacement materials(CRM) like ground granulated blast furnace slag(GGBS) up to a level of 40percent in respect of their 28 day strength. Beyond 40 percent replacement level of GGBFS, there is a reduction in compressive strength. But at the age of 56 days the compressive strength of concrete mix without CRM and with slag based CRM at 40 percent and 70 percent were almost same. It was further reported that durability properties like water absorption and chloride diffusion were very much improved with the addition of GGBFS.

The general particle size of slag being 10-20µm, it takes more than three days for hydration of slag and strength contribution property of cement[15].

Bharat Kumar, Narayanan et.al[14] have reported that slag mixes with up to 50 percent replacement level show better performance in terms of mechanical properties and durability characteristics as compared with fly ash mixes.

In general the early age strength of cement replacement material mixes show lower value for the same water binder ratio due to slower pozzolanic reaction. Generally in CRM mixes there is an increase in total binder content as the effective water binder ratio decreases. However, as the CRM content increases, the cement required per unit strength reduces, thus it is possible to effectively utilize the cement by adopting the lower effective water binder ratio with higher CRM content[14].

Long term strength of concrete containing ordinary cement and silica fume was similar to those concretes containing ordinary cement, silica fume at 10 percent replacement level and 15 or 25 percent of the cementitious material as fly ash[15] with total cementitious content of 425kg/m^3.

2.34. Superplasticizers

Superplasticizers are admixtures which are water reducing but significantly and distinctly more so than the water reducing admixtures. Superplasticizers are also usually highly distinctive in their nature, and they make possible the production of concrete which, in its fresh or hardened state, is substantially different from concrete made using water-reducing admixtures of Types A, D or E.

2.34.1 Nature of superplasticizers

There exists four main categories of superplasticizers : sulfonated, melamineformaldehyde condensates, sulfonated naphthalene formaldehyde condensates; modified lignosulfonates, and other such as sulfonic acid esters and carbohydrate esters.

The first two are the most common ones. For brevity, they will be referred to as melamine-based superplasticizers and naphthalene-based superplasticizers, respectively.

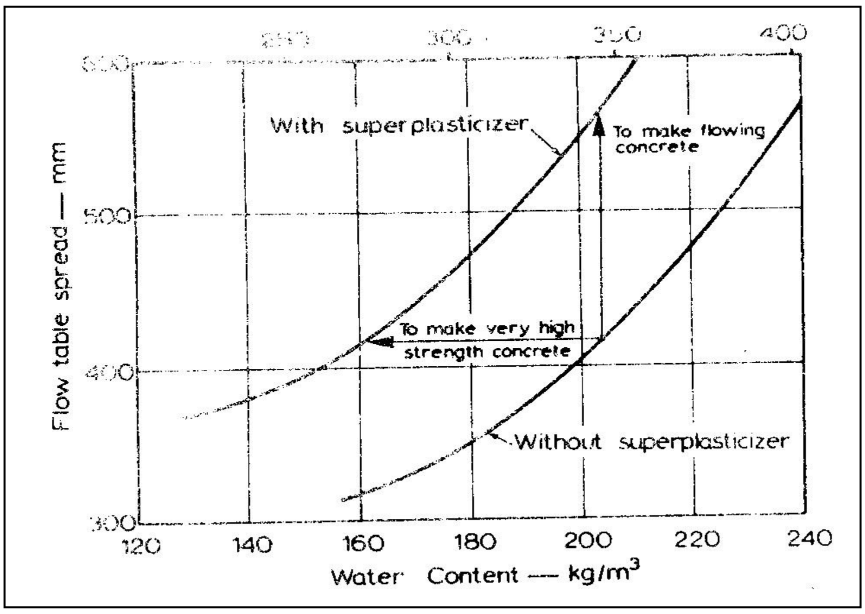


Fig. (2.12) Relation between flow table spread and water content of concrete with and without superplasticizer.

Superplasticizers are water soluble organic polymers which have to be synthesized, using a complex polymerization process, to produce long molecules of high molecular mass, and they are therefore relatively expensive. On the other hand, because they are manufactured for a specific puporse, their characteristics can be optimized in terms of length of molecules with minimum cross linking. They also have a content of impurities so that, even at high dosages, they do not exhibit unduly harmful side effects.

A large molecular mass, within limits, improve the efficiency of superplasticizers. Their chemical nature also have an effect, but no generalizations about the overall superiority of either naphthalene or melamine based superplasticizers is possible, probably because more than one property of a superplasticizers affects its performance and also because the chemical properties of the cement used play a role as well.

The majority of superplasticizers are in the form of sodium salts but calcium salts are also produced, the latter, however, have a lower solubility. A conseuqnece of the use of sodium salts is the introduction of additional alkalis into the concrete which may be relevant to the reactions of hydration of the concrete and to a potential alkali-silica reaction. For this reason, the soda content of admixtures should be known; in some countries e.g. Germany, the content is limited to 0.02 per cent of soda by mass of cement.

A modification of the naphthalene based superplasticizers by the inclusion of a copolymer with a funcational sulfonic group and carboxyl group has been developed. This maintains the electrostatic charge on the cement particles and prevents flocculation by absorption on the surface of cement particles. The copolymers is more active at higher temperatures, which is particularly beneficial in concreting in hot weather when high workability can be retained for up to one hour after mixing.

2.33.2 Effects of superplasticizers

The main action of the long molecules is to wrap themselves around the cement particles and give them a highly negative charge so that they repel each other. This results in deflocculation and dispersion of cement particles. The resulting improvement in workability can be exploited in two ways by producing concrete with a or concrete with a very high strength.

At a given water/cement ratio and water content in the mix, the dispersing action of superplasticizers increases the workability of concrete, typically by raising the slump from 75 mm (3 in.) to 200 mm (8 in.) the mix remaining cohesive. The resulting concrete can be placed with little or no compaction and is not subject to excessive bleeding or segregation. Such concrete is termed flowing concrete and is useful for placing in very heavily reinforced sections, in inaccessible areas, in floor or road slabs, and also where very rapid placing is desired. Properly compacted flowing concrete is believed to develop normal bond with reinforcement. It should be remembered, when designing form work, that flowing concrete can exert full hydrostatic pressure.

The second use of superplasticizers is in the production of concrete of normal workability but with an extremely high strength owing to a very substantial reduction in the water/cement ratio. Water/cement ratios down to 0.32 have been used with 28 day cylinder strengths of about 150 Mpa (22000 psi.)

2.33.3 Dosage of superplasticizers

For increasing the workability of the mix, the normal dosage of superplasticizers is between 1 and 3 litres per cubic metre of concrete, the liquid superplasticizers cotaiing about 40 percent of active material. When superplasticizers are used to reduce the water content of the mix, their dosage is much higher : 5 to 20 litres per cubic metre of concrete.

An example of the loss of workability of concrete made with a naphthalene based superplasticizer is shown in fig. (2.13). For comparison, the loss of workability of an admixture free mix with the same initial slump is shown in the same figure. It can be seen that the loss occurs much faster with a superplasticizer but, of course, the superplasticized concreted has a lower water/cement ratio and consequently a higher strength.

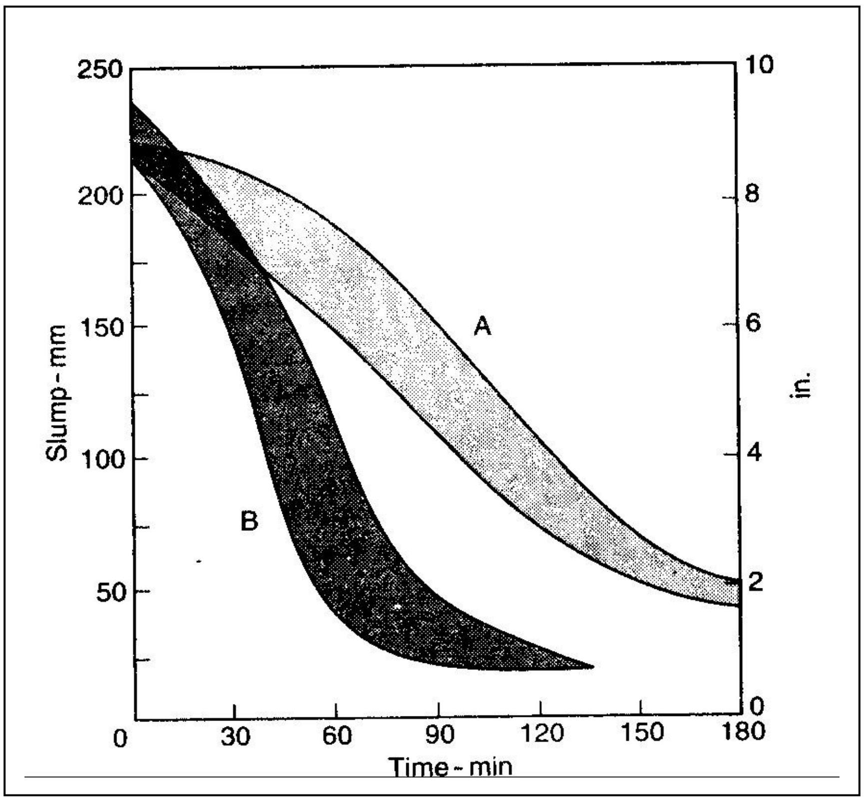


Fig. (2.13) Loss of slump with time of concretes : (A) water/cement ratio of 0.58 and no admixture (B) water/cement ratio of 0.47 and superplasticizer

Because the effectiveness of superplasticizers is limited in duration, it may be advantageous to add the superplasticizer to the mix in two, or even three, operations. Such repeated addition, or re dosage, is possible if an agitator truck is used to deliver the concrete to site. They can be successfully used in concrete containing fly ash and are particularly valuable when silica fume is present in the mix because that material increases the water demand of the mix.

Superplasticizers do not influence shrinkage, creep, modulus of elasticity or resistance to freezing and thawing. They have no effect per se on the durability of concrete. Specifically, durability on exposure to sulfates is unaffected.

2.35 SILICA FUME

DEFINITION

The American Concrete Institute (ACI) defines silica fume as “very fine non-crystalline silica produced in electric arc furnaces as a by-product of the production of elemental silicon or alloys containing silicon” (ACI 116R). It is usually a gray coloured powder, somewhat similar to portland cement or some fly ashes. Figure (1) shows a typical silica fume as it appears after being collected from a furnace.

Fig. 2.14. As produced silica fume. This is what the material looks like after it is collected.

Silica fume is usually categorized as a supplementary cementitious material. This term refers to materials that are used in concrete in addition to portland cement. These materials can exhibit the following properties.

2.35.1 Pozzolanic – will not gain strength when mixed with water. Examples include silica fume meeting the requirements of ASTM C 1240, Standard Specification for Silica Fume Used in Cementitions Mixtures, and low calcium fly ash meeting the requirements of ASTM C 618, Standard Specification for Coal Ash and Raw or Calcinied Natural Puzzolan for Use in Concrete, Class F.

2.35.2 Cementitions – will gain strength when mixed with water. Examples include ground granulated blast furnace slag meeting the requirements of ASTMC 989, Standard Specification for Ground Granulated Blast – Furnace Slag for use in Concrete and Mortars or high calcium fly ash meeting the requirements of ASTMC 618, Class C.

2.35.3 Pozzolanic and cementitious – a combination of both properties. Examples include some fly ashes.

2.36 Other Names of Silica Fume – Silica Fume is frequently referred to by other names. The report has used the term silica fume, as adopted by the American Concrete Institute. Here are some of the other names for silica fume

(i) Condensed silica fume
(ii) Microsilica
(iii) Volatilized Silica

2.37 Other Materials – There are several materials that are physically and chemically quite similar to silica fume. These materials may or may not be by –products. Some of these materials may perform well in concrete; however, their cost usually prohibits such use.

1) Precipitated Silica
2) Fumed Silica
3) Gel Silica
4) Collodial Silica
5) Silica flour and silica dust – caution : these materials are a crystalline form of silica that will not perform like silica fume in concrete.

2.38 PRODUCTION OF SILICA FUME

Silica Fume is a by product of producing silicon metal or ferrosilicon alloys in smelters using electric are furnaces. These metals are used in many industrial applications to include aluminium and steel production, computer chips fabrication, and production of silicones, which are widely used in lubricants and sealants. While these are very valuable materials, the by product silica fume is of more importance to the concrete industry.

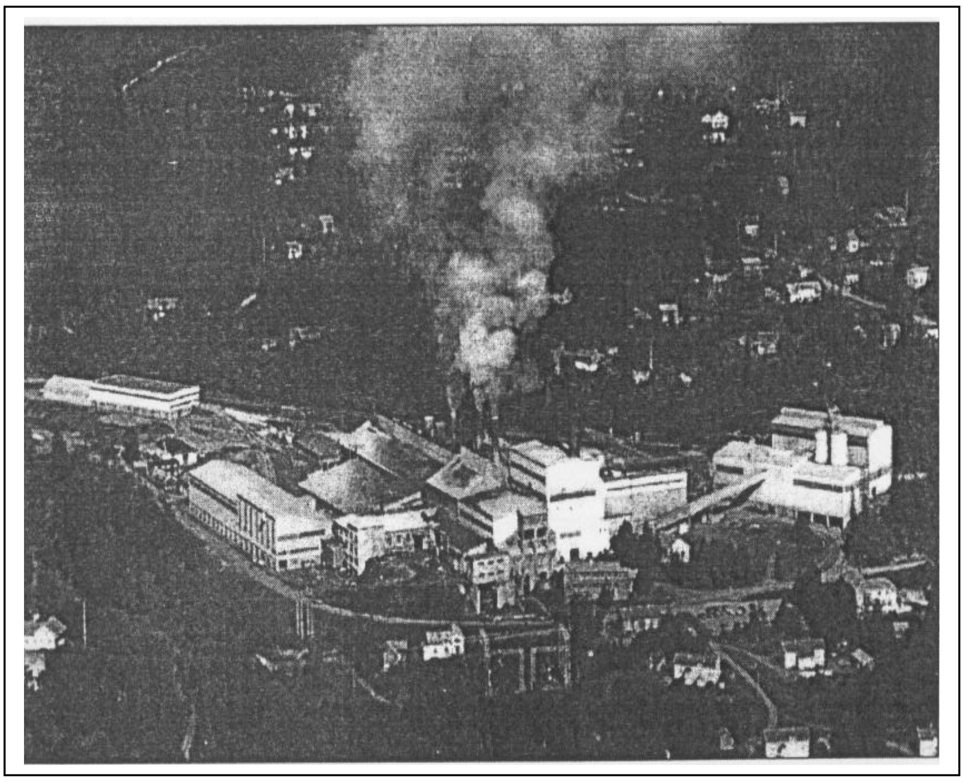


Fig. 2.15 Smelter before installation of equipment to collect silica fume. The "smoke" is silica fume being released to the atmosphere. Toda in the U.S. no silica fume is released – it is all captured and used.

Figure 2.15 shows a smelter in the day before silica fume was being captured for use in concrete and other applications. The "smoke" leaving the plant is actually silica fume. Today in the US, no silica fume is allowed to escape to the atmosphere. A schematic of silica fume production is shown in Fig (2.15) and a schematic of a smelter is shown in fig (2.16). The silica fume is collected in very large filters in the baghouse and then made available for use in concrete directly or after additional processing.

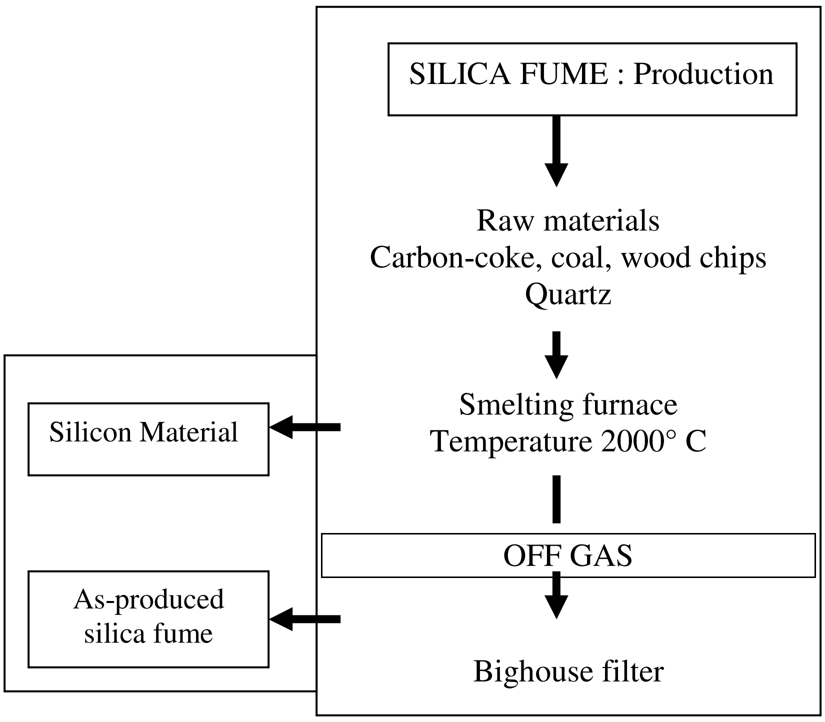


Fig. 2.16. Schematic of silica fume production

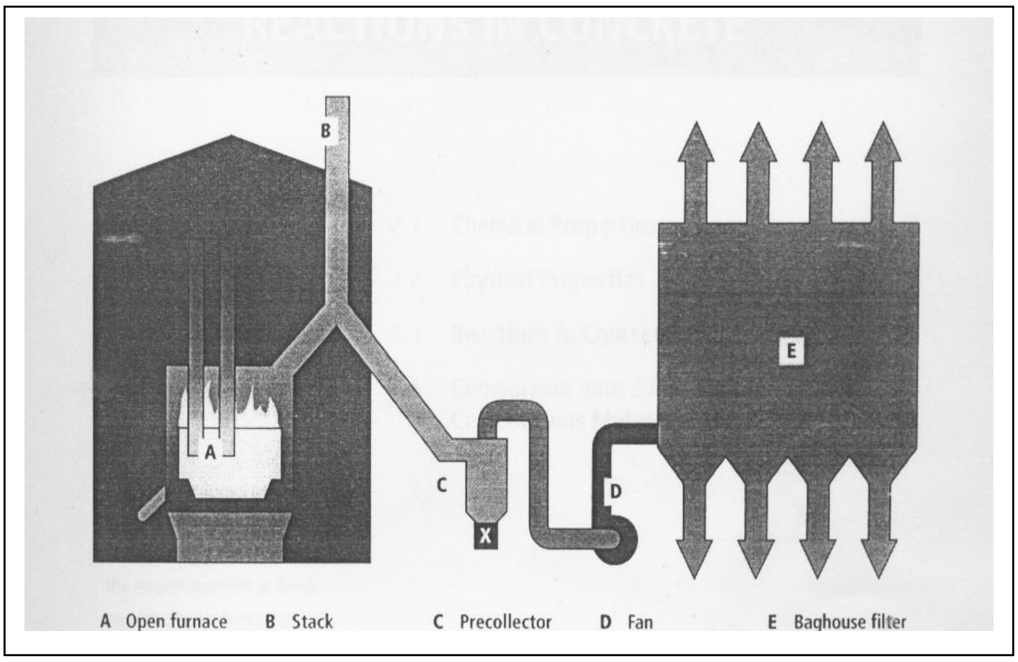


Fig. 2.17 Schematic of a smelter for the production of silica metal or ferrosilicon alloy. The silica fume is collected in large bags in the baghouse.

2.39 SILICA FUME PROPERTIES AND REACTIONS IN CONCRETE

Silica fume affects both the fresh and hardened properties of concrete. The effects on concrete are a result of the physical and chemical properties of Silica fume.

2.39.1 CHEMICAL PROPERTIES OF SILICA FUME

- Amorphous
- Silicon Dioxide > 85%
- Trace elements depending upon type of fume

Following is a discussion of each of these properties.

Amorphous – The term simply means that silica fume is not a crystalline material. A crystalline material will not dissolve in concrete, which must occur before the material can react. Don't forget that there is a crystalline material in concrete that is chemically similar to silica fume. That material is sand. While sand is essentially silicon dioxide (SiO_2), it does not react because of its crystalline nature.

Silicon Dioxide (SiO_2). This is the reactive materail in silica fume.

Trace elements : There may be additional materials in the silica fume based upon the material being produced in the smelter from which the fume was recovered. Usually, these materials have no impact on the performacne of silica fume in concrete. Standard specifications may put limits on some of the materials in this category.

2.40 PHYSICAL PROPERTIES OF SILICA FUME

Physical Properties of Silica Fume

1. Particle size (typical) : < 1 MM
2. Bulk density (as produced) 130 to 430 kg/m^3
   Densified : 480 to 720 kg/m^2
3. Specific gravity 2.2

Specific surface : 15000 to 30000 m^2/kg

Particle Size : Silica fume particles are extremely small, with more than 95% of the particles being less than 1 um (one micrometer). Particle size is extremely importance for both the physical and chemical contributions of silica fume in concrete.

Bulk density : This is just another term for unit weight. The bulk density of the as product fume depends upon the metal being made in the furnace and upon how the furnace is operated. Because the bulk density of the as-produced silica fume is usually very low, it is not very economical to transport it for long time.

Specific gravity : Specific gravity is a relative number that tells how silica fume compares to water, which has a specific gravity of 1.00. This number is used in proportioning concrete. Silica fume has a specific gravity of about 2.2, which is somewhat lighter than portland cement, which has a specific gravity of 3.15. Thus, adding silica fume to a concrete mixture will not ‘densify’ the concrete in terms of increasing the density of the concrete.

Specific surface : Specific is the total surface area of a given mass of a material. Because the particles of silica fume are very small, the surface area is very large. We know that water demand increases for sand as the particles become smaller, the same happens for silica fume. This fact is why it is necessary to use silica fume in combination with a water reducing admixture or a superplasticizer. A specialised test called the “BET method” or ‘nitrogen adsorption method” must be used to measure the specific surface of silica fume. Specific surface determination based on sieve analysis or air permeability testing are meaningless for silica fume.

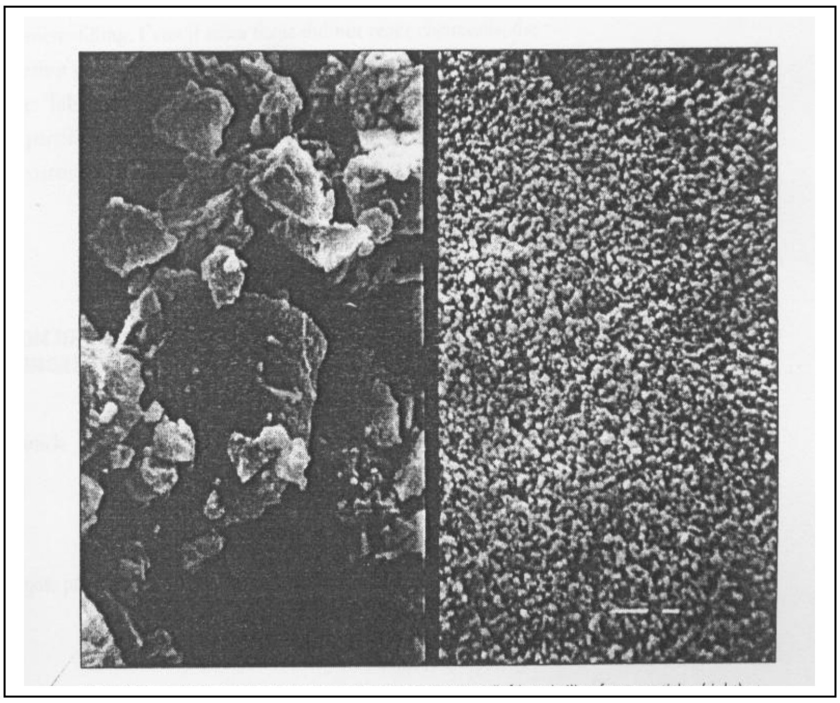


Fig. 2.18 Photomicrograph of portland cement grains (left) and silica fume particles (right) at the same magnification. The longer white bar in the silica fume side is 1 micrometer long.

2.41. REACTIONS IN CONCRETE

The benefits seen from silica fume are the result of changes to the microstructure of the concrete. These changes result from two different but equally important processes. The first of these is the physical aspect of silica fume and the second is its chemical contribution. Here is a brief description of both of these aspects :

2.41.1 Physical contributions — Adding silica fume brings millions and millions of very small particles to a concrete mixture. Just like fine aggregate fills in the spaces between coarse aggregate particles, silica fume fills in the spaces between cement grains. This phenomenon is frequently referred to as particle packing or micro filling. Even if silica fume did not react chemically, the micro filler effect would bring about significant improvements in the nature of the concrete. Table (2.3) and Fig (2.19) present a comparison of the size of silica fume particles to other concrete ingredients to help understand how small these particles actually are.

Table 2.3

COMPARISON OF SIZE OF SILICA FUME PARTICLES AND OTHER CONCRETE INGREDIENTS

Material	Nominal Size	SI Units
Silica fume particle	N/A	0.5 µm
Cement grain	No 325 sieve	45 µm
Sand grain	No. 8 sieve	2.36 mm
Coarse aggregate particle	¾ inch sieve	19.0 mm

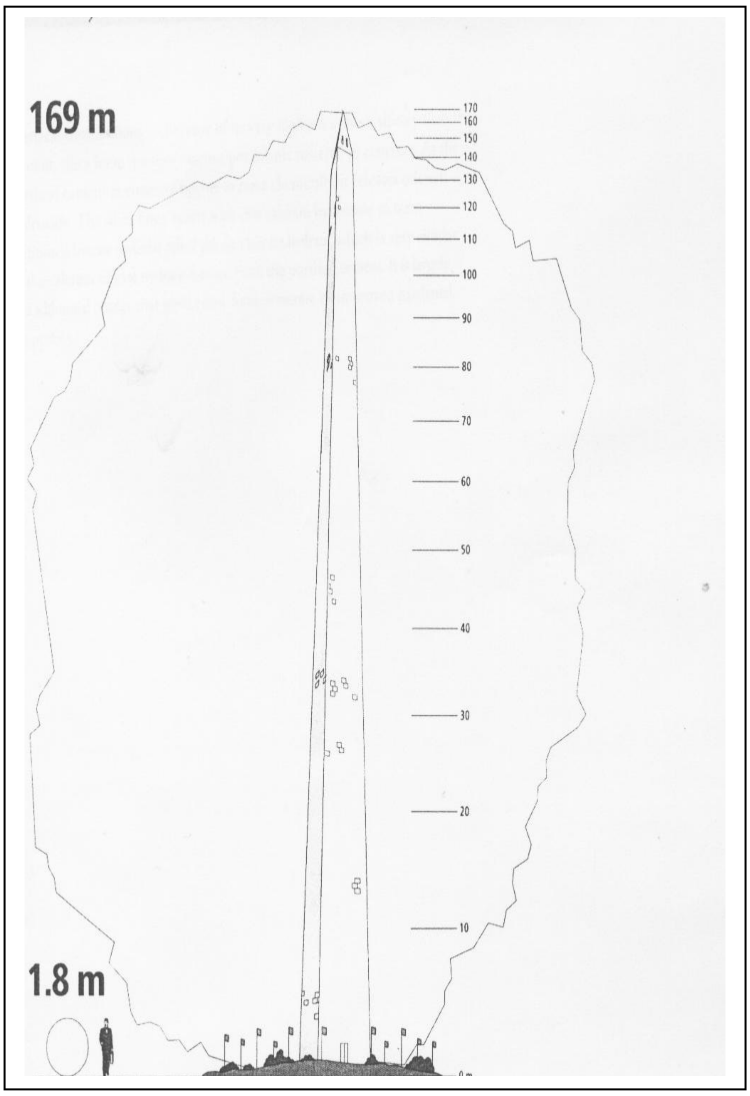


Fig. 2.19 General size comparison of silica fume paricles. If a person (1.8 m) were the size of a silica fume particle, then a cement grain would be approximately the size of the Washington *Monument* (169)

2.41.2 Chemical contributions — Because of its very high amorphous silicon dixoide content, silica fume is a very reactive pozzolanic material in concrete. As the portland cement in concrete begins to react chemically, it releases calcium hydroxide. The silica fume reacts with this calcium hydroxide to form additional binder material called calcium silicate hydrate, which is very similar to the calcium silicate hydrate formed from the portland cement. It is largely this additiona binder that gives silica fume concrete its improved hardened properties.

2.42 COMPARISON WITH OTHER SUPPLEMENTARY CEMENTITIOUS MATERIALS

Table (2.4) presents a comparison of silica fume and other commonly used supplementary cementitious materials. Silica fume is typically much more reactive, particularly at early ages, because of its higher silicon dioxide content and because of its very small particle size.

Table (2.4)

Comparison of chemical and physical characteristics – Portland cement, Fly ash, Slag cement and Silica fume

Property	Portland Cement	Class F Fly Ash	Class C Fly Ash	Slag Cement	Silica Fume
SiO_2 content %	21	52	35	35	85 to 97
AL_2O_3 cotent%	5	23	18	12	
Fe_2O_3 content%	3	11	6	1	
CaO content %	62	5	21	40	<1
Fineness as surface area, m^2/kg(Note 2)	370	420	420	400	15,000 to 30,000
General use in concrete	Primary binder	Cement replacement	Cement replacement	Cement replacement	Cement replacement

Note 1. Information from SFA and Kosmatka, and Panarese (2002)

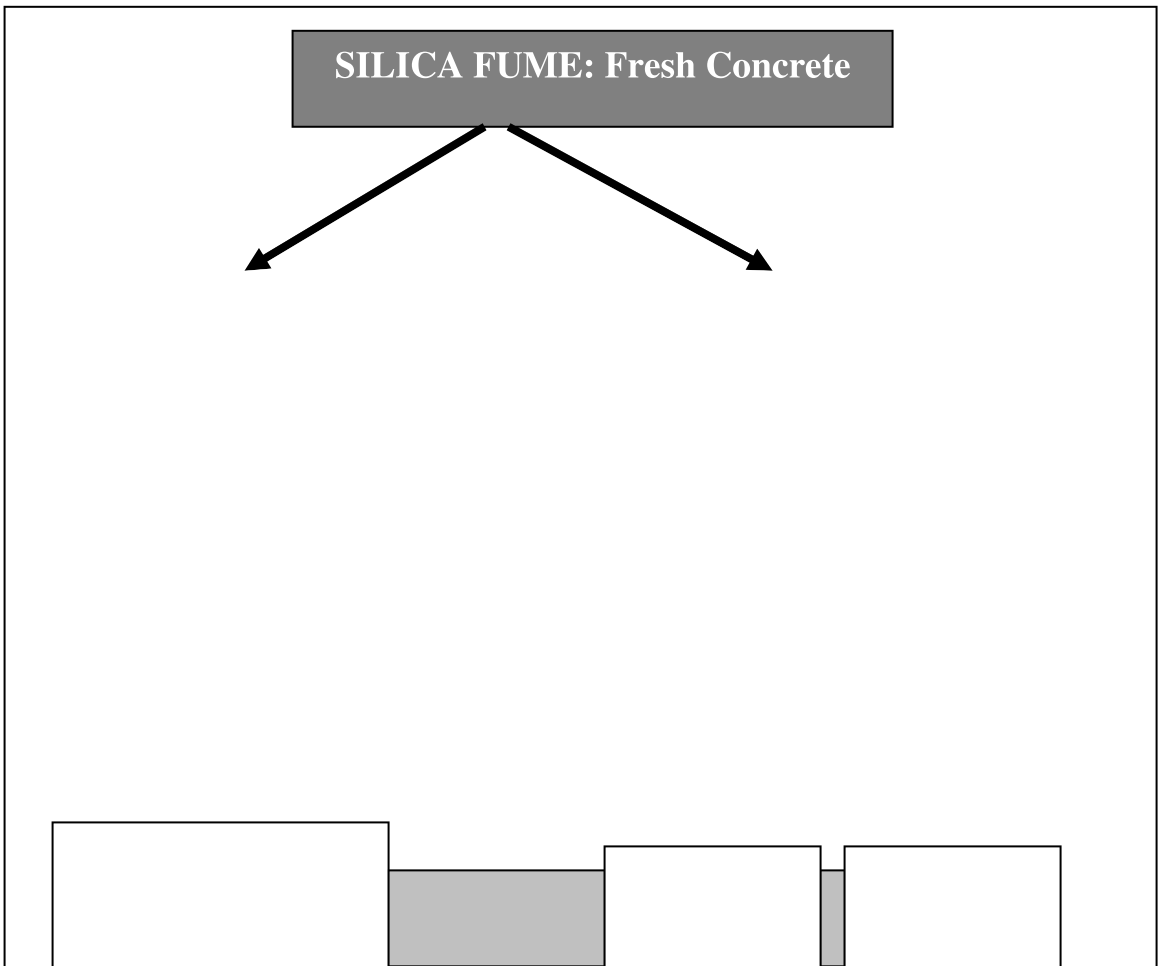
Note 2. Surface are measurement for silica fume by nitrogen adsorption method. Others by air permeaiblity method (Blaine)

2.43 REQUIREMENT OF SILICA FUME IN CONCRETE

Silica fume is used in concrete because it significantly improves the properties of fresh and hardened concrete. The potential for the use of Silica fume in concrete was known in the late 1940s but the material did not become widely used until the development of another concrete technology. This parallel technology is the use of high powerful dispersants known as range water reducing admixtures or superplasticizers. Once these chemical admixtures became available and accepted the use and development of Silica fume in concrete became possible.

2.44 EFFECT OF SILICA FUME IN FRESH CONCRETE

Fig. (2.20) shows the effects of silica fume in fresh concrete Note that there are two distinct effects : the concrete is more cohesive and the concrete exhibits little or no bleeding. Although some finishers may look at these effects as making the concrete more difficult to place and finish, these are actually advantages to the fresh and hardened concrete.



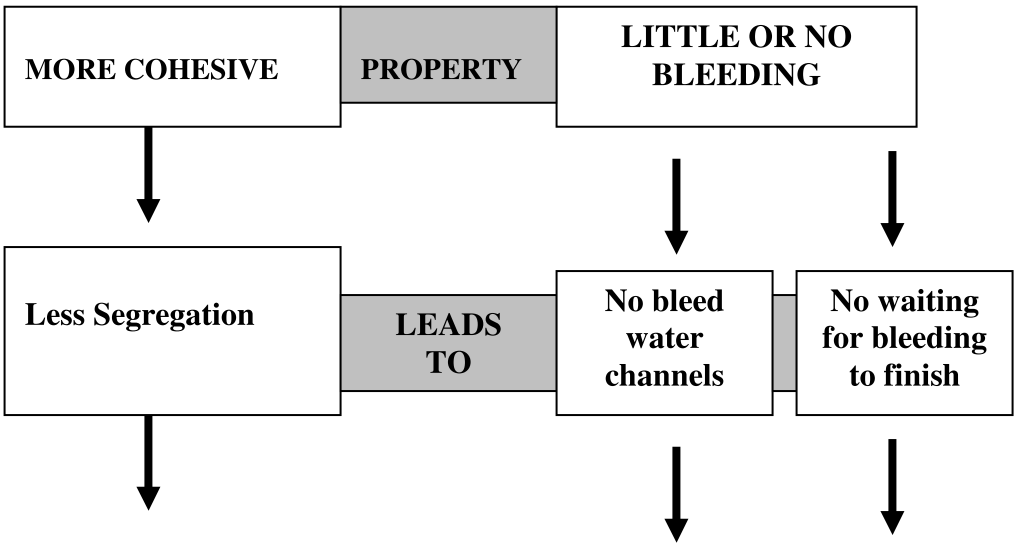


Fig.2.20 Effects of silica fume on fresh concrete and how those effects improve construability and the final concrete.

2.44.1. Increased Cohesion

Fresh concrete made with silica fume is more cohesive and therefore less prone to segregation than concrete without silica fume. To offset this increased cohesion when placing, silica fume concrete is typically placed at 40 to 50 mm greater slump than concrete without silica fume is the same placement.

The main benefit from increased cohesion can be seen in shotcrete Fig (2.21) whether it is for new construction, repair of existing structures, or ground support in tunneling operations. Using silica fume in shotcrete allows for greater thickness of shotcrete layers, particularly when shooting overhead, and a significant reduction in rebound. Silica fume shotcrete frequently includes steel fibres to provide increased flexural strength. Silica fume is compactiable with all of the accelerators that are commonly used in shotcrete. Once the shotcrete is in place, all of the expected benefits of silica fume in hardened concrete come into play. An additional benefit is the increased bond strength of the silica fume shortcrete to the underlying material and between lifts or layers in multi pass applications.

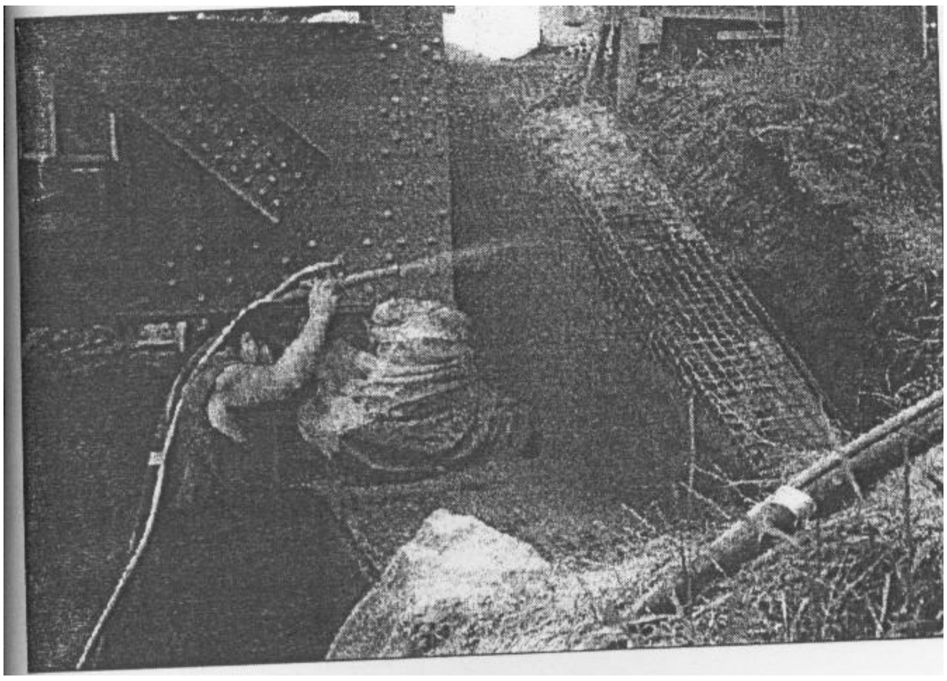


Figure 2.21 Silica fume shotcrete being used for repair of deteriorated bridge abutment. because of its increased cohesion, silica fume shotcrete has much less rebound and allows for greater lift thickness when shooting overhead than shotcrete without silica fume.

2.44.2 Reduced Bleeding

Because of the very high surface area of the silica fume and the usually very low water content of silica fume concrete, there will be very little, if any bleeding. Once a silica fume content of about five percent is reached, there will be no bleeding in most concrete.

Concrete bleeds as the heavier components (cement and aggregates) settle under the influence of gravity before the concrete stiffens. As the heavier components settle, the lighter water is forced upward. Some of the water is trapped under aggregate particles or reinforced steel and some of it reaches the capillary channels as is shown in Fig (2.22). Once the water evaporates, these channels serve as shortcuts for aggressive agents such as chloride ions formed deicing salts or sea water to get back into the concrete. Therefore, the reduction or elimination of these channels improve the durability of the concrete.

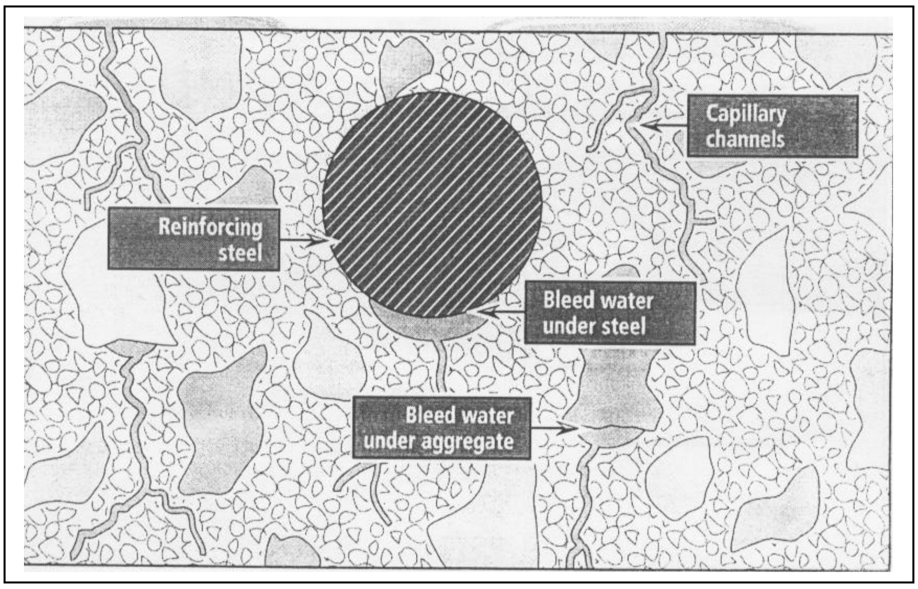


Fig. 2.22 Schematic of bleeding and capillary channels. Reduction or elimination of bleeding is a benefit of adding silica fume to a concrete mixture.

2.45. EFFECT OF SILICA FUME IN HARDENED CONCRETE

Fig. (2.23) shows the effects of silica fume in hardened concrete. Note that there are two distinct effects : enhanced mechanical properties such as strength and modulus of elasticity, and reduced permeability, which directly improves durability.

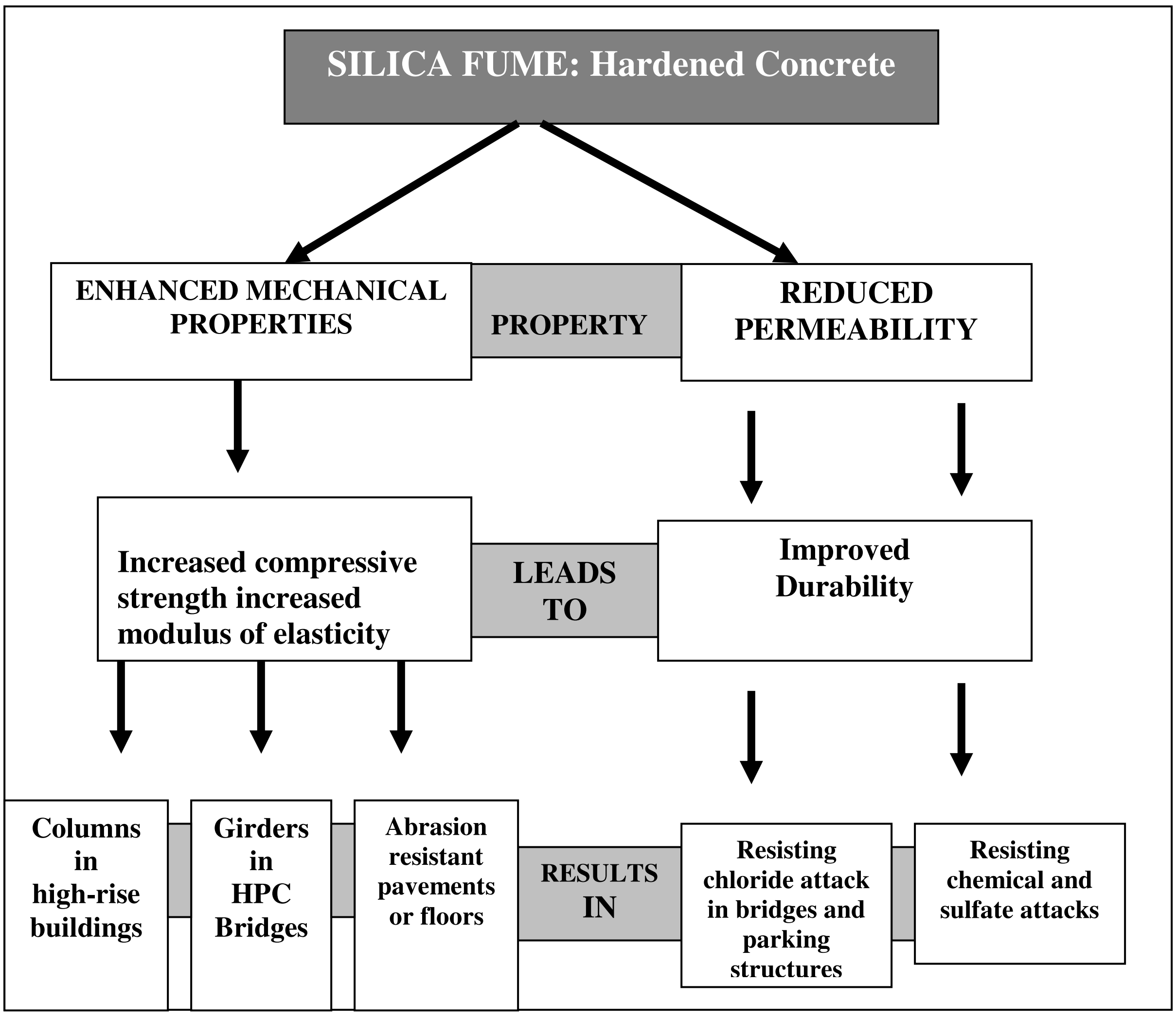


Fig. 2.23 Effects of silica fume on hardened concrete and how these effects are used in concrete application

2.45.1 Enhanced Mechanical Properties

Silica fume gained initial attention in the concrete market place because of its ability to produce concrete with very high compressive strength. Improvements in other mechanical properties such as modulus of elasticity or flexural strength are also seen. Although concrete has been specified to take advantage of improvements in these other properties, the property of most interest is certainly compressive strength.

2.46 Silica Fume and Hardened Concrete

The earliest applications for high-strength silica-fume concrete were in columns for high-rise structures. When analyzing how building loads are carried to a foundation, it turns out that using high-strength concrete is very efficient. As concrete strength is increased, column size can be reduced. In addition to reducing the size of the columns using this concrete can reduce and simplify the reinforcing steel used in the columns. Overall, more floor space is available to the owner of the structure, which can be a significant cost advantage in urban areas.

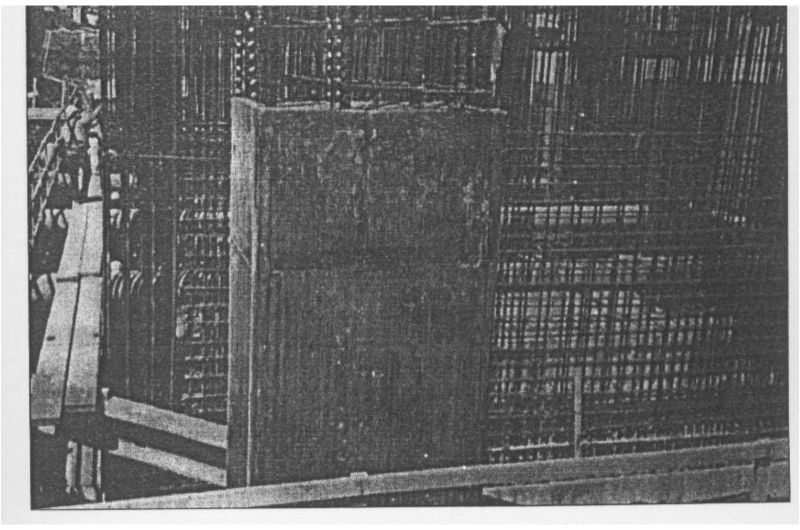


Fig. 2.24. High strength silica fume concrete column in high rise structure.

2.46.1 To increase the span of a bridge. Figure. 2.25 shows a bridge constructed by Ohio DOT in which a single span replaced three spans in the previous bridge at this state.

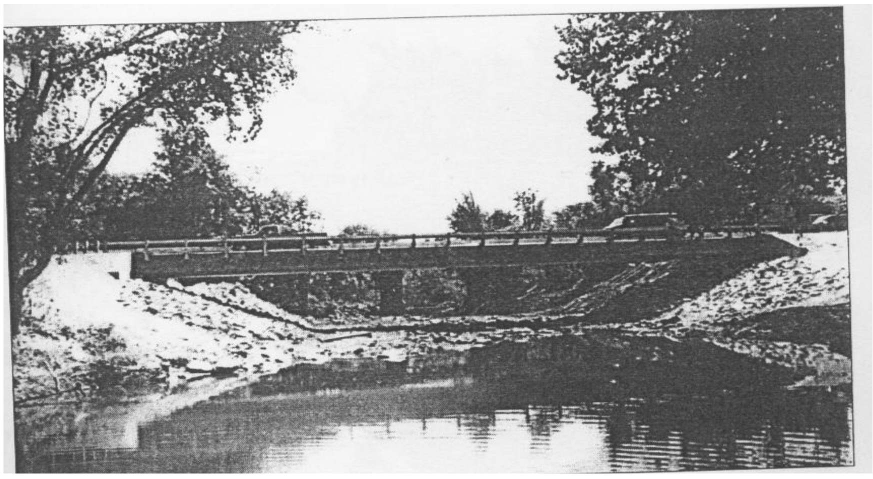


Fig. 2.25 High performance concrete bridge. In this bridge in Ohio, the high strength concrete was used to increase span length and eliminate a plier in the river.

2.46.2 To reduce the number of girders for a given span. Figure. 2.26 shows a bridge constructed by New Hamsphire DOT where the number of griders was reduced from seven to five.

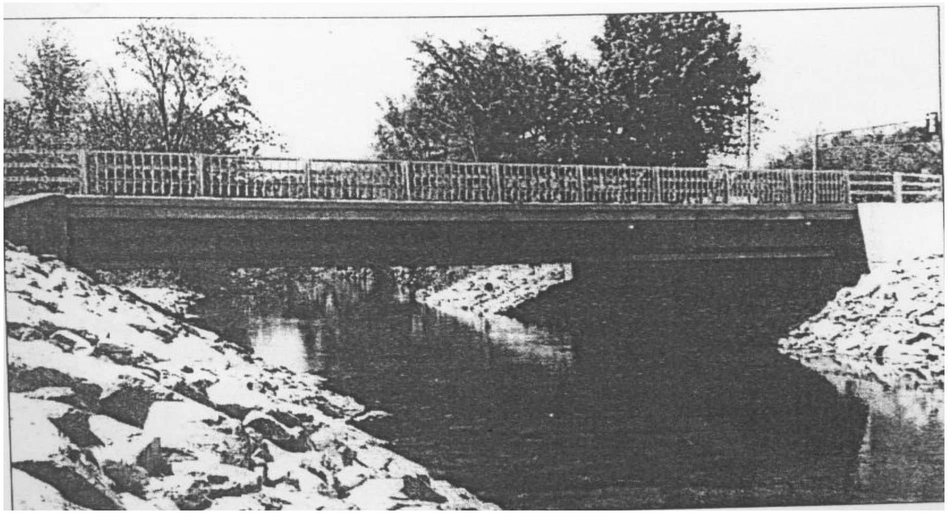


Figure 2.26 : High performance concrete bridge. In this bridge in New Hamsphire, the high-strength concrete was used to reduce the number of girders required for the structure. For more information on this bridge, see the article Wasczik (1999).

2.46.3 To reduce the section height for a given span. Colorado DOT used high strength silica-fume concrete for the bridge in figure. 2.27 Here, a two-span bridge replaced an earlier four-span bridge. The new girders were shallower that the earlier ones giving an increase in clearance of about 450 mm.

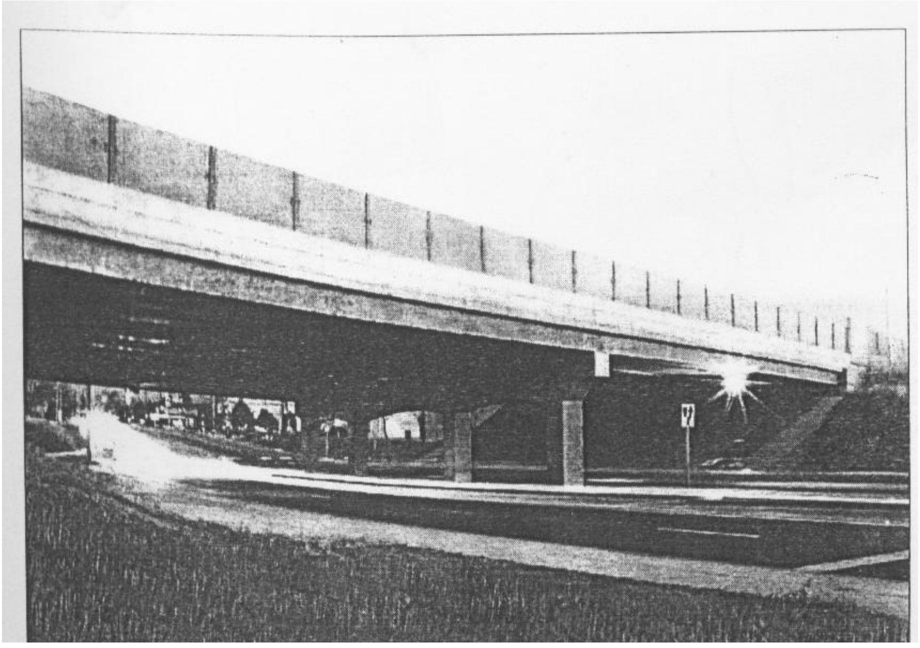


Fig. 2.27 High performance concrete bridge. In this bridge in Colorado, the high strength concrete was used to increase the head under the bridge.

2.46.4 Reduced Permeability : In many situations, the durability of concrete is directly related to its permeability. The contribution of silica fume is to reduce the permeability of the concrete. Fig. 2.28 explains the permeability and why it is important in concrete. By reducing the permeability, the time is extended for any aggressive chemical to get into the concrete where it can do its damage. Here a few examples of how reducing permeability is used in actual structure.

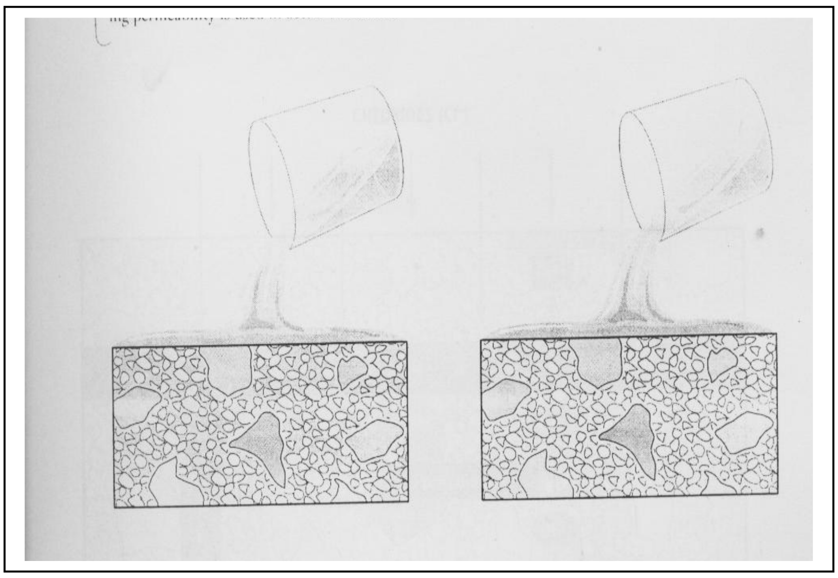


figure. 2.28 Schematic of concrete permeability. A high permeability concrete (left) allows water to move into and through the concrete readily. Lowering the w/cm and adding silica fume can make reduce permeability to essentially zero. Such a reduction makes it very difficult for water and aggressive chemicals such as chlorides or sulfates to enter the concrete.

2.46.7 Chloride damage to reinforcing steel. Corrosion of reinforcing steel is the most significant and costly cause of concrete deterioration. Figure 2.29 shows how corrosion occurs in concrete. It doesn't matter whether the chloride comes from the ocean or from deicing salts, the results are the same. Silica-fume concrete is used widely in applications where the concrete is exposed to salt from any source. The reduced permeability of this concrete can result in many years of extended life for a structure.

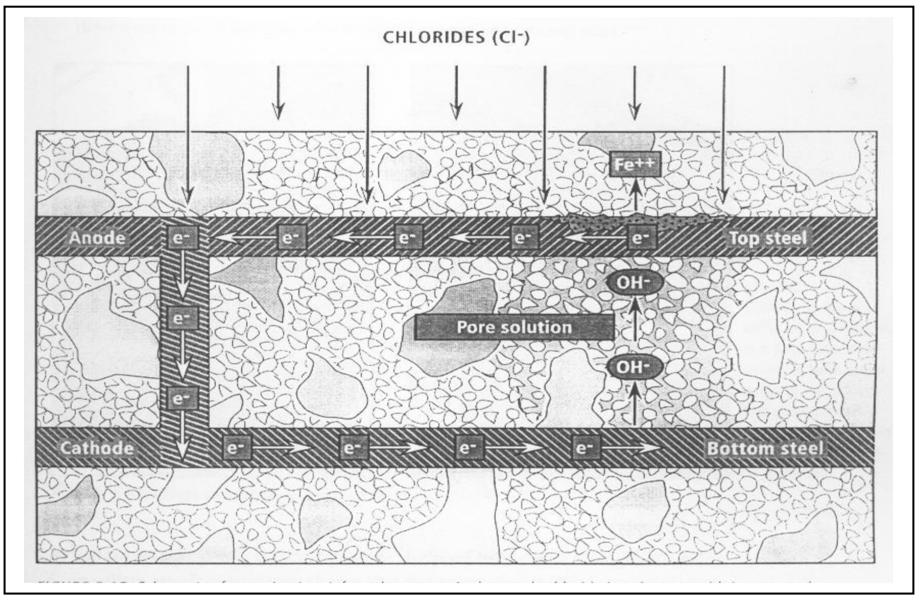


figure. 2.29. Schematic of corrosion in reinforced concrete. At the anode chloride ions interact with iron to produce Fe++ ions. The electrons released flow through the reinforcing steel to the cathode. The electrical path is completed by OH- ions flowing through the pore solution (electrolyte). In some cases the anode and cathode may both be on the same bar. By reducing the permeability of the concrete, silica fume delays the chlorides reaching the steel.

Fig 2.29 and 2.30 show concrete with damage caused by corrosion. Note that corrosion damage in concrete is a multi step process as follows :

1. The chloride ions slowly work into the concrete to reach the level of the reinforcing steel. Once a certain amount of chlorides, called the threshold amount, reach the steel, corrosion begings.
2. As the ions are removed from the reinforcing steel, they go through several stages of oxidation or rusting. The volume of the iron increases with each stage.
3. As the amount of rust increases, rust stains will be seen on the surface of the concrete. Next, cracking will be seen. Finally, the cracking will result in delaminations and spalling of concrete over the reinforcing steel.

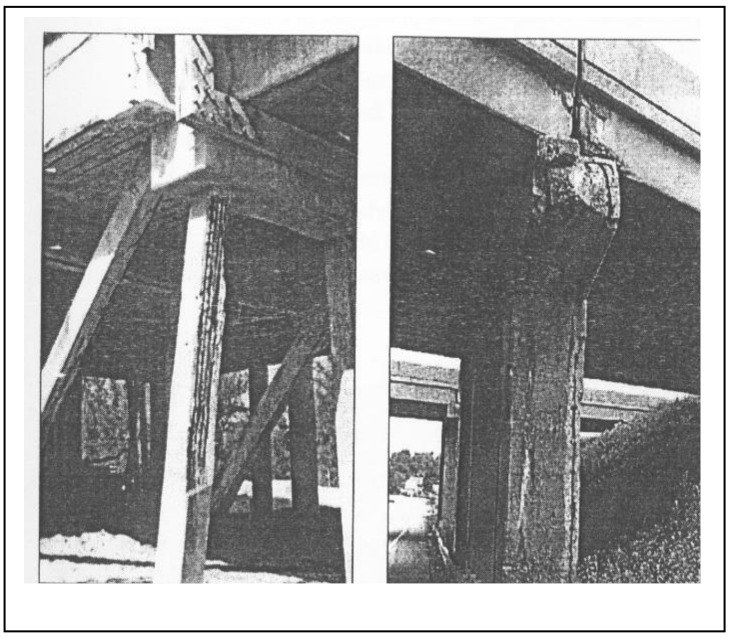


Fig.2.30 Chloride induced corrosion on a highway overpass. Note that cholorides have apparently run off of deck and onto this pier. Structural elements as well as decks should be protected.

2.46.8 Sulfate Attack : While the chemistry of the portland cement used plays a role in sulfate attack, it has been shown that the water cementitious materials ratio (w/cm) is also a critical factor. Reducing the w/cm effectively reduces the permeability of the concrete. Adding silica fume will further reduce the permeability resulting in further delays of any adverse reactions.

2.46.9 Acid or other chemical attack : The overall resistance of silica fume concrete to attack by an aggressive chemical is not significantly different from that of conventional portland cement concrete. However, the reduced permeaiblity of silica fume concrete may extend the life of a concrete structure or extend the time between repairs simply by slowing down the rate of the attack. If protection against a particular chemical is required on a project, we strongly urge testing to include exposure of specimens of varying silica fume contents to the particular chemical.

The reduction in permeability is not the only contribution of silica fume to durability. There is ample evidence that silica fume, when used alone or in conjunction with a suitable fly ash, can reduce or eliminate the potential for alkali aggregate reaction when reactive aggregates are used. Again, testing will be required to determine the appropriate amount and types of cementitious materials also be used for each particular application.

Finally, the higher strength of silica fume concrete will add additional abrasion resistance. For concrete made with a particular aggregate, the higher the compressive strength, the higher the abrasion resistance. High strength silica fume concrete has been used in applications such as trash transfer stations and stilling basins in major dames.

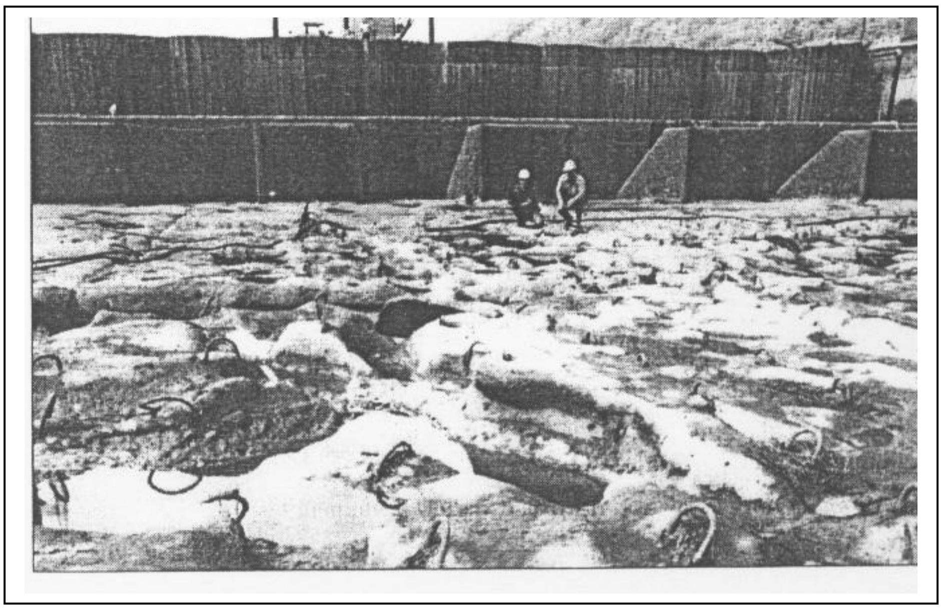


Fig. 2.31 Abrasion erosion damaged concrete. This structure was repaired using high strength silica fume concrete with a specified compressive strength of 86 MPa

2.47. PERFORMANCE OF SILICA FUME DURING CONSTRUCTION

One pass finishing : In this case, we are taking advantage of the lack of bleeding in silica fume concrete to complete finishing of flatwork in a single, continuous operation. The owner will get a better surface and the contractor will be able to complete the finishing in a shorter time using fewer finishes.

Reduced heat of hydration : Although silica fume contributes about the same amount of heat of hyderation or does portland cement on a pound for pound basis, its strength contribution is much greater on the same basis. Therefore, by balancing portland cement and silica fume in a mixture, heat of hyderation can be reduced while strength is maintained.

Use of three cementitious Materials : There is an ever increasing emphasis on using more water materials such as fly ash and slag in concrete. However, the early age waste strength of concrete may suffer as a result. Adding small amounts of silica fume can offset this reduction in early strength. Figure () shows a structure where silica fume was added to gain both a reduction in heat and to offset the loss of early age strength resulting from using a large volume of fly ash. Usually, using combinations of three cementitious materials will reduce the cost of concrete. Mixtures containing three cementitious materials are referred to an “ternary mixtures”.

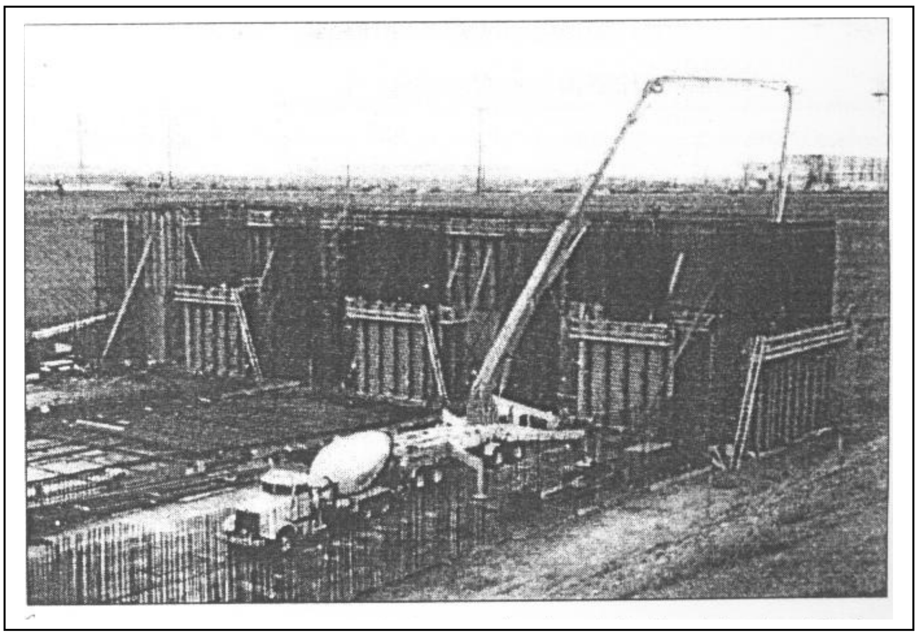


Fig. 2.32 Concrete containing portland cement, fly ash, and silica fume being placed. The fly ash was used to control heat of hydration while the silica fume provided early strength required for stripping forms.

Shotcrete : silica fume shotcrete is being widely used, both the wet and dry processes and with and without steel fibres. The cohesive nature of this shotcrete allows for many applications that would have been difficult, uneconomical, or impossible to accomplish without the silica fume.

2.48 STANDARD SPECIFICATIONS

The version discussed here in the 2004 edition of the specification.. Each of the mandatory, optional, and report only items is described below :–

(a) **Silicon dioxide (SiO_2) content (mandatory).** This requirement calls for a minimum SiO_2 content of 85%. Because SiO_2 is the reactive ingredient of silica fume, a limit on the content is deemed appropriate. Other standard specifications (for example, Canada) allow the use of silica fume with a SiO_2 content less than 85% after appropriate testing in concrete.

(b) **Moisture content (mandatory) :**This requirement limits maximum moisture content to 3%. The intent here is simply to minimize the amount of moisture that is brought along with the silica fume.

(c) **Loss on ignition (mandatory) :** This requirement limits maximum loss on ignition to 6%. Fly ashes have had this requirement for many years because of the potential for partially combusted coal particles being included in the fly ash. This coal can be of a form with a very high surface area, which significantly increases the demand for air entraining admixture in air-entrained concrete. It is not clear whether any coal of this same nature is present in silica fume, so the LOI requirement is more of a control on any unburned coal or other material from the electric-arc furnace.

(d) **Oversize material (mandatory) :** This requirement limits the amount of oversize material retained on a 45-um (No. 325) sieve to a maximum of 10%. There is a further requirement that the maximum variation from average to no more than 5 percentage points. Silica Fume is an extremely fine material and a sieve analysis will not provide any significant information on particle size on surface area. This requirement is aimed at minimizing the amount of foreign material in the silica fume. Such material could include uncombusted materials from the furnace or rust particles from the silica fume collection system.

(e) **Accelerated pozzolanic activity (mandatory).** This requirement states that the accelerated pozzolanic activity of a silica fume must be at least 105% of the control made without silica fume. This requirement is also a carry over from the fly ash specification. Note that this test is carried out at a constant water-cementitious materials ratio for both the cement only and the cement plus silica fume mixtures. The silica-fume mixtures use a dry superplasticizer to achieve a flow value equal to the cement only mixtures.

(f) **Specific surface (mandatory).** This requirement calls for a maximum specific surface (surface area) of $15 m^2/g$. determining specific surface for silica fume requires a very sophisticated technique known as nitrogen adsorption or the ‘BET’ method. Values obtained from this type of testing are not directly comparable with air-permeability test methods such as Blaine. Specific surface is an important parameter for silica fume because the higher the surface, the smaller the particles.

(g) **Uniformity requirements (optional).** This requirement limits the variation in air-entraining admixture demand for mortar containing silica fume to a maximum of 20% over the ten preceding tests. This testing is infrequently done and is not of much significance to the user of the silica fume. What is more important to the actual demand for air-entraining admixture in concrete made with project materials. Adding silica fume should be expected to increase the requirement for AEA by about 50-100%, depending upon the nature and the amount of the silica fume being added and the actual AEA being used. Increases in AEA usage outside this range or decreses (very rare) should be investigated to ensure that the suitable air-void system is being developed.

(h) **Reactivity with cement alkalies (optional)** This requirement calls for a reduction in expansion of mortar bars of 80% when tested at 14 days.. As noted earlier, because silica fume, used in the appropriate levels, is known to be very effective in controlling ASR, this limit is not of much value. If preventing the ASR is important in a particular application, appropriate testing with the actual project concrete materials will provide much more meaningful information.

(i) **Sulfate resistance expansion (optional)** This requirement establishes permissible expansion limits for silica fume used in sulfate resistance applications. Limits are presented for moderate, high and very high resistance. The same philosophy applies here as was true for ASR prevention: if sulphate resistance is of importance, the only meaningful data will come from testing with project specific materials.

(j) Bulk density (report only). Bulk density is the loose unit weight of the silica fume. There is no limit established-the value is simply reported for use by the purchaser of the silica fume.

(k) Density (report only). Density is the term used for ASTM for the specific gravity of the silica fume. There is no limit established-the value is simply reported for use by the purchaser of the silica fume.

(l) Total alkalies (report only). There is no limit established for total alkalies-the value is simply reported for use by the purchaser of the silica fume. Reporting the total alkalies was originally, a mandatory requirement that was derived from the fly ash specification. It is now recognized that silica fume will not contribute to the total alkali content of the concrete. If preventing ASR is important in a particular application, appropriate testieng with the actual project concrete materials will provide much more meaningful information than knowing the alkali content of the silica fume.

2.46 Silica Fume Concrete MiIestones

1948 Researchers in Norway identify potential for silica fume as concrete admixture.

1952 First field experiment using silica fume involves the Blindtarmen Tunnel in downtown Oslo.

1971 First experiment on use of condensed silica fume in concrete takes place at University of Sherbrooke in Quebec.

1976 First standard on use of condensed silica fume. with the addition of 10 percent by weight of cement, is permitted in Norway.

1976 Naphalene sulfonate-based Type F and Type G high-range water reducers are commercialized in North America by Grace Construction Products: they become critical in making high-strength or high-performance concretes containing silica fume or other admixtures commercially available; subsequently they are added to ASTM 494 admixtures. Melamine-based water reducers appear earlier.

1977 Norchem begins selling silica fume in North America.

1980 Using technology from Norchern. Pittsburgh-based Elkem Materials begins building staff. and introduces silica fume for commercial concrete use in the U.S. in 1981.

1982 Demonstration slabs of 20.000 psi concrete are placed at site of Dashields Lock & Dam on Ohio River in Pennsylvania.

1982 First use of shotcrete containing silica fume. attaining 13.000 psi. at Lake Lynn Testing Facility.southwestern Pennsylvania. Bureau of Mines.

1983 In two Important applications. both Involving abrasion resistant concrete, U.S. Army Corps of Engineers Specifies silica fume for Kinsua Dam Stilling Basin Rehabilitation. Warren. Pa. (l0.000 psi in seven days. and 12.500 psi in 28 days), and Los Angeles River Low-Flow Channel Liner.

1984 First U.S. bridge deck using silica fume is placed on Oct. 18 in northeastern Ohio by Chapin & Chapin, Norwalk, Ohio

First use of silica fume specified for commercial building in U.S., Nashville's 28-story Third National Bank and Finance Center. Concrete is supplied by Metro Ready Mix.

1985 First use of silica fume in a parking garage, for repair work in Horne's Garage, Pittsburgh. using 10 percent by weight of cementitious material. Concrete was provided by Frank Bryan, Inc.. Southside, Pa.

1986 First use of silica fume in a new parking deck, the Manor Parking Structure in Pittsburgh, featuring cast. in-place slabs, post-tensioned two ways. and precast architectural parapets. By 1990 over 15 parking garages in Pittsburgh will have incorporated silica fume

First state to issue a proposal note. permitting contractors to propose use of silica fume in DOT projects, is Ohio Effective finishing and curing techniques for silica fume concrete flatwork are developed. including the use of fresno trowels, fog misting, and immediate application of wet curing techniques, such as wet burlap

Canadian National Standard for silica fume is published (Canadian Standards Association Standard CAN/CSA A23.5-M86 Supplementary Cementitious Materials)

Scotia Plaza is constructed in Toronto with a composite concrete/steel system. using 10.000 psi (70 MPa) silica fume mixes.

1988 Two early ultra-high-strength concrete Seattle towers are constructed, Two Union Square. and Pacific First Center, with silica fume supplied by WR. Grace. Both are designed by Skilling Ward Magnusson Barkshire. 14,000 psi concrete is specified for 62 story Two Union Square, but at times reaches compressive strengths of 19,000 psi, and is supplied by Lonestar Northwest. Nominal 14,000 psi concrete for the 45-story Pacific First Center is supplied by Stoneway Concrete of Seattle.

1989 High-strength, 9,000 to 10.000 psi prestressed girders using silica fume are incorporated into Perdido Pass marine structure, Gulf Shores, Ala.

1989-1992 Silica fume concretes are specified for reinforced concrete columns or composite concrete/steel structures in a wave of high-rise buildings that close the 1980s binge of speculative construction. These include: Chicago's 311 South Wacker Drive, 12.000 psi mixes supplied by Prairie Materials: Atlanta's One Peachtree Center, 12.000 psi mixes supplied by Blue Circle Williams. Marietta. Ga.; Minneapolis' Dain Bosworth Tower. 14,000 psi mixes supplied by AVR Inc., Apple Valley, Minn., Cleveland's Society Tower, 12,000 psi mix.

es supplied by Cuyahoga Concrete, Cleveland; and New York City's Trump Palace, 12,000 psi mixes.

1990 Phase I of Concrete Canada is launched, through 1994, with Phase II from 1994 through 1998. A consortium of research centers - the Network of Centres of Excellence on High-Performance Concrete - encompasses 12 research projects, six bridges in Ontario and Quebec.

and a number of repair projects incorporating silica fume.

1991 In a first for Canadian prestressed concrete. Vancouver. B.C based Con-Force Structures Ltd. fabricates I girders. cast from 9,000 psi silica fume mixes. for the spliced
171ft-long Esker Overhead Bridge in British Columbia.

1992 With the assistance of the Federal Highway Administration, the Louisiana Transportation Research Center begins an investigation of highstrength concrete in design and construction of highway bridges. Tests involve prestressed girder and pile specimens cast from silica fume mixes with design strengths of 10,000 psi. fabricated by Sherman Prestress. Mobile, Ala. Study suggests bridge designs can be economized by potentially lowering the number of girders required to carry Comparable weight. and higher-strength concrete piles are suited to extra loads and forces when being driven.

1996 All states have used silica fume at least once in bridge decks. Also, despite having used silica fume in over *550* bridge decks in 12 years, Ohio a forerunner in applying the mix technology - has yet to put silica fume into standard specs for bridge decks.

CHAPTER 3

MATERIALS AND METHODS

3.0 MATERIALS USED FOR THE INVESTIAGTION:

The Materials used for the manufacturing of High Strength concrete with silica fume and properties of various materials used in the investigation are determined by as per recommendations of BIS in the following paragraph.

3.1 CEMENT

Cement is a well-known building material and has occupied an indispensable palce in construction works.

Portland cement is an extremely ground material having adhesive and cohesive properties, which provide a binding medium for the discrete ingredients. It is obtained by burning together, in a definite proportion, a mixture of naturally occurring argillaceous (containing alumina) and calcareous (containing calcium carbonate or time) materials to a partial fusion at high temperature (about 1450°C). The product obtained on burning called clinker or nodules (5 to 25 mm diameter), is cooled and ground to the required fineness to produce a material known as cement. Its inventor, Joseph Aspdin, called it Portland cement because when it hardened it produced a material resembling stone from the quarries near Portland in England. During the grinding of clinker, gypsum or plaster of Paris ($CaSO_4$) is added to adjust the setting time. The amount of gypsum is about 3 percent by weight of clinker. It also improves the soundness of cement.

Depending upon the location of the cement manufacturing plant, available raw materials are pulverized and mixed in proportions such that the resulting mixture well have the desired chemical composition. The common calcareous materials are lime stone, chalk, oyster shells and marl. The argillaceous materials are clay, shale, slate and selected blast furnace slag. When limestone and clay are the two basic ingredients, the proportions will be approximately four parts limestone to one part of clay. Certain clays formed during volcanic eruption, known as volcanic ash or pozzolana, found near Italy, have properties similar to that of Portland cement.

Since the raw materials consists mainly of lime, silica, alumina and iron oxide, these form the major constituents of Portland cement also

The ultra tech 53 grade cement (OPC) confirming IS :12269:1987 is used in the laboratory .The determination of physical properties of the cement is carried out in laboratory is explained briefly in the following paragraph.

The chemical propertied of the cement was determined by Shreeram Industrial Research Testing Centre, Delhi by using spectro pnotometer

Table No. 3.1. Physical characteristics of cement

Sr. No	Properties	Referred Code	Value	Codal Requirement
1	**Fineness (cm^2/g)**	IS:4031(P-2)-1999	2950	225 Min
2	**Specific Gravity**		**3.15**	-
3	**Soundness**	IS: 4031(P-3)-1988	1.8	30
4	**Normal consistency**		32	…
5	**Initial Setting Time (min)**	IS:4031(P-5)-1988	90	30
6	**Final Setting time (min)**		230	600 Max

Table No.3.2 Chemical Properties of Cement

Sr No.	Chemical	Chemical compositions (%)
1	Loss of ignition	2.05
2	SiO_2	20.84
3	Al_2O_3	3.85
4	Fe_2O_3	5.4
5	CaO	62.44
6	MgO	1.4
7	SO_3	4.16
8	Free Lime	1.49

3.2 SILICA FUME

The silica fume was procured in the plastic bag from ORKLA INDIA (P) LIMITED OF Lot No. M007 with trade name Elkem Microsilica grade 920-D packed in 25 Kgs HDPE Bags. The Physical and chemical properties of silica fume are given in the following table 3 & 4.

Table No. 3.3. Physical Properties of Silica Fume

Sr. No.	Properties	Values	Required Specification ASTMC 1240-03A
1	Size greater 45 M	0.5%	Maximum 10
2	Pozzoloan Activity Index (7d)	146.60%	Min^{m} 105
3	Specific Surface	20.3m^2/g	Min^{m}15
4	Bulk density	520.kg/m^3	500-700
5	Density	2.30 Mg/m^3	…..

Table No.3.4. Chemical Characteristics of Silica Fume

Sr. No.	Chemical	Values	Required Specification
1	SiO_2	88.1%	Min^{m}85
2	Moisture content	07.%	Max^{m}3.0
3	Loss of Ignition	2.7%	Max^{m}6.0
4	Available Alkalies	0.6%	……

3.3 AGGREGATES

Concrete can be considered to be an artificial stone obtained by binding together the particles of relatively inert fine and coarse materials, with cement paste. Aggregate are generally cheaper than cement and impart greater volume stability and durability to the concrete.

The aggregates provide about 75 percent of the body of the concrete and hence its influence is extremely important. They should therefore meet certain requirements if the concrete is to be workable, strong, durable and economical. The aggregate must be of proper shape (either rounded or approximately cubical), clean, hard, strong and well graded. It should possess chemical stability and, in many cases, exhibit abrasion resistance to freezing and thawing.

An aggregate are the important constituent in concrete. They give body to the concrete, reduce shrinkage and effect economy. The mere fact that the aggregate occupy 70-80 per cent of volume of concrete, their impact on various characteristics and properties of concrete is undoubtedly considerable.

3.3.1 Coarse aggregates.

The aggregates most of which are retained on the 4.75 mm IS Sieve and contain only that much of fine material as it permitted by the specifications are termed coarse aggregates. The coarse aggregate may be one of the following types :

1) Crushed gravel or stone obtained by crushing of gravel or hard stone,
2) Uncrushed gravel or stone resulting from the natural disintegration of rock or
3) Partially crushed gravel or stone obtained as a product of the blending of the above two types.

For this study we procure the crushed stone coarse aggregate from market and performed the two test namely specific gravity and Sieve analysis for gradation as per IS:383:1970.

(A)Specific Gravity using Pycnometer is given by expression

Specific gravity = $(W_2 – W_1) / ((W_2- W_1)-(W_3 – W_4))$

= (1292 - 692) / ((1292 -692) – (1900 - 1530))

= 2.61

Where,

W_1 = Wt. of empty Pycnometer = 692 gm

W_2= Wt. of Pycnometer + Wt. of oven dried aggregate = 1292 gm

W_3 = Wt. of Pycnometer + aggregate + water = 1900 gm

W_4= wt. of Pycnometer + water. = 1530 gm

(b) Sieve Analysis

Table No.3.4 Sieve Analysis of 20 MM graded Aggregate

Sample Weight 2000 gm

IS Sieve Size	Wt. Retained gm	Wt. Passed gm	Percentage Passing	Grading Limits IS:383-1970
40 mm	0	2000	100	100
20 mm	40	1960	97.90	95 – 100

10 mm	1170	790	39.5	25 - 55
4.75 mm	690	100	5	0 -10
Fineness Modulus of Coarse Aggregate = 7.10				

3.3.2 Fine aggregate:

The aggregate most of which passes IS:4.75mm sieve is classified as fine aggregate. The fine aggregate obtained from natural disintegration of rocks and deposited by streams are known as natural sands. Fine aggregates resulting from crushing of hard stone and natural gravel are known as crushed stone sand and crushed gravel sand respectively.

For this study we procure the Badarpur sand form vendor as per BIS code for fine and coarse aggregates. We perform the sp. gravity, silt content and sieve analysis and bulking of sand .all test result on aggregates are follows

(B)Sand

(a)Specific Gravity using Pycnometer is given by expression

Specific gravity = $(W_2 – W_1) / ((W_2- W_1)-(W_3 – W_4))$

= (1310 - 692) / (1310 -692) – (1912 - 1530))

= 2.63

Where,

W_1 = Wt. of empty Pycnometer = 692 gm

W_2= Wt. of Pycnometer + Wt. of oven dried sand = 1310 gm

W_3 = Wt. of Pycnometer + sand + water = 1912 gm

W_4= wt. of Pycnometer + water. = 1530 gm

(C) Bulking of sand

Free moisture forms a film around each particle this film of moisture exerts what is known as surface tension which keeps the neighboring particles away from it .similarly the force exerted by surface tension keeps every particle away from each other.

Therefore, no point contact is possible between the particles. This phenomenon is called bulking of sand

The bulking of fine aggregate is determined in laboratory using measuring jar. The result obtained is given in table no 3.4

Table No.3.5 Observation Table of Bulking of Sand

% of water	Initial Reading (h1)	Final Reading (h2)	Volume of Bulking (H1–h2)/h1 x 100
5 %	200	215	6.97 %
10 %	200	220	9.09 %
15 %	200	195	2.56 %
20 %	200	150	1.33 %

(D)Silt content test.

In sand sample contain appreciable amount of clay as in that case silt and clay sized particles will stick to sand sized particles. The pipette testing is used for the determination of silt content in sand, The silt content in sand sample is given in table no 3.5

Table No.3.6 Silt content Test

Sr.No.	Silt above Sand height Sand	Sand height below silt	Silt Content
1	4 ml	110 ml	3.64%

(E) Sieve analysis

Sand sample: - Wt of sample 1000 gm

Table No 3.7 Grading zones for fine aggregate from natural sources for concrete (as per IS Code 383 : 1970)

Sr. No	IS Sieve Size in mm	**Percentage passing for**				
		Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV	
1	10	100	100	100	100	
2	4.75	60-95	90-100	90-100	95-100	
3	2.36	30-70	75-100	85-100	95-100	
4	1.18	35-59	55-90	75-100	90-100	
5	0.600	15-34	35-59	60-79	80-100	
6	0.300	5-20	8-30	12-40	15-50	
7	0.150	0-10	0-10	0-10	0-15	

(E) Sieve Analysis Test of Fine Aggregate (Sand)

Table No.3.8 Sieve analysis of sand sample.

Wt of sample	Sr. No.	Sieve Size	Wt. Retained	Wt. Passed	% age Passing	Requirement of Zone III Type
1000 gm	1	10 mm	0	1000	100 %	100%
	2	4.75 mm	0	1000	100 %	90-100
	3	2,36 mm	0	1000	100 %	85-100
	4	1.18 mm	122	878	87.8 %	75-100
	5	600 micron	213	665	66.50 %	60-79
	6	300 micron	401	264	26.40 %	12-40
	7	150 micron	234	30	3 %	0-10

From the test result sand sample Satisfy and confirming the Zone III As per IS 383:1970

3.4 Admixture:

The admixtures is procured from the fosroc chemical ltd. as we expected that the slump value for water/cement ratio 0.40and 0.35 is observed to be very low, so we used the fosroc admixture for workability test on concrete. In this study we take the 1.5 % wt of cement to get 90 to 100 mm slumps.

3.5 Water and Acid

The water for curing of concrete is taking normal water having ph 7 and it is free form organic matters. The water test is carried out in lab. The values obtained in test is shown in following table no 3.9

The sulfuric acid having the 98.9 concetration is procured form market because of its highly acidic concentration .special care should be taken for its handing and shipping

The acid is mixed with water and make the 0.2 Normal of concentration of solution for the acid curing for both type FRC and normal concrete

Table no 3.9 Permissible limit for solids as per IS 456 of 2000

Sr. No	**Material**	**Tested as per**	**Value**	**Permissible limit (max)**
1	Organic	IS 3025(pt18)	140 mg/l	200 mg/l
2	In-organic	IS 3025 (pt18)	507 mg/l	3000 mg/l
3	Sulphate (as SO_3)	IS 3025(pt24)	102 mg/l	400 mg/l
4	Chloride (CL)	IS 3025(pt32)	120 mg/l	2000 mg/l for concrete work containing embedded steel and 500 mg/l for reinforced concrete work
5	Ph	-	7	6 to 8
6	Total Suspended Solids	IS 3025(pt17)	850mg/l	2000 mg/l

3.6 Mix Design

According to IS: 456:2000 and IS: 1343-1980 the design of concrete mix should be based on the following factors:

- ✓ Grade of designation
- ✓ Types of Cement
- ✓ Maximum nominal size of aggregates
- ✓ Grading of combined aggregates

- ✓ Water- Cement ratio
- ✓ Workability
- ✓ Durability
- ✓ Quality control.

(A) Design of concrete mix of Grade M-35 (N1)

Details

a) Type of cement - 53 grade
b) Fine aggregate - Sand grading zone – III
c) Coarse aggregate - 20 mm size as per IS:383
d) Specific gravity of cement - 3.15
e) Specific gravity of sand - 2.63
f) Specific gravity of aggregate - 2.61
g) Degree of quality control - Very Good
h) Type of exposure - severe
i) Degree of workability - 0.80 compacting factor

Design (From IS : 10262 – 1982)

1. Target mean strength

$$fc\bar{k} = fck + t \times s$$

$$= 35 + 5.3 \times 1.65 = 43.7\ \text{N/mm}^2$$

2. Selecting w/c ratio

From Fig. 2, from graph corresponding to target mean strength

W/C = 0.42

3. Air Content

For nominal maximum size of 20 mm aggregate

Entrapped air from table -3

= 2% of volume of concrete

4. Water content and fine to total aggregate ratio
From table 5

Water = 186 kg/m^3
Sand = 35%

5. Adjustment in water and sand percentage. For change in values in water cement ratio compacting factor and sand belongings to Zone – III the following adjustment is required.

For Sand conforming to Grading zone – III	Adjustment Required in water content	Percentage sand in total aggregate
For decrease in water	0	(-) 1.5 Percent
Cement ratio by	0	(-) 3.60 percent
(0.60 – 0.40) = 0.18		
	0	(-) 5.1 percent

Therefore required sand content as = 35 – 5.1 = 29.90%
Water content = 186 Kg/m^3

6. Determination of cement content

Water Cement ratio = 0.42

Qty. of water = 186 lit

Qty. of cement = $\frac{186}{0.42} = 443\,kg$

The calculated cement content is > 310 Kg/m^3 as per durability requirement

7. Determination of coarse and fine aggregate content

For the specified maximum size of aggregate of 20 mm the amount of entrapped air in the wet concrete = 2 percent

Quantity of sand $V = \left[W + \frac{C}{S_c} + \frac{1}{\rho} \cdot \frac{f_a}{S_{fa}}\right] \times \frac{1}{1000}$

$$0.98 = \left[186 + \frac{443}{3.15} + \frac{1}{0.299} \times \frac{f_a}{2.63}\right] \times \frac{1}{1000}$$

Quantity of sand f_a = 514 Kg/m^3
Quantity of coarse aggregate

$$0.98 = \left[186 + \frac{443}{3.15} + \frac{1}{(1-0.299)} \times \frac{C_a}{2.61}\right] \times \frac{1}{1000}$$

Quantity of C_a = 1196 Kg/m^3

The Mix proportion for M-35 grade concrete becomes

Water	Cement	Fine Aggregate	Coarse Aggregate
186 lit (0.42 W/C)	443 Kg :	514 Kg :	1196 Kg

Ratio of Mix for M-35 (N1) = 1 : 1.16 : 2.70

(B) Design of concrete mix of Grade M-45 (M1)

Details

j) Type of cement - OPC 53 grade
k) Fine aggregate - Sand grading zone – III
l) Coarse aggregate - 20 mm size as per IS:383
m) Specific gravity of cement - 3.15
n) Specific gravity of sand - 2.63
o) Specific gravity of aggregate - 2.61
p) Degree of quality control - Very Good
q) Type of exposure - severe
r) Degree of workability - 0.80 compacting factor
s) Water absorbtion of aggregate - 0.50 percent
t) Water absorbing of sand - 1.0 percent

Design from IS : 10262 - 1982

2. Target mean strength

$$fc\bar{k} = fck + t \times s$$

$$= 45 + 1.65 \times 6 = 55 \text{ N/mm}^2$$

2. Selecting w/c ratio

From Fig. 1 from graph corresponding to target mean strength 55 N/mm^2

w/c = 0.34

3. Air Content

For nominal maximum size of 20 mm aggregate entrapped air from table -3

= 2% of volume of concrete

4. Water content and fine to total aggregate ratio
From table 5
Water = 186 kg/m^3
Sand = 35%
As superplasticizers is proposed, we can reduce water content by 15%
So water content = 180 – 180 x 0.15 = 153 litre

5. Adjustment in water and sand percentage. For change in values in water cement ratio compacting factor and sand belongings to Zone – III the following adjustment is required.

For Sand conforming to Grading zone – III	Adjustment Required in water content	Percentage sand in total aggregate
For decrease in water	0	(-) 1.5 Percent
Cement ratio by	0	(-) 0.20 Percent
(0.35 – 0.34) = 0.01		
	0	(-) 1.70 percent

Therefore required sand content as = 25 – 1.70 = 23.30%
Water content = 153 lit/m^3

6. Determination of cement content

Water Cement ratio = 0.34

Qty. of water = 153lit

Qty. of cement = $\frac{153}{0.34} = 450\ kg$

The calculated cement content is > 310 Kg/m^3 as per durability requirement

7. Determination of coarse and fine aggregate content

For the specified maximum size of aggregate of 20 mm the amount of entrapped air in the wet concrete = 2 percent

Quantity of sand $V = \left[W + \frac{C}{S_c} + \frac{1}{\rho} \cdot \frac{f_a}{S_{fa}} \right] \times \frac{1}{1000}$

$$0.98 = \left[153 + \frac{450}{3.15} + \frac{1}{0.233} \times \frac{f_a}{2.63} \right] \times \frac{1}{1000}$$

Quantity of sand f_a = 403 Kg/m^3

Quantity of coarse aggregate

$$0.98 = \left[153 + \frac{450}{3.15} + \frac{1}{(1-0.233)} \times \frac{C_a}{2.61} \right] \times \frac{1}{1000}$$

Quantity of C_a = 1316 Kg/m^3

The Mix proportion for M-45 grade concrete becomes

Water	Cement	Fine Aggregate	Coarse Aggregate
153 lit (0.34W/C)	450 Kg :	403 Kg :	1316 Kg

Ratio of Mix for M-45 (M1) = 1 : 0.90 : 2.92

3.7 EXPERIMENTAL SETUP AND TEST PROCEDURE

In this study, an ordinary Portland cement 53 grade with specific gravity 3.15 was used as a cementations material and silica fume is used by replacing 5% and 15% with cement.

With specific gravity of 2.61 coarse aggregate and specific gravity of 2.63 fine aggregate used in the test and super plasticizer was used to achieve the required work ability (slump value 100 mm to 120 mm) of the concrete mixes.

Concrete mixes were prepared for two different grade m-35 and m-45 having w/c ratio 0.42 and 0.34 respectively.

The proportioning and description of concrete mixture are summaries in table (3.8) fresh concrete mixtures were prepared in mixer. The sequence of mixing procedure was as follows

1. The aggregates were placed in the mixer and dry mixed for two minutes.

2. Half of the water with addition of superplasticizer was added to mixture and the mixture is run for two minutes.
3. Afterwards, cement and silica fume and the remainder of water +superplasticizer were added to the mixer and the mixer was run for and additional two minutes. Total mixing time was six minutes for all concrete mixtures The mixing was carried out conventionally in an electrically driven mechanical mixer of epicyclic type with imparted both rotary and a revolving motion to the mixture pedal.

   150 mm x 150 mm cube and 150mm diameter and 300mm height cylinder specimen and 100mmx100mmx500 mm prism were prepared for uniaxial compression strength and split tensile strength test and flexure strength test.

   Immediately after mixing and casting of concretes, the cube molds were stored in humidity room for 24 hrs at 95 % relative humidity and 20°C temperature and half then the cube and cylinder specimens were removed from the molds and cured in water for 28 day and half of specimen in 0.2 N H_2SO_4 Acid water 7 days, 28days and 90 days.

The test specimens were de-moulded after 24 hours at room temperature, cured in a water bath at a temperature of 20 ± 2 “C and then tested after 7 day , 28 day and 60 days immersion

Control specimens (pure cement concrete specimen) were also made for carrying out comparison of compressive strength tests and tensile strength. All the specimens were compacted by table vibration and had 2000 x 1500 x 300 mm final dimensions

After the specimen De-moulded, after 24 hours the specimens were immersed in pure water and solutions of sulfuric acid at *pH* values of 0.70 ±0.01 (i.e. 0.2 N Mix. Solution). All the solutions were prepared by adding concentrated acid to top water. The *pH* levels of the solutions were monitored weekly with a portable *pH*-meter of the type WTW pH 597, and concentrated acids were added to maintain the *pH* values at the stated tolerances. During pH monitoring, an a wooden blade was used for mixing each of the solutions thoroughly. All solutions were renewed monthly and the temperature of the solutions was kept constantly at 20°C.

At least six specimens of cube (150mm x150mm) and six specimen of cylinder having (150mm dia. x 300mm long) and six specimen of prism (100mmx100mmx500mm long) were tested for each grade of concrete in two curing condition (i.e. acid and water)for 7 day ,28 day, and 90 days., All the tests reported here were carried out at the same constant accuracy and Procedures. The compressive strength, split tensile strength, mass loss, rebound no. and ultrasonic pulse velocity tests were perform on all specimens for each temperature level and each concrete mixture.

Table No.3.10 Preparation of various kind of sample

Sr.No.	**Designation**	**Description**
A	**M-45 Grade Concrete**	
1	M1	OPC + sand + Aggregate + superplasticisers (1.5%)
2	MSF1	OPC with 5% cement (wt.) replaced by silica fume + sand + aggregate + superplasticisers (1.5%)
3	MSF2	OPC with 15% cement (wt.) replaced

		by silica fume + sand + aggregate + superplasticisers (1.5%)
B	**M-35 Grade Concrete**	
1	N1	OPC + sand + Aggregate + superplasticisers (1.5%)
2	NSF1	OPC with 5% cement (wt.) replaced by silica fume + sand + aggregate + superplasticisers (1.5%)
3	NSF2	OPC with 15% cement (wt.) replaced by silica fume + sand + aggregate + superplasticisers (1.5%)

Table No. 3.11 Preparation of various kind of sample

Sr No	Designation	**No of sample Casted**		
		Cube (150x150x150mm)	Cylinder (150mm diax 300 Height)	Prism (100 mmx 100mmx 500mm)
1	M1	18	18	18
2	MSF1	18	18	18
3	MSF 2	18	18	18
4	N1	18	18	18
5	NFS1	18	18	18
6	NFS2	18	18	18

3.8 TEST ON FRESH CONCRETE

3.8.1 Workability Test: -

The diverse requirements of mixibility, stability, transportability, placeability, mobility, compactability and finishability, of fresh concrete mentioned above are collectively referred to as workability. The workability of fresh concrete is thus a composite property. It is difficult to define precisely all the aspects of the workability in a single definition. IS:6461 (Part-VII)-1973 defines workability as that property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, compacted and finished.

Ease is related to rheology of fresh concrete which includes performance parameters of stability, mobility and compactibility. These parameters are redefined in rheology in terms of forces involved in transmission of mechanical stresses, resistance to segregation and bleeding, and resistance to flow by cohesive, viscous and frictional forces.

Workability defines as the property of concrete which determines the amount of useful internal work necessary to produce full compaction. Another definition which envelopes a wider meaning is that, it is defined as the “ease with which concrete can be compacted hundred per cent having regard to mode of compaction and place of deposition

Workability is carried out by conducting the slump test compaction factor test and cone penetration test on normal concrete .The slump in experiment were taken 100 to 120.

3.9 Test on Hardened concrete

3.9.1 Mass Test: the mass test is performed on cube size 150x150x150 the electronic balance is used to determine the mass of cube sample of 2 grade of concrete. The details of test results is given in test result chapter 4 and it is shown in Graph 4.1.

3.9.2 Rebound hammer Test:

The concrete surface hardness testing with SCHMIDT rebound hammer (developed by a Swiss engineer Ernst Schmidt) is most frequently used method worldwide for non-destructive testing (NDT) of concrete structural element. In this method a test hammer hits the concrete at a definite energy and its rebound which is dependent on the hardness of concrete, is measured by test equipment. By reference to the conversion table, the rebound value furnishes the compressive strength of in-situ concrete. A test hammer is used for testing the strength of the concrete, to check the uniformity of concrete and structural element; to detect the damaged zones.

Schmidt's rebound hammer developed in 1948 is one of the commonly adopted equipments for measuring the surface hardness. Rebound hammer is performed because of it provide the quick inexpensive means of checking uniformity of concrete. The method is based on the principle that the rebound of an elastic mass depends on the hardness of the surface which it strikes. The test is fast and is unlikely to cause damage to the concrete

The rebound hammer is carried on the cube sample and rebound number is correlate with the compressive strength of concrete. The details of rebound number is given table No 4.4 and it is shown in fig.3.1

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Fig.3.1 Rebound Hammer

3.9.3 Ultra sonic Pulse Velocity Test:

The ultrasonic pulse velocity (UPM) method basically involves the measurement of velocity of electronic pulses passing through concrete from a transmitting transducer to a receiving transducer. The method is based on the principle that the velocity of pulse passing through concrete is primarily dependent upon the density and the elastic properties of the materials and is independent of geometry of the components. The density and elastic properties are in turn related to the quality and strength of the material. The pulse velocities range from about 3 to 5 km/s. The methods employ pulses in the frequency range of 15-175 kHz, generated and recorded by electronic circuits.

Ultra sonic pulse velocity method which involved measurement of the time of travel of electronically generated mechanical pulses through the concrete. The basic principle of this method of testing is that the velocity of an ultrasonic pulse through concrete is related to its density and elastic properties. Some care is necessary when testing, but an experienced operator may obtain a considerable amount of information about a concrete member. The advantage of this method is that the pulse passes through the complete thickness of the concrete so that the significant defects can be detected. The pulse can be generated either by the use of an elecroacoustic transducer, elecroacoustic transducers are preferred as they provide better control on the type and frequency of pulses generated

The unit which is used in work "PUNDIT' (Portable ultrasonic Non destructive Digital Indicating Tester) .the direct transmit ion type of method is used. The all the test value obtained from the test is verified from the codal provision. The suggested pulse velocity is given in table No. 3.9 and it is shown in fig.3.2

Table No 3.12 Velocity criteria for concrete quality grading (As per IS : 13311 – Part I) in m/sec

Pulse Velocity	**Concrete Quality control**
4575	**Excellent**
3660 – 4575	**Good**
3050 – 3660	**Questionable**
2135 – 3050	**Poor**
2135	**Very Poor**

Fig. 3.2 USPV Test Equipment.

3.9.4 Compressive Strength Test: - The comp strength of concrete is one of most important properties of concrete .in most structural applications concrete is employed primarily to resist compressive stresses.

Cube of 150x150x1150 mm size is used to determine the compressive strength of the normal concrete the mix design we taken for the M35 and M45. The test result came from the 28 days are given in table no (4.5) and it is shown in figure no. (4.4 and 4.5) Specimens before failure and after failure are shown in fig. 3.5 and fig. 3.6 respectively and experiment setup is also shown in fig.3.3and 3.4.

Fig. 3.3 Experimental setup for compression test

Fig. 3.4 Specimen:Before failure

Fig. 3.5 Specimen: After Failure

3.7.5 Spilt Tensile Strength: Apart from the flexure test, the other methods used to determine the tensile strength of concrete can be broadly classified as direct and indirect method. The indirect method of test i.e. in general a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses. The magnitude of this tensile stress (acting in a direction perpendicular to the line of action of applied compression) is given by (2P/(3.14DL)), where, P is applied load, D and L are the diameter and length of cylinder. Due to the tensile stress, the specimen fails finally by splitting along the loaded diameter and knowing P at failure, the tensile strength is determined.

This ASTM test method covers the determination of the splitting tensile strength of cylindrical concrete specimens. This method consists of applying a diametral compressive force along the length of a cylindrical specimen. This loading induces tensile stresses on the plane containing the applied load.

Tensile failure occurs rather than compressive failure. Plywood strips are used so that the load is applied uniformly along the length of the cylinder. The maximum load is divided by appropriate geometrical factors to obtain the splitting tensile strength

The spilt tensile strength is carried on the cylinder, and result obtained given in table no (4.7) and it is shown in figure (4.6). Specimens before failure and after failure were shown in fig. 3.6 and fig. 3.7 and experiment setup us also shown in fig. 3.7

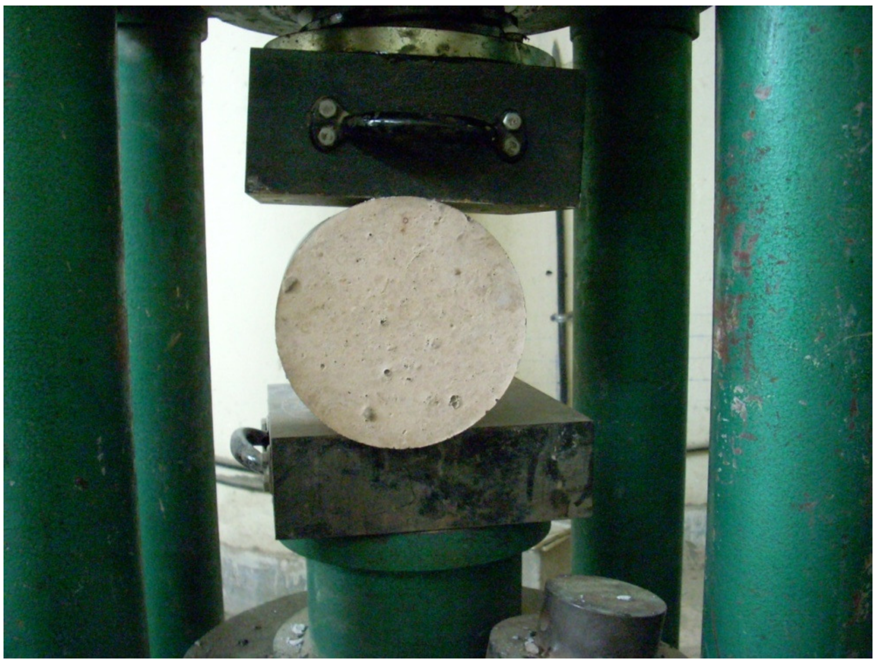

Fig. 3.6 Experimental setup for spilt tension test.

Fig.3.7 Top view of cylinder before failure

Fig.3.8Top view of cylinder after

Fig3.9Cylindrical specimen: After failure.

CHAPTER NO : 4

RESULTS AND DISCUSSION

On the basis of the experiments conducted on plain concrete and silica fume blended concrete the various results obtained are presented in following paragraph the cement coarse aggregate water silica fume are already presented in the previous chapter.

4.1 Results discussion on the workability Test

The tests for workability of fresh concrete were conducted in form of slump test, compaction factor test. The results are shown in following tables.

Table no 4.1 Mix without superplasticizer

Sr .No	**Mix**	**Slump test**	**Compaction Factor**
A	**M-45 Grade**		
1	M1	35	0.82
2	MSF1	30	0.80
3	MSF2	24	0.78
B	**M-35 Grade**		
1	N1	40	0.23
2	NSF1	35	0.81
3	NSF2	28	0.79

Table no 4.2 Mix with Superplasticizers

Sr .No	Mix	Slump test	Compaction Factor
A	**M-45 Grade**		
1	M1	80	0. 90
2	MSF1	72	0.88
3	MSF2	65	0.87
B	**M-35 Grade**		
1	N1	100	0.92
2	NSF1	90	0.91
3	NSF2	76	0.88

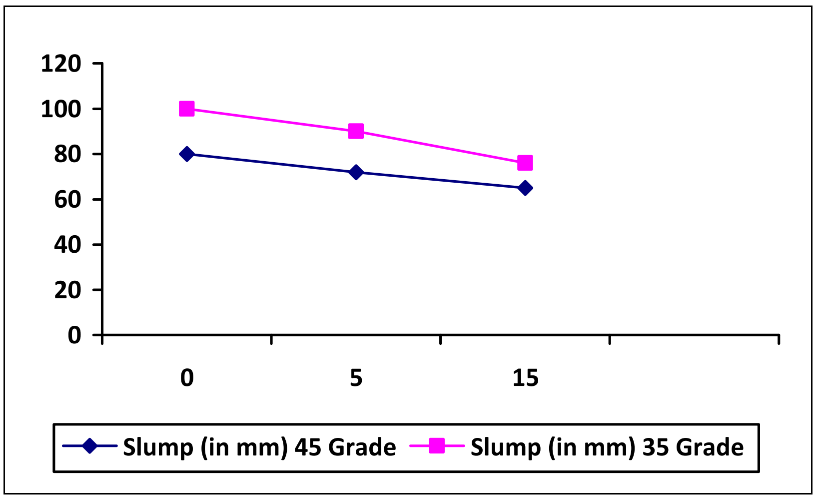

Fig.4.1 Variation of workability values with silica fume content

- The silica fume consists of fine particles when it is added to concrete ; it makes the concrete cohesive and hence the workability decreases with increase in content of silica fume to concrete mixture.
- The grade of concrete are shows the medium workable concrete. As we increased the silica fume content in concrete, the workability is decreased.
- As the grade of concrete increases the slump and compaction factor decreases.

4.2 MASS TEST

- As shown in table 4.3 there is loss of mass of for all grades of concrete in acid curing.
- This is because of degradation of concrete in acid. As number of days in acid concrete curing increases from 7 days, 28 days, 90 days the loss of mass inceases as shown in table 4.4.
- As the percentage of silica fume in concrete increases from 5% (MSF1 and NSF1) to 15% (MSF2 and NSF2) the loss of mass in acid curing decreases. With the addition of silica fume there is increase in cohesiveness in concrete. This reduces the infiltration of acid in concrete mass which reduces degradation of concrete. Thus with increase in content of silica fume in concrete the loss of mass reduces.

Table No 4.3:- Mass test for CONCRETE

Grade	Curing Type	Mass of Specimen in (gms)		
		7 Day	28 Day	90 Day
(A) M-45 Grade				
M1	Water	8320	8330	8350
	Acid	8080	7920	7600
MSF1	Water	8330	8350	8360
	Acid	8205	8060	7860
MSF2	Water	8320	8330	8350
	Acid	8240	8125	8020
(B) M-35 Grade				
N1	Water	8260	8270	8290
	Acid	7930	7775	7460
NSF1	Water	8250	8260	8280
	Acid	8085	7930	7700
NSF2	Water	8260	8270	8280

	Acid	8135	8020	7865

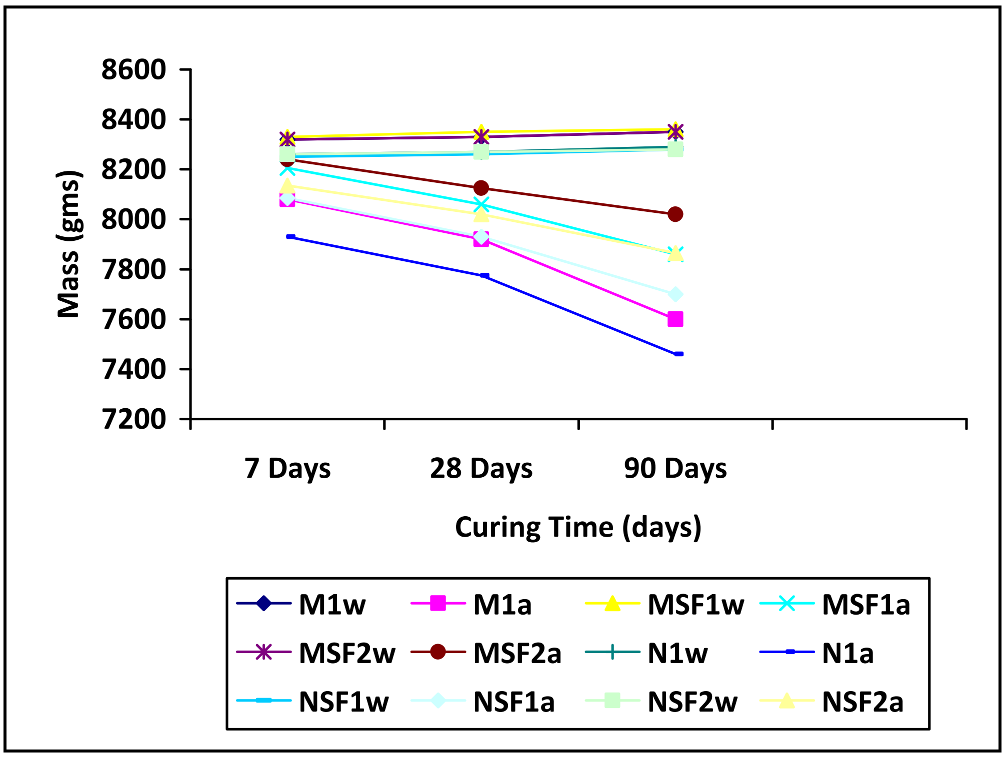

Fig No 4.2. Variation of mass of plain concrete and silica fume blended concrete cured in both acid and water

Table No 4.4 Percentage loss in mass test

Sr. No	Grade	Loss in Mass (%) exposed for		
		7 Days	28 Days	90 Days
1	M1	3	5	9
2	MSF1	1.5	3.5	6
3	MSF2	1	2.5	4
4	N1	4	6	10
5	NSF1	2	4	7
6	NSF2	1.5	3	5

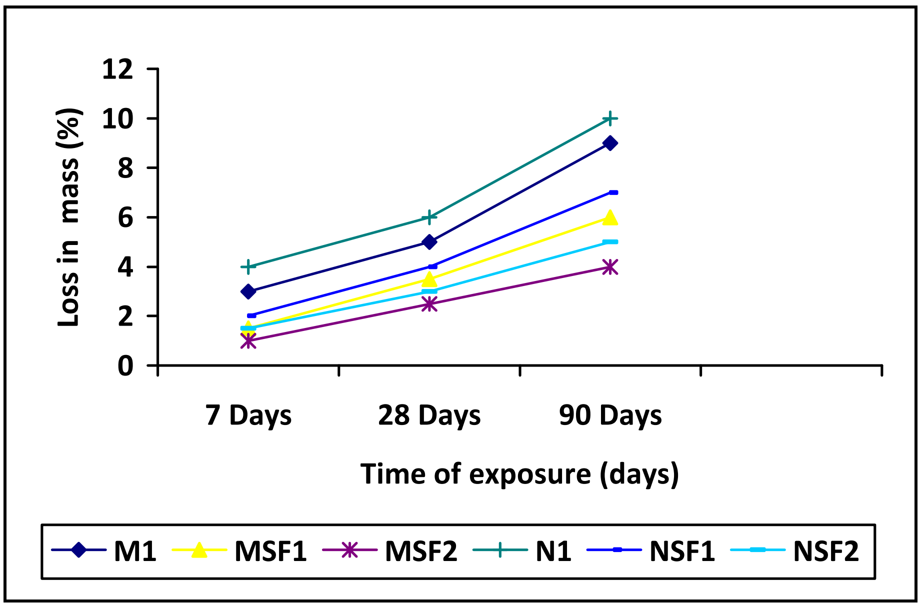

Fig No 4.3 Variation in the percentage loss in mass of plain and silica fume blended concrete exposed to sulfuric acid of concentration of 0.2 N

4.3 REBOUND HAMMER TEST

The compressive strength of concrete is increased with time so corresponding the rebound number i.e. hardness of the concrete is also increase up to the certain limit

- The compressive strength and surface harness of concrete increases with time hence the corresponding rebound number i.e. hardness of the concrete also increases. With time as shown in table 4.5 the rebound number increases as number of days of concrete in water increases from 7 days, 28 days and 90 days. A number of days of curing of concrete increases there is gain of strength and surface hardness of concrete.
- As shown in table 4.5 and 4.6 the rebound number increases as percentage of silica fume increases from 5% (MSF1 and NSF1) to 15% (MSF2 and NSF2). With the addition of silica fume the strength of concrete and surface hardness increases hence rebound number increases with increase in content of silica fume.

- As shown in table 4.6 the loss of rebound number increases as grade of concrete decreased from M-45 to M-35.

Table No 4.5: Rebound hammer number table

Grade	Curing Type	Rebound Number		
		7 Days	28 Days	90 Days
(A) M-45 Grade				
M1	Water	38	42	44
	Acid	36	38	36
MSF1	Water	40	48	49
	Acid	37	44	43
MSF2	Water	40	48	49
	Acid	39	46	45
(B) M-35 Grade				
N1	Water	29	38	39
	Acid	27	33	31
NSF1	Water	32	43	44
	Acid	30	39	38
NSF2	Water	34	43	45
	Acid	32	40	41

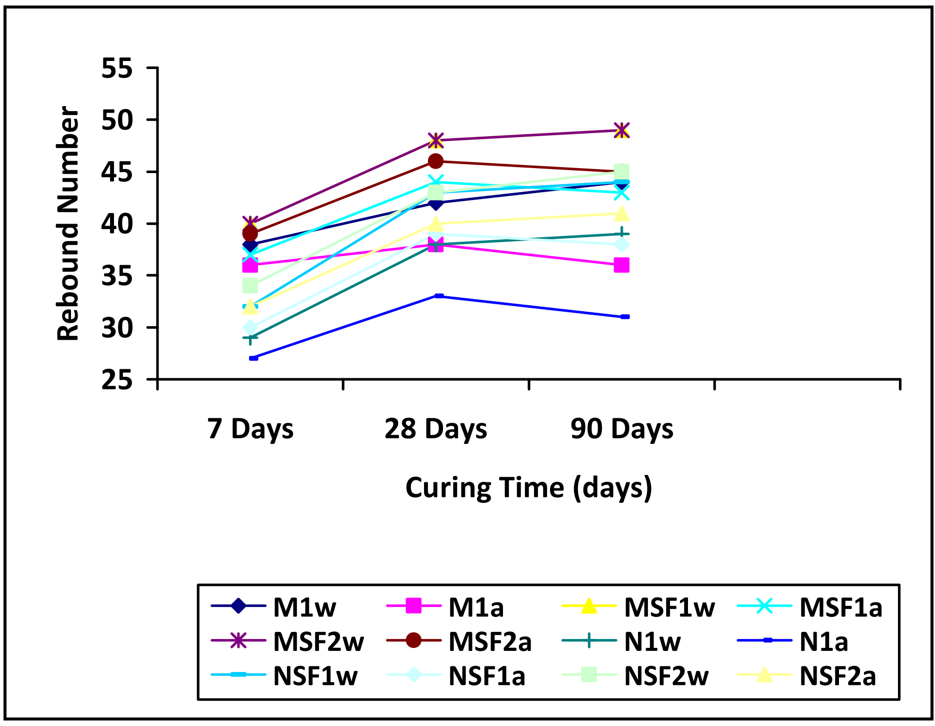

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Fig No 4.4 Variation of Rebound Number of plain concrete and Silica Fume concrete cured in both acid and water

Table No.4.6: Percentage-loss for rebound hammer Test

Grade	Percentage Loss(%) in Rebound Number		
	7 Days	28 Days	90 Days
M1	5	9.5	18
MSF1	6	8	12
MSF2	2.5	4	8
N1	7	13	20.5
NSF1	6	9	13.5
NSF2	5	7	9

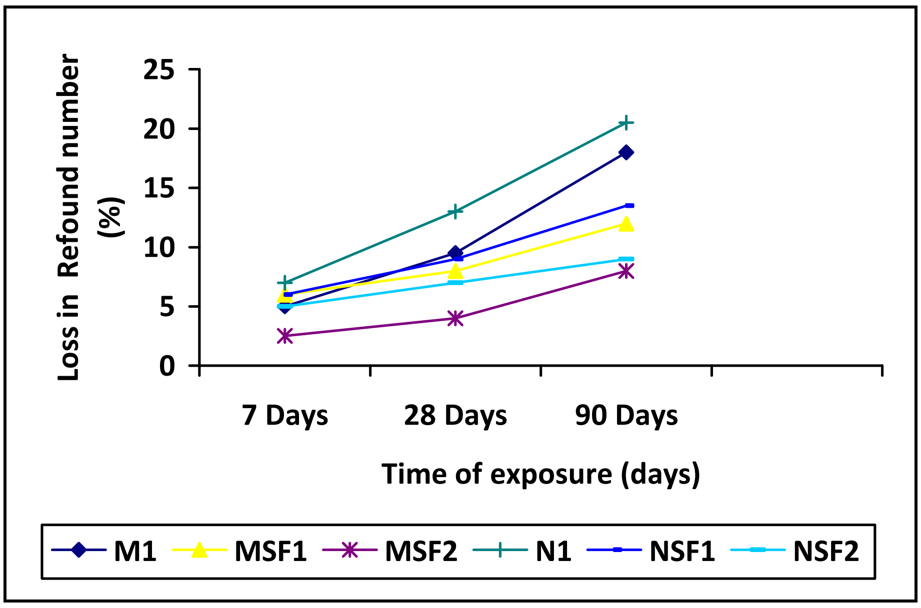

Fig No 4.5 Variation in the percentage loss in Rebound Number of plain and Silica fume concrete exposed to sulfuric acid of concentration of 0.2

4.4 ULTRA SONIC PULSE VELOCITY

Table No.4.7 : Ultra sonic pulse velocity test

Grade	**Curing Type**	**Pulse Velocity in (m/sec)**		
		7 Days	**28 Days**	**90 Days**
(A) M-45 Grade				
M1	Water	4300	4420	4500
	Acid	3910	3620	3375
MSF1	Water	4610	4730	4800
	Acid	3209	3973	3720
MSF2	Water	4700	4810	4850
	Acid	4418	4185	3880
(B) M-35 Grade				
N1	Water	4050	4100	4200
	Acid	3605	3280	3065
NSF1	Water	4160	4620	4700
	Acid	3765	3835	3572
NSF2	Water	4220	4700	4720
	Acid	3903	4020	3680

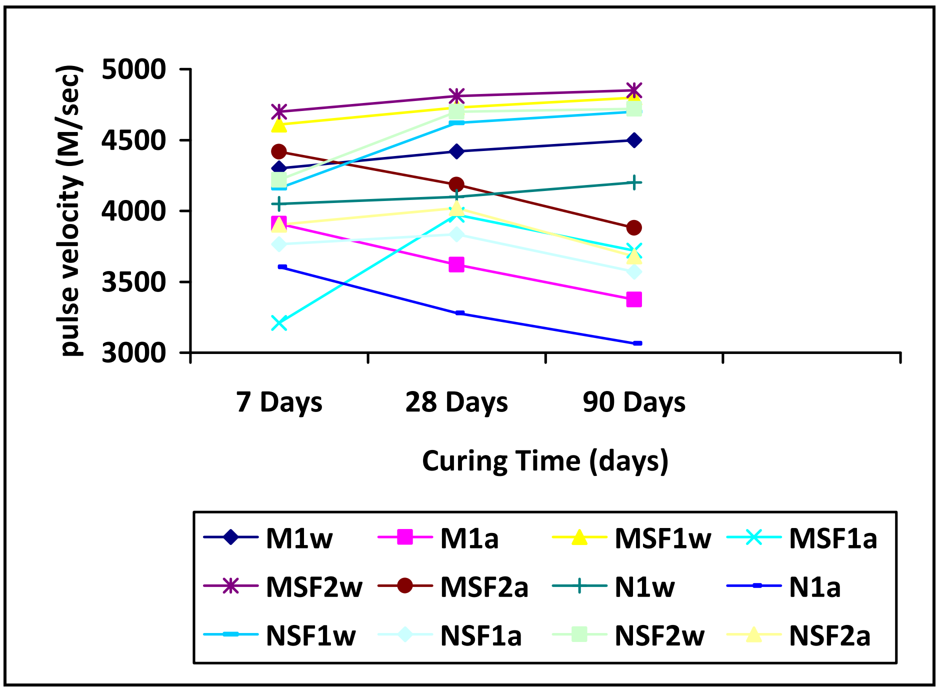

Fig No 4.6 Variation of pulse velocity of plain concrete and Silica Fume concrete cured in both acid and water

- As shown in table 4.7 the pulse velocity increases as number of days in water curing increases from 7 days to 90 days as number of days increases the concrete in water curing gains strength and permeability reduces in water curing. Thus pulse velocity increases with time.
- As shown in table 4.7 the pulse velocity decreases as number of days in acid curing increases from 7 days to 90 days. As number of days in acid curing is increased the degradation of concrete increases which result in decrease of pulse velocity.
- As shown in table 4.7 the pulse velocity increases as percentage of silica fume increases from 5% (MSF1 and NSF1) to 15% (MSF2 and NSF2) as percentage of silica fume in concrete increases the degradation of concrete decreases because increase in silica fume decreases ingressing of acid in concrete which lowers degradation of concrete.

Table No.4.8 Percentage loss for

Grade	Loss in percentage (%) for		
	7 Days	28 Days	90 Days
M1	9	18	25
MSF1	7	16	22.5
MSF2	6	13	20
N1	11	20	27
NSF1	9.5	17	24
NSF2	7.5	14.5	22

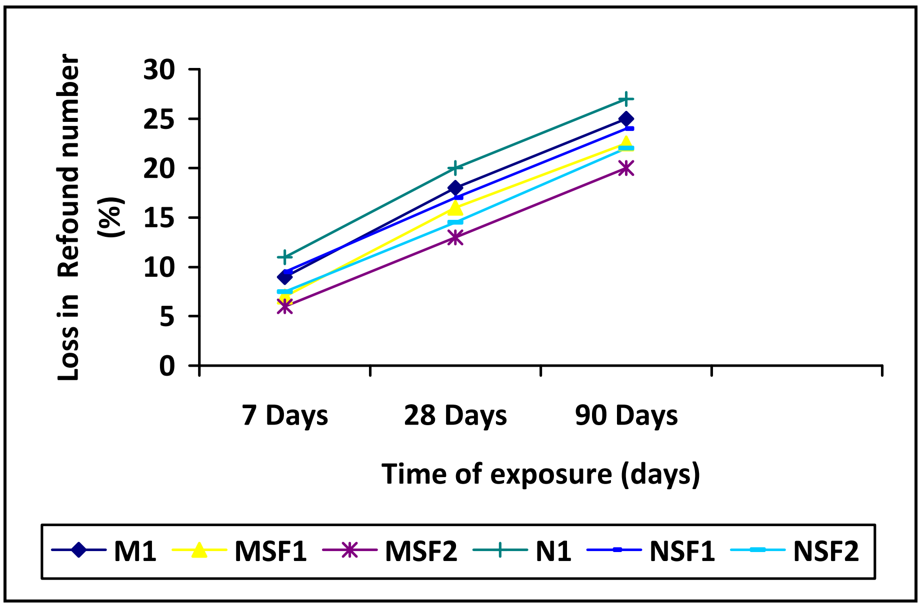

Fig No 4.7 Variation in the percentage loss in pulse velocity of plain and Silica fume concrete exposed to sulfuric acid of concentration of 0.2 N

4.5 COMPRESSIVE STRENGTH TEST

Compressive Strength: The average 28th dayd unconfined compressive strength for Plain concrete and Silica fume is found to be 48, 62 and 66 Mpa.

Table No 4.9 .: Compressive strength test table

Grade	Curing Type	Compressive strength in (Mpa)		
		7 Days	28 Days	90 Days
(A) M-45 Grade				
M1	Water	39	48	49
	Acid	36	40	37
MSF1	Water	43	62	63
	Acid	40.5	53	50.5
MSF2	Water	44	66	68
	Acid	42	58.5	56.5
(B) M-35 Grade				
N1	Water	26	39	40
	Acid	23.5	31.5	29
NSF1	Water	31	52	53
	Acid	29	43.5	41.5
NSF2	Water	33	54	55
	Acid	31	46	44.5

- As shown in table 4.9 and table 4.10 the compressive strength of concrete in water curing increases as number of days increases from 7 days to 90 days. The silica fume reacts with the calcium hydroxide released from cement to form calcium silicate hydrate which acts as additional binder resulting in improved hardened properties of silica fume contained concrete. As presented in table 4.9 the strength of concrete increases as percentage of silica fume in concrete increases from 5% (MSF1) to 15% (MSF2) due to the reason discussed above.

- The effect of acid in the compressive strength of M-45 grade concrete as less degradation effect then M-35 grade concrete.
- Due to increase in silica fume in concrete it is observed that the strength increases as seen from table 4.9 and 4.10. For M-45 grade the 28 days compressive strength is 48 Mpa for normal grade concrete and after addition of silica fume 5% (MSF1) and 15% (MSF2) the compressive strength was 62 Mpa and 66 Mpa respectively.

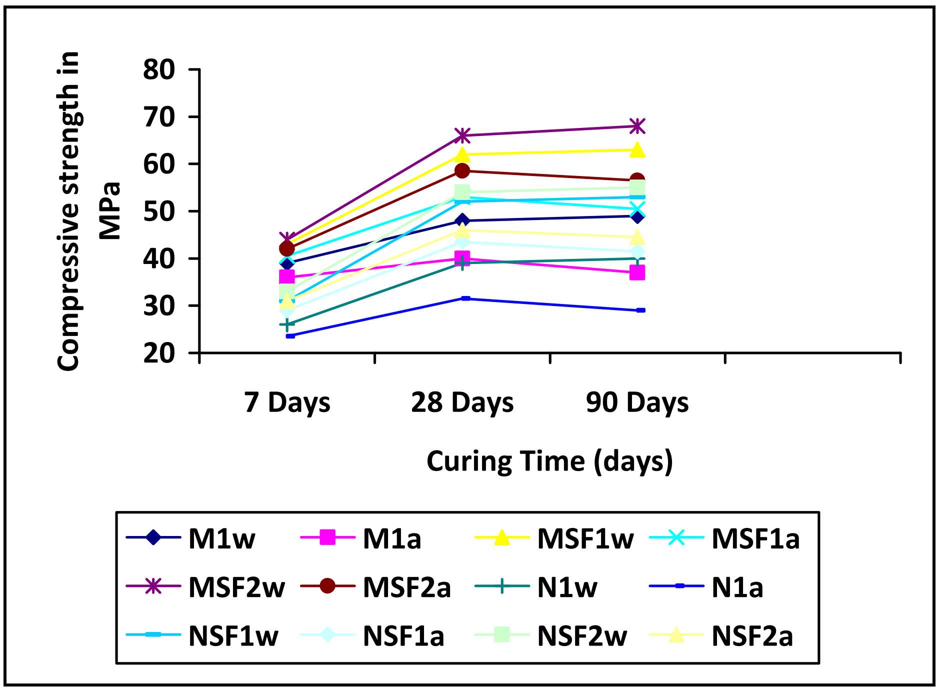

Fig No 4.8 Variation of compressive strength of plain concrete and Silica Fume blended concrete cured in both acid and water

Table No. 4.9 Percentage loss in compressive strength

Specimen Type Grade	Loss in compressive strength (%)		
	7 Days	28 Days	90 Days
M1	7.5	16.5	24.5
MSF1	6	14	20
MSF2	4.5	11.5	17
N1	9.5	19	27.5
NSF1	6.5	16.5	21.5
NSF2	6	15	19

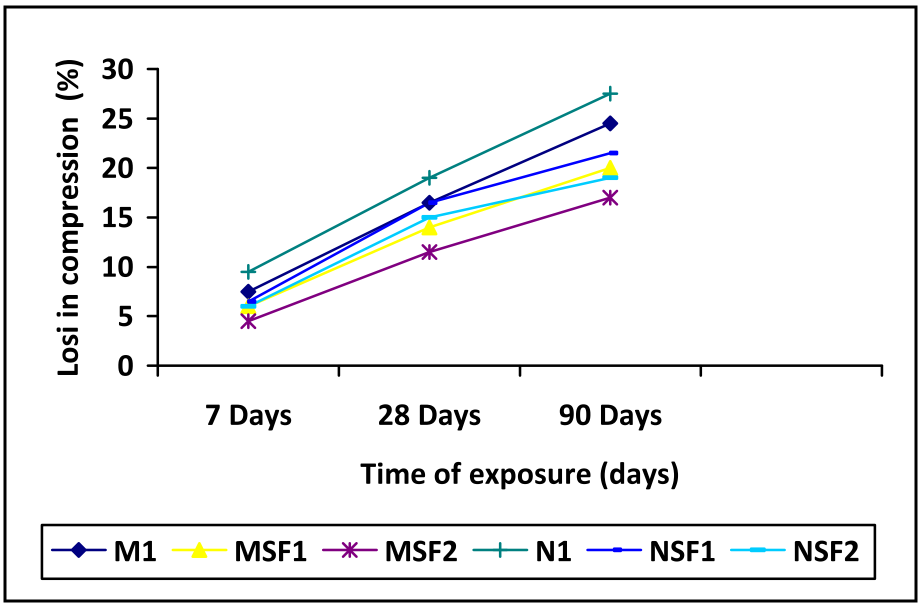

Fig No 4.9 percentage loss in compressive strength of plain and Silica Fume concrete exposed to sulfuric acid of concentration of 0.2

4.6 TENSILE STRENGTH TEST

Table No.4.10 :- Tensile strength test table

Grade	**Curing Type**	**Spilt Tensile Strength in (Mpa)**		
		7 Days	**28 Days**	**90 Days**
(A) M-45 Grade				
M1	Water	3.15	3.7	3.9
	Acid	2.88	3	2.89
MSF1	Water	3.4	4.5	4.60
	Acid	3.16	3.8	3.6
MSF2	Water	3.5	4.7	4.8
	Acid	3.3	4.1	3.85
(B) M-35 Grade				
N1	Water	2.3	3.14	3.3
	Acid	2.05	2.48	2.33
NSF1	Water	2.6	4	4.1
	Acid	2.4	3.35	3.12
NSF2	Water	3	4.2	4.28
	Acid	2.8	3.6	3.35

- As presented in table 4.10 the split tensile strength increases with increase in time of curing from 7 days to 90 days.
- The split tensile strength is less in acid curing as compared to concrete in water curing.
- The split tensile strength increases as content of silica fume increases from 5% (MSF1 and NSF1) to 15% (MSF2 and NSF2).
- The split tensile strength of normal concrete is lower than silica fume contained concrete.
- The percentage of loss of tensile strength is more for M-35 grade concrete as compared to M-45 grade. Also the effect of acid is less in silica fume contained concrete.

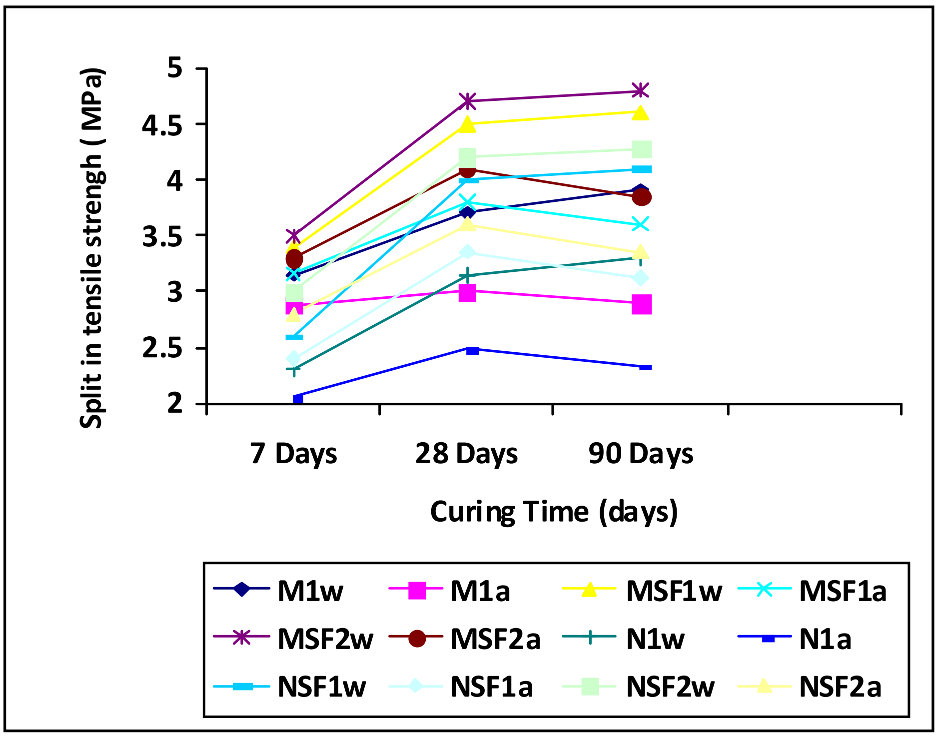

Fig No 4.10 Variation of spilt Tensile strength of plain concrete and silica fume concrete cured in both acid and water

Table No.4.11 : Percentage Loss occurred in Tensile strength

Specimen Type Grade	Loss in percentage (%) for		
	7 Days	28 Days	90 Days
M1	8.5	19	26
MSF1	7	15.5	22
MSF2	5.5	13	20
N1	10.5	21	29.5
NSF1	8	16.5	24
NSF2	7	14.5	22

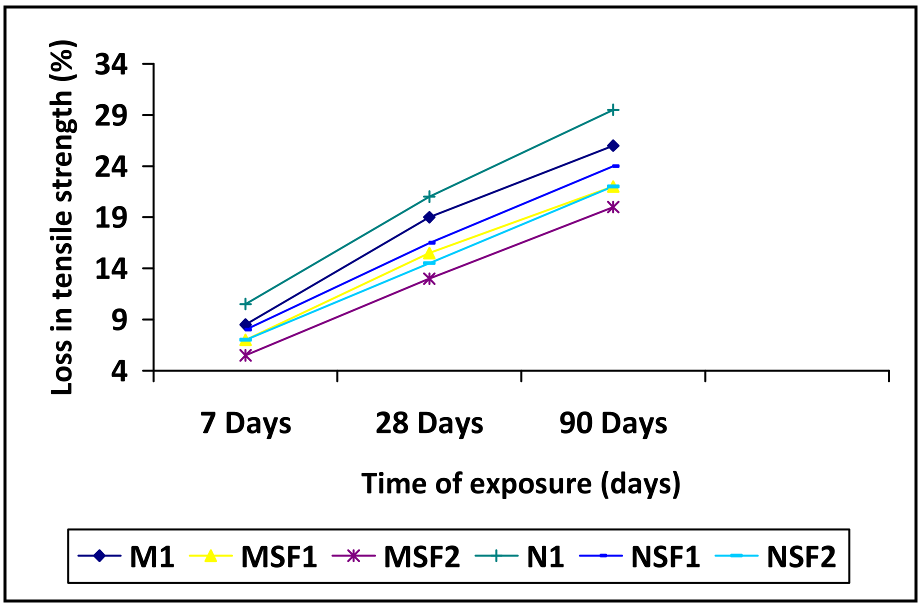

Fig No 4.11 Variation in the loss in Tensile strength of plain and Silica Fume Concrete concrete exposed to sulfuric acid of concentration of 0.2 N

4.7 MODULUS OF RUPTURE

Table No 4.12 : Flexural Modulus test results

Grade	**Curing Type**	**Flexural Modulus in (Mpa)**		
		7 Days	**28 Days**	**90 Days**
`(A) M-45 Grade				
M1	Water	4.8	5.7	5.8
	Acid	4.42	4.65	4.35
MSF1	Water	5.3	6.7	6.8
	Acid	4.93	5.7	5.35
MSF2	Water	5.35	6.85	6.9
	Acid	5.08	5.95	5.6
(B) M-35 Grade				
N1	Water	3.6	4.8	4.9
	Acid	3.25	3.85	3.52
NSF1	Water	4.1	5.15	6

	Acid	3.8	4.32	4.62
NSF2	Water	4.3	6.15	6.3
	Acid	4.02	5.3	5.05

- As per table 4.12 and 4.13 the flexural modulus of concrete increases from 7 days to 90 days.
- The flexural modulus of concrete in acidic environment was less as compared to concrete in water curing.
- The flexural modulus of concrete increased as percentage of silica fume increased from 5% (MSF1 and NSF1) to 15% (MSF2 and NSF2).
- The flexural modulus of concrete increased as grade of concrete increased from M-35 (N1) to M-45 (M1)
- The percentage of flexural modulus decreased as percentage of silica fume increased from 5% to 15% due to decrease in deterioration of concrete with increase in percentage of silica fume.

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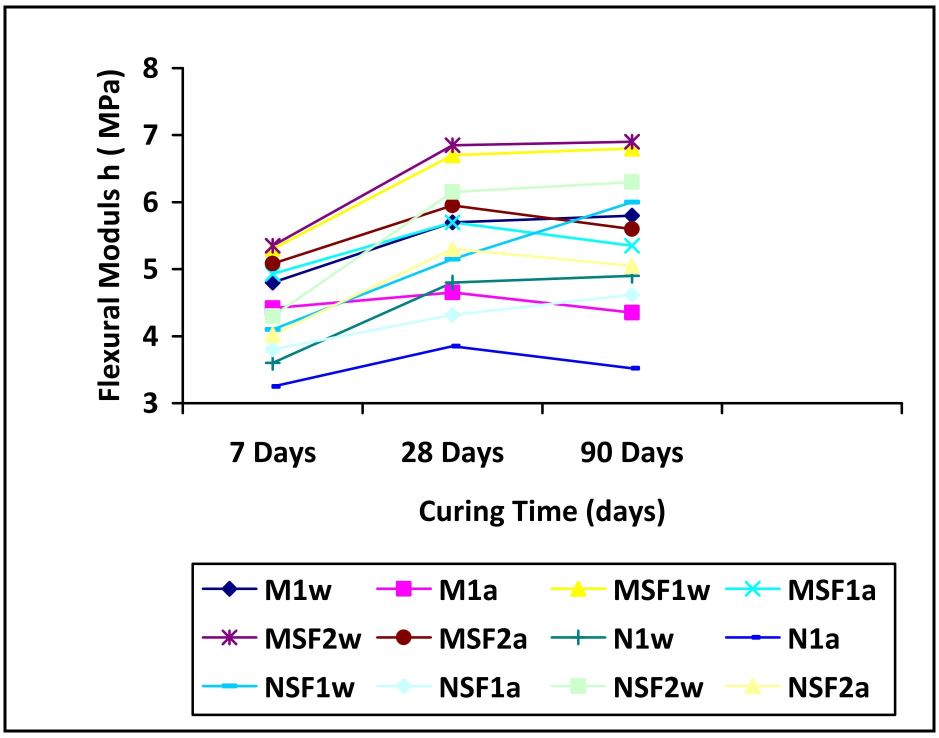

Fig No 4.12 Variation of flexural Modulus of plain concrete and Silica Fume Concrete cured in both acid and water.

Table No.4.13 Loss in percentage for flexural Modulus of concrete

Specimen Type Grade	Loss in percentage (%) for		
	7 Day	28 Day	90 Day
M1	8	18.5	25
MSF1	7	15	21.5
MSF2	5	13	19
N1	10	20	28
NSF1	7.5	16	23
NSF2	6.5	14	20

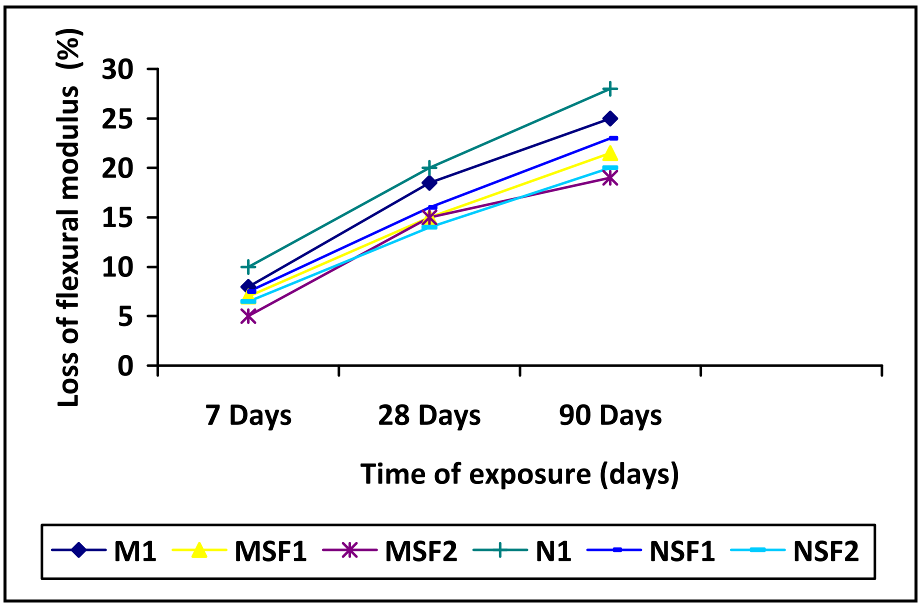

Fig No 4.13 Variation in the percentage loss in Flexural modulus of plain and Silica Fume concrete exposed to sulfuric acid of concentration 0.2 N.

4.8 RELATION BETWEEN PLAIN CONCRETE AND SILICA FUME CONCRETE

The relation of comp. Strength Vs rebound Number is carried out and following points is observed

- The rebound number is increased the corresponding the comp. strength is also increased
- The addition of mineral admixture silica fume in concrete shows that, hardness of concrete i.e. increased in rebound number in comparison to plain concrete.
- The compressive strength and hardness i.e. rebound number are six grade shown in following fig no.

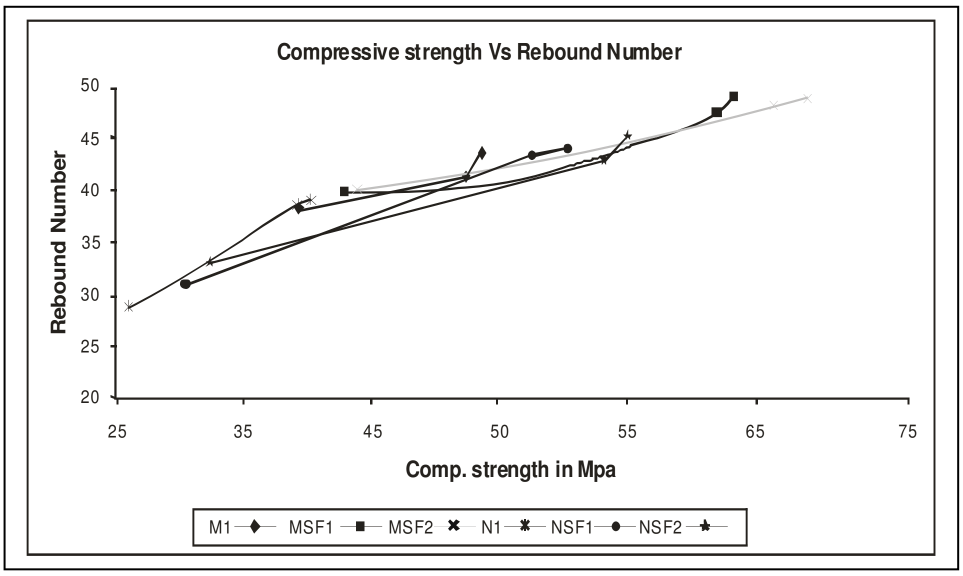

Fig. 4.14 Relationship between Compressive strength V/s Rebound Number

4.9 RELATION BETWEEN COMPRESSIVE STRENGTH AND SPILT TENSILE TEST

The comp strength and spilt tensile stress are required for the design the reinforced concrete. The following point Is observed in relationship. The details of relation ship is shown in fig no.

- If the grade of concrete is increased the corresponding the tensile strength is increased

For all normal concrete and Silica Fume concrete the relation between comp. strength and spilt tensile strength is found to be linear

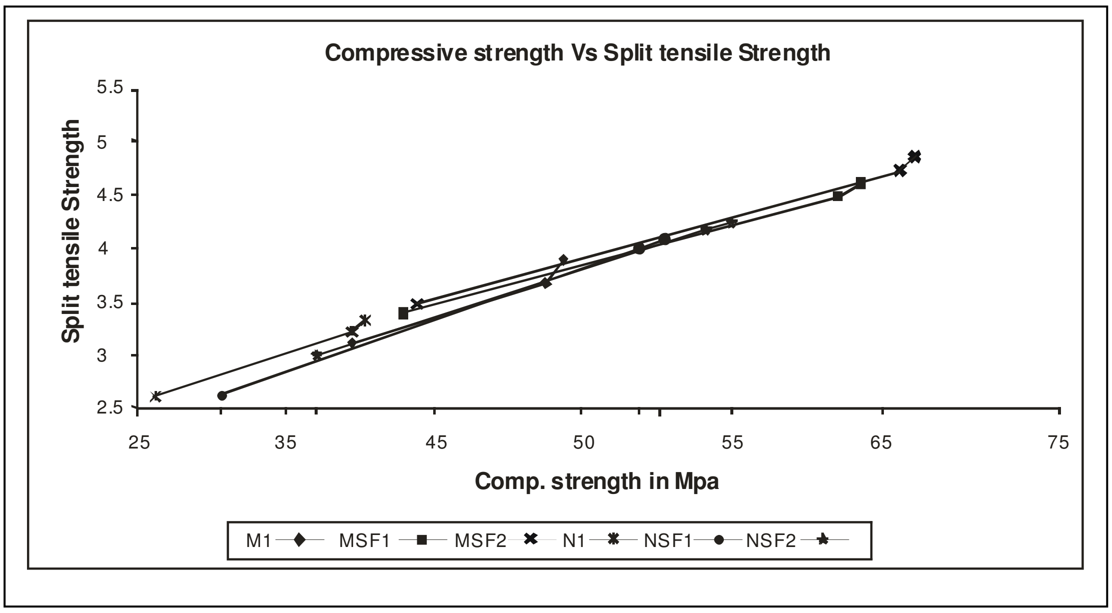

Fig No 4.15 Relationship between the compressive Strength and spilt tensile Strength

4.10 RELATION BETWEEN COMPRESSIVE STRENGTH VS MODULUS OF RUPTURE

The relation between comp strength vs MOR is carried on the normal and Silica Fume Concrete and found the following points, The relationship is shown in fig no.4.16

- The normal concrete has found the less MOR in comparision to Silica Fume concrete

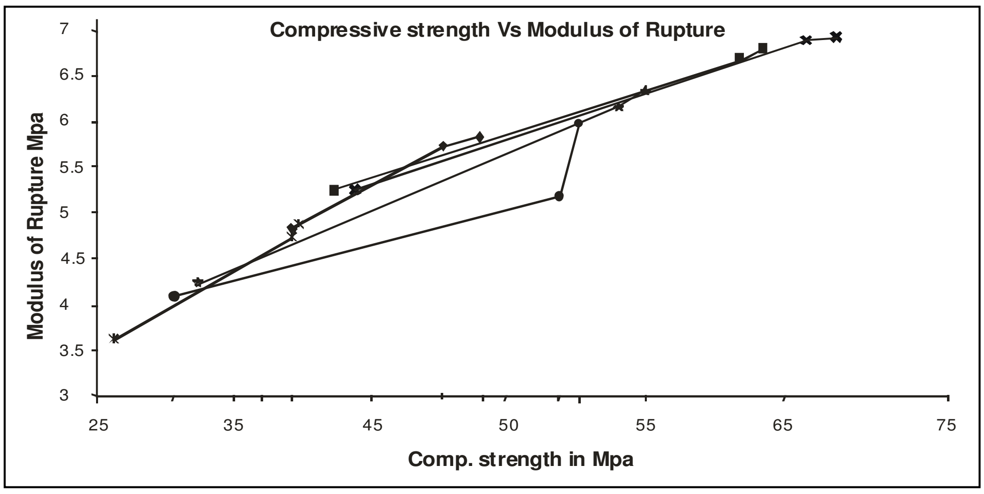

Fig. 4.16 Relationtion between compressive strength and moudulus of rupture

4.11 RELATIONSHIP OF MASS TEST VS COMPRESSIVE STRENGTH

The make relation between the mass and compressive strength of plain concerete and silicafune concrete, the following kind of point is found from graph

- There is a reduction in mass of plain concrete and also the compressive strength at same time of curing period in acid.
- The increased in mass is observed in all silicafune grade and due to the mineral admixtures the production of calcium hydroxide component is less and significantly increased the compressive Strength when curing in water.

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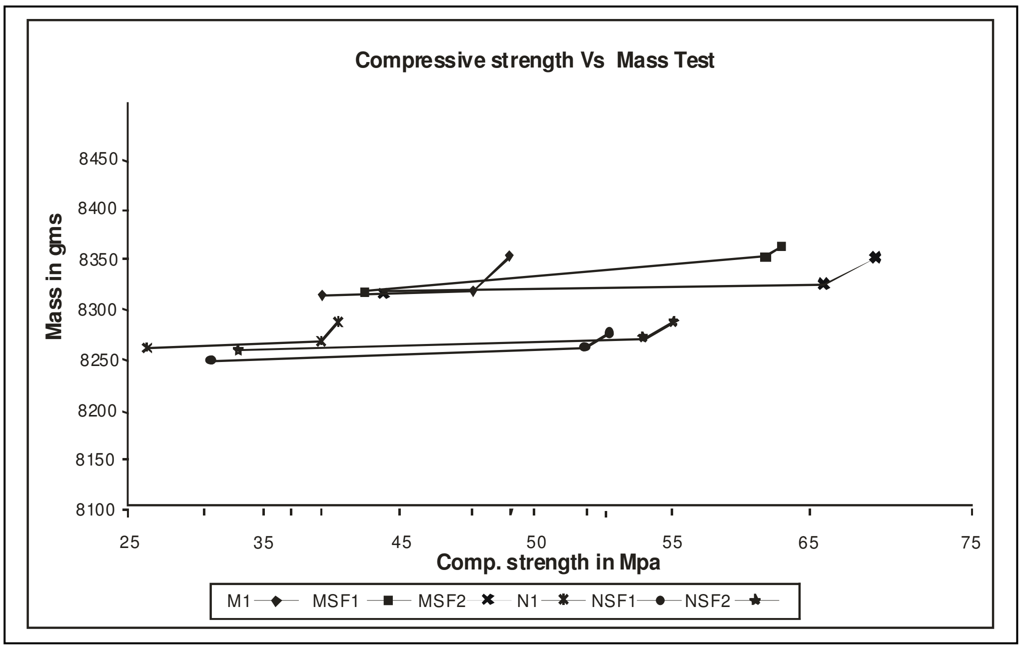

Fig No 4.17 : Relationship between the compressive Strength and Mass Test

4.12 RELATIONSHIP BETWEEN THE COMPRESSIVE STRENGTH AND PULSE VELOCITY

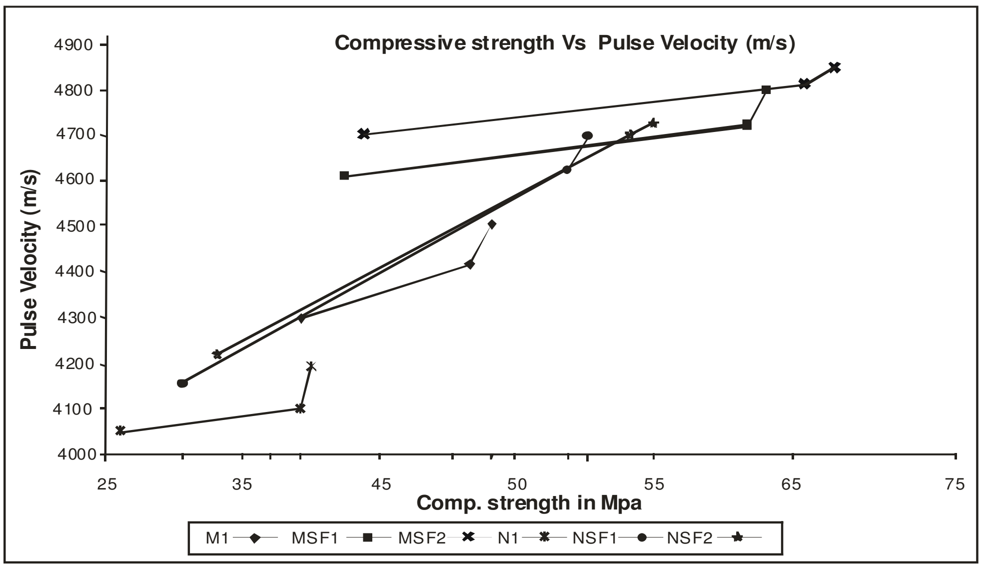

Fig No 4.18 Relationship between the compressive Strength and pulse Velocity

Chapter No. 5

CONCLUSIONS

The present study was performed to understand the mechanism of Silica Fume reinforced concrete deterioration caused by Sulfuric Acid Solution i.e. acidic environment. The effect of the acidic environment and the use of mineral Admixtures (silica fume) on the deterioration of concrete were investigated in this study.

The following conclusions were obtained after carrying out various tests on concrete.

- The percentage loss of mass test is varied from 5 to 9% for M-45 Grade Concrete (M1) and 6 to 10% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 2.5 to 6% for M-45 (MSF1) Grade Concrete and 3 to 7% for M-35 (NSF1)Grade concrete at the same days curing.
- The percentage loss of hardness is varied from 9.5 to 18% for M-45 Grade Concrete (M1) and 13 to 20.5% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 8 to 12% for M-45 (MSF1) Grade Concrete and 9 to 13.5% for M-35 (NSF1) Grade concrete at the same days curing.
- The percentage loss of UPVT is varied from 18 to 25% for M-45 Grade Concrete (M1) and 20 to 27% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 8 to 12% for M-45 (MSF1) Grade Concrete and 9 to 13.5% for M-35 (NSF1) Grade concrete at the same days curing.
- The percentage loss of compressive strength Test is found varied from 16.5 to 24.5% for M-45 Grade Concrete (M1) and 19 to 27.5% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 14 to 20% for M-45 (MSF1) Grade Concrete and 16.5 to 21.5% for M-35 (NSF1) Grade concrete at the same days curing.

- The percentage loss in Tensile Strength Test is found varied from 19 to 26% for M-45 Grade Concrete (M1) and 21 to 29.5% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 15.5 to 22% for M-45 (MSF1) Grade Concrete and 16.5 to 24% for M-35 (NSF1) Grade concrete at the same days curing.
- The percentage loss of Modulus of Rupture is varied from 18.5 to 25% for M-45 Grade Concrete (M1) and 20 to 28% for M-35 (N1) Normal Grade concrete at the 28 days to 90 days curing. Whereas the percentage loss of mass test with silica fume blended concrete varied from 15 to 21.5% for M-45 (MSF1) Grade Concrete and 16 to 23.5% for M-35 (NSF1) Grade concrete at the same days curing.
- With addition of silica fume on fresh concrete the slump decreased due to increase in cohesiveness of concrete making it less prone to segregation.
- With addition of silica fume 5% and 15% a high compressive strength of concrete was obtained hence silica fume can be used to produce high performance concrete.
- The effect of acidic environment with increase in curing period deterioration of concrete increased from 28 days to 90 days curing but the effect of deterioration was less with addition of silica fume as seen from various tests carried out for the present study.
- The effect of acidic environment decreased with increase in grade of concrete from M-35 (N1) to M-45 (M1).
- The deterioration of concrete in acidic environment decreased with addition of silica fume in concrete. The deterioration of concrete in acidic environment further

decreased when percentage of silica fume was increased from 5% (MFS1) to 15% (MSF2)

FUTURE SCOPE OF STUDY

The following research works can be undertaken for future work

- To study the effect of silica fume for higher level of concrete above M-45 Grade.
- To study the effect of silica fume by increasing the percentage of silica fume in cement above to 15%.

- To study the effect of varying concentration of acid on silica fume concrete.
- To study the effect of silica fume in concrete increasing the period of acidic environment (more than 90 days)

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