CHAPTER 1

INTRODUCTION

1.1 General

Concrete, a composite consisting of aggregates enclosed in a matrix of cement paste including possible pozzolans, has two major components – cement paste and aggregates. The strength of concrete depends upon the strength of these components, their deformation properties, and the adhesion between the paste and aggregate surface.

The use of concrete as structural material is favored by its mechanical properties, mainly compressive strength. Compressive strength of concrete is the most important parameter to assess its quality. High Strength Concrete (HSC) mixes are generally characterized by low water/binder ratios, high consumption of cement, and the presence of various chemical and mineral admixtures.

It is possible to make concretes having compressive strength up to 120 MPa by improving the strength of the cement paste, which can be controlled through the choice of water-content, water/binder ratio, type and dosage of admixtures. The lower range of the strength of HSC varies with time and geographical location depending primarily on the availability of raw materials and technical know-how, and the demand from the industry. Normal strength concrete by ACI definition is a concrete that has a cylinder compressive strength not exceeding 42 Mpa. All other concretes with strength more than the specified one are referred as High Strength Concretes (HSC).

In spite of the rapid development in concrete technology in recent years, concrete with compressive strength higher than 40-60 MPa is still regarded as HSC. The lower water to binder ratio (w/b) and higher content of binder are needed to produce HSC. Consequently, high-range water-reducing admixtures (HRWRA) are used to achieve the required workability.

Investigations of the performance of silica fume (SF) in concrete began since the 1950s.

During the previous decades, enormous researchers evaluated the effects of the partial replacement of cement by SF on the properties of concrete. Silica fume is a by-product resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufacture of ferro-silicon alloys and silicon metal. Nowadays, it has been well known that the use of SF can significantly improve the mechanical properties as well as durability of HSC. The very high content of amorphous silicon dioxide and very fine spherical particles are the main reasons for its high pozzolanic activity. The advantages of SF caused SF being the most well-known additive material for HSC in recent years.

The use of fly ash in high performance concrete has been tried for long and sufficient literature and data is available on the topic. Still, there is a scope of studying the effect of varying percentages of fly ash on various properties of different grades of concrete in India.

Fly ash is most commonly used as a pozzolona in concrete. Pozzolonas are silicious or silicious and aluminous materials, which in a finely divided form and in presence of water, react with calcium hydroxide at ordinary temperatures to produce supplementary cementitious compounds. The spherical shape and particle size distribution of fly ash improves the fluidity of flowable fill, thereby, reducing the demand of mixing water and contributing to long term strength of high strength concrete with fly ash.

1.2 Ingredients Materials

1.2.1 Cement

Strength development of concrete will depend on both cement characteristic and cement content. The choice of Portland cement for HSC is extremely important.

Ultra Tech's Ordinary Portland Cement (OPC) of 53 grade conforming to IS: 12269-1987 has been used having specific gravity of 3.15.

1.2.2 Sand/Fine Aggregate (FA)

Fine aggregates with a rounded particle shape and smooth texture have been found to require less mixing water in concrete and for this reason are preferable in HSC. HSC typically contain such high contents of fine cementitious materials that the grading of the fine

aggregate used is relatively unimportant. However, it is sometimes helpful to increase the fineness modulus (FM) of fine aggregates as the lower FM of fine aggregate can give the concrete a sticky consistency (i.e. making concrete difficult to compact) and less workable fresh concrete with a greater water demand. Therefore, sand with a FM of about 3.0 is usually preferred for HSC.
Earlier trials were made with sand having FM of 2.67. Later, it was replaced by coarser sand having FM of 3.3 and specific gravity of 2.73.

1.2.3 Coarse Aggregate

In normal strength concrete (NSC), the aggregate has a higher strength and stiffness than the cement paste. Therefore, failures in NSC are characterized by fractures in the cement paste or in the transition zone between paste and aggregate. Reduced water-cement ratio, therefore, causes a great improvement in compressive strength of cement paste and hence of concrete.

In HSC, the capacity of the coarse aggregate (CA) can be the limiting factor. Failure of HSC mix may be either the result of the aggregate being weaker than the low water-cement matrix, or alternatively paste is not sufficiently strong and rigid to provide the strengthening effect.

Crushed stone produces higher strengths than rounded gravel. The most likely reason for this is the greater mechanical bond, which can develop with angular particles. However, accentuated angularity is to be avoided because of the attendant high water requirement and reduced workability. The ideal CA should be clean, cubical, angular, 100% crushed aggregate with a minimum of flat and elongated particles.

Optimum strength and workability of HSC are attained with a ratio of coarse aggregate to fine aggregate above that usually recommended for NSC. After doing proper gradation of CA and fine aggregate and casting some trial mixes. Final ratio was fixed to 0.6:0.4. Also, two different sizes of CA were used. Coarse aggregate CA-I having 20 mm down size with specific gravity of 2.94 and water absorption 0.58%. Whereas, CA-II having 10 mm down size with specific gravity of 2.81 and water absorption 0.88%. The ratio of CA-I: CA-II was kept as 0.52 : 0.48.

1.2.4 Mineral Admixtures

Finely divided mineral admixtures, consisting mainly of fly ash (Fl.) and silica fume (SF), has been widely used in HSC. Fly ash, also known as flue-ash, is one of the residues generated in combustion of coal and comprises the fine particles that rise with the flue gases. Fly ash for HSC is classified into two classes. Class F fly ash is normally produced from burning anthracite or bituminous coal and has pozzolanic properties, but little or no cementitious properties. Class C fly ash is normally produced from burning lignite or sub-bituminous coal, and in addition to having pozzolanic properties, has some autogenous cementitious properties. When adding fly ash during concrete production, the workability is normally improved due to the 'lubricating' effect of the spherical particles.

Class F fly ash has been used in this project work having specific gravity of 1.92. Normally FA content varies from 15 to 40 % and even higher, but in the present research, 20%, 25% and 30% replacement of cement by fly ash has been tried.

Silica fume (SF) is a by-product of the melting process used to produce silicon metal and ferrosilicon alloys. The main characteristics of SF are its high content of amorphous SiO_2 ranging from 85 to 98%, mean particle size of 0.1 – 0.2 micron (approximately 100 times smaller than the average cement particle) and its spherical shape. Because of its extreme fineness and high silica content, SF is a highly effective pozzolanic material. The SF reacts pozzolanically with the lime which is produced during the hydration of cement to form the stable cementitious compound i.e. calcium silicate hydrate (CSH).

Elkem's Micro Silica has been used having specific gravity of 2.2. The grade of SF used was 968(D). Normal SF content ranges from 5 to 15 percent of Portland cement. In the present work 5% and 10% replacement of cement by SF have been studied.

1.2.5 Chemical Admixture

Chemical admixtures such as superplasticizers (high–range water reducer) increase concrete strength by reducing the mixing water requirement for a constant slump, and by dispersing cement particles, with or without a change in mixing water content, permitting more efficient hydration. BASF's Glenium SKY 777 conforming to IS 9103: 1999 has been used as the HRWRA. What differentiates GLENIUM SKY 777 from the traditional superplasticizers is a new, unique mechanism of action that greatly improves the effectiveness of cement dispersion. Traditional superplasticizers based on melamine and naphthalene sulphonates are polymers which are absorbed by the cement granules. They wrap around the granules' surface areas at the very early stage of the concrete mixing process. The sulphonic groups of the polymer chains increase the negative charge of the cement particle surface and disperse these particles by electrical repulsion. This electrostatic mechanism causes the cement paste to disperse and has the positive consequence of requiring less mixing water to obtain a given concrete workability. GLENIUM SKY 777 has a different chemical structure from the traditional superplasticizers. It consists of a carboxylic ether polymer with long side chains. At the beginning of the mixing process it initiates the same electrostatic dispersion mechanism as the traditional superplasticizers, but the side chains linked to the polymer backbone generates a steric hindrance which greatly stabilizes the cement particles' ability to separate and disperse. Steric hindrance provides a physical barrier (alongside the electrostatic barrier) between the cement grains. With this process, flowable concrete with greatly reduced water content is obtained.

A constant dosage of 1.8% by weight of cementitious material has been added in all the trial mixes. It is to be noted that a super plasticized mix that appears stiff and difficult to consolidate is very responsive to applied vibration.

1.3 Role of Pozzolona

The utilization of pozzolans in combination with Portland cement to obtain high-performance concrete principally aims at improving concrete microstructure. The small particles of pozzolans are less reactive than Portland cement. When dispersed in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes the paste more homogeneous and dense as for the distribution of the finer pores, because of the pozzolanic reactions between the amorphous silica of the mineral addition and the calcium hydroxide produced by the cement hydration reactions. In addition, the physical effect of the finer grains allows denser packing within the cement and reduces the wall effect in the transition zone between the paste and the aggregates. This weaker zone is strengthened due to the higher bond between the two phases, improving the concrete microstructure and properties.

In general, the pozzolanic effect (PE) depends not only on the pozzolanic reaction but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolans to cement results in increased mechanical strength and durability when compared to the plain paste because of the interface reinforcement. Thus, the PE on the paste microstructure depends not only on the pozzolanic reactions but also on the filler effect (FE) of the finer particles. The physical action of the pozzolans provides a denser, more homogeneous and uniform paste.

1.4 Objective

The objective of the present thesis work is to design mixes ranging above 95-100 MPa by varying the percentage replacement of cement by fly ash (0-30%) and silica fume (0-10%) while keeping a constant dosage of super plasticizer at a constant water-binder ratio. The mix designing was carried out by using guidelines and available literature on design of HSC. The work focused on concrete mixes having a fixed water/binder ratio of 0.22 and a constant total binder content of 635 kg/m^3. The percentages of fly ash that replaced cement in this research were 0%, 20%, 25% and 30% whereas percentages of silica fume were 5% and 10%, and compressive strength testing was conducted at the ages of 7, 28, 56 and 90 days.

Total 8 mix trials were made, for each trial mix, 12 cubes were cast, taking an average value of 3 cubes for each curing period. Trial-1 was plain cement concrete, without any cement replacement; trial- 2,3 and 4 consisted of replacement of cement by fly ash by 20%, 25% and 30% respectively. Trial-5 and 6 consisted of replacement of cement by silica fume by 5% & 10% respectively. Trial-7 was exactly similar to trial-2,but the only difference was that instead of regular fly ash a fine fly ash (FFl.) was used. Fine fly ash, the one with a fineness of 99% passing through 45 µm sieve, was used for comparing the change in strength of the concrete at different ages. Trial-8 had a 30% replacement of cement by mineral admixture consisted of 20% fly ash and 10% silica fume in order to see the combined effect on the strength of concrete at various ages.

CHAPTER 2
LITERATURE REVIEW

Rashid and Mansur [1] gave a review of literature regarding the requirements of ingredient materials for producing high strength concrete (HSC) along with the results of an experimental study on achieving HSC. Use of quality materials, smaller water-binder ratio, larger ratio of coarse aggregate to fine aggregate, smaller size of coarse aggregate, and suitable admixtures with their optimum dosages are found necessary to produce HSC. In the experimental study, the targeted strengths of concretes were from 60 MPa to 130 MPa. A larger ratio of coarse aggregate to fine aggregate (1.81 except one mix of 1.60) was considered in the study. While the variables considered were the water-binder ratio (from 0.34 to as low as 0.20) and the superplasticizer-binder ratio (from 0.73% to 2.95%). Test results are found to support the reviewed information on HSC production. Also the water-binder ratio and the suitable admixtures with their optimum dosages are found to be the most important parameters for producing HSC.

Zain et.al. [2] investigated the possibility of developing high performance concrete (HPC) using silica fume (SF) at relatively high water binder ratios. For this purpose, water binder ratios of 0.45 and 0.50 were considered. Test specimens were air and water cured. The mechanical properties like compressive strength, modulus of elasticity and initial surface absorption (ISA) of hardened concrete were determined. This research work concluded that SF concrete subjected to dry air at 35°C after 14 days initial water curing produced the highest compressive strength and dynamic modulus of elasticity when continuously cured under water at 20°C.

Vinayagam [3] formulates a simplified mix design procedure for HPC by combining BIS and ACI code methods of mix design and available literature on HPC. Based on the above procedure mixes of compressive strength of 80 MPa and 100 MPa were arrived at. These HPC mixes are tested experimentally for compression, split tension, flexure and workability. Study concluded the optimum percentage of cement replacement by SF is 10% for achieving maximum compressive, split tensile and flexural strength and elastic modulus. The 7 days to

28 days compressive strength ratio of HPC was 0.75 -0.8. The use of SF in concrete reduces the workability. The compression failure pattern of concrete is due to crushing of coarse aggregate and not due to bond failure.

Brooks et.al. [4] investigated the effect of silica fume (SF), metakaolin (MK), fly ash and ground granulated blast-furnace slag (GGBFS) on the setting times of high-strength concrete using the penetration resistance method. In addition, the effect of a shrinkage-reducing admixture (SRA) on the setting times of normal and high-strength concrete was also studied. The investigation concluded that the general effect of SF, MK, fly ash and GGBFS is to retard the setting times of high-strength concrete. The SRA has negligible effect on the setting times of normal strength concrete, but it has a significant retarding effect when used in combination with a superplasticizer in high-strength concrete. The influence of increasing the levels of SF, Fl. and GGBFS is to provide greater retardation in the setting times of high-strength concrete.

Mailroom et.al. [5] analyzed the short- and long-term mechanical properties of high-strength concrete containing different levels of silica fume. The work focused on concrete mixes having a fixed water/binder ratio and constant total binder content with varying percentage of replacement by SF. The mechanical properties evaluated were: workability, development of compressive strength; secant modulus of elasticity; strain due to creep, shrinkage, swelling and moisture movement. The conclusion drawn from this research was that in concrete mixtures with a constant slump of 100±10 mm, those incorporating higher silica fume replacement levels tended to require large dosages of superplasticizer. Also the compressive strength of concrete mixtures containing silica fume did not increase after the age of 90 days. Silica fume did not affect the total shrinkage; however, as the proportion of silica fume increased, the autogenous shrinkage of high strength concrete increased and its drying shrinkage decreased.

Haque and Kayali [6] used a Class F fine fly ash (FFl.) with a fineness of 99% passing a 45 μm sieve to produce workable high-strength concrete. The replacement of cement by FFl. was 0, 10, and 15%. The mixtures were tested for workability and strength. At 10%

replacement of cement by the FFl, it was possible to reduce the mixing water by 35% to produce a concrete of similar workability. At 15% cement replacement there was a rapid reduction in the workability of the concrete. The concretes with 10% FFl. exhibited higher early strength followed by an excellent development of strength over time. The values represented 20% increase in strength compared to the corresponding concrete without FFl.

Alves et.al. [7] studied the influence of the different mixing methods on the production of HSC. Four different methods were chosen to be executed in accordance with the criteria of practicability, costs, material consumption and technical feasibility. The chosen proportioning methods for this research were the IPT/EPUSP method, the Mehta/Aitcin method, the Toralles Carbonari method, and the Aitcin method. This study concluded that there is a significant difference between producing HSC as per HSC specific proportioning methods and proportioning methods for conventional concrete. The material consumption per cubic meter of concrete, particularly of cement, varies considerably from one method to another. Also concerning the cost per cubic meter of HSC, it is shown that the concrete having the highest consumption of cement per m^3 of concrete is not, necessarily, always the most expensive one.

Del Viso et.al. [8] observed the shape and size effects of specimen on the compressive strength of HSC. Cubes and cylindrical specimen of different sizes were chosen and tests were performed at a single axial strain rate of $10^{-6}s^{-1}$. This study concluded that post-peak behavior in cubes is milder as compared to that of the cylinders. In cylinders, a main inclined fracture surface is nucleated, while in cubes spalling of lateral sides leading to hour-glass shaped failure mode is observed. The size effect in cubes is more prominent. Larger sizes resist less stress.

Oner et.al. [9] has carried out study on development of strength of concrete containing fly ash and determined optimum usage of fly ash in concrete. A total of 28 mixtures were tried with different mix designs. Four control mixtures having 250, 300, 350, and 400 kg/m^3 cement content were kept as base and six different percentages of cement replacement by fly ash were studied. This study concluded that strength of mix increased up to a certain optimum percentage of Fl. replacement and then decreased. The optimum percentage of replacement determined for four test groups was 40 percent.

Bhanja and Sengupta [10] developed a mathematical model that can predict the 28-days compressive strength of silica fume concrete using statistical methods. Strength results of 26 concrete mixes having w/c ratio between 0.3 to 0.42 and percentage of silica fume varying between 5 to 30 were analyzed. An expression independent of specimen parameters,

$$f_{SF}/f_C = 1.0063 + 0.0159\ (SF\%) + 0.0007\ (SF\%)^2 - 0.00003\ (SF\%)^3$$

relating percentage of SF, 28-days compressive strength of control mix and silica fume mix was generated. The validity of model was examined with results of previous researchers and predictions were within 7.5%.

Zhou et.al. [11] studied effect of coarse aggregate on elastic modulus and compressive strength of high performance concrete. The mixes containing six different types of aggregates of constant volume fraction were used. 28-days compressive strength of about 90 N/mm^2 with normal aggregates was found to be drastically reduced, as expected, by the weaker aggregates and also by about 9% by the stiffer aggregates.

Naik and Bruce [12] presented results of research performed at a precast/prestressed concrete plant to identify optimum mix proportions for production of high early strength concrete with high fly ash contents. Compressive strength, workability and water demand results are presented. Concrete mixes containing Type C fly ash up to 30% replacement can be used with confidence to produce high early strength concrete for precast/prestressed products.

CHAPTER 3

THEORETICAL APPROACH

3.1 Cement

Cement is a fine powdery material which when mixed with water forms a paste, which sets in few hours and gets transformed into a solid mass in few days of time. Cement plays the role of binder that binds sand and aggregate together to form firm concrete. We can call cement as hydraulic binder that hardens on addition of water.

3.2 Making of Cement

In broader sense cement making is a two steps process. Step one involves making of clinkers from the raw material i.e., limestone, clay and sand from the quarry and heating in rotary kiln to form clinkers. Step two includes the milling and grinding of clinkers along with addition of gypsum to form a fine powdery material which is cement.

(i) Formation of clinkers

Basic raw materials for production of cement are limestone and clay which are obtained from the quarries. These raw materials are then crushed together to form a homogenized mixture. This is then fed into a rotary kiln, which is a huge pipe having length of 100-200 m and measuring approximately 6 m in diameter. The rotary kiln is slightly inclined to facilitate the forward movement of the material inside. Material enters at one end and gradually moves towards the other end where it is heated to temperature of 1500º C approximately with flame within the kiln.

Mixing of four oxides, calcium oxide (CaO-65%), silicon oxide (SiO_2-20%), alumina oxide ($Al2O_3$-10%) and iron oxide (Fe_2O_{3-}5%) in correct proportion marks the formation of clinkers. These homogeneously mixed compounds are called raw feed, which combine together when heated at a temperature about 1450ºC to form silicates, aluminates and ferrites of calcium. Hydration of cement is mainly due these compounds. Clinker is the final product of this phase.

(ii) Cement from clinkers

Formation of cement from clinkers is carried out at grinding mils. Along with clinkers gypsum (calcium sulphates- $CaSO_4.2H_2O$) and limestone or other cementitious materials are grinded. Gypsum is added to cement for retarding its setting. The fine powder which is obtained after grinding is cement. This is then stored in huge silos.

3.3 Chemical composition

Due to the complexity of chemical compounds present in raw ingredients of cement, these are denoted with a shorthand form. The chemical composition and shorthand form are presented in Table 3.1 given below:

Table 3.1: Shorthand

Name of compound	Formula	Shorthand form
Calcium oxide (lime)	CaO	C
Silicon dioxide (silica)	SiO_2	S
Aluminum oxide (alumina)	Al_2O_3	A
Iron oxide	Fe_2O_3	F
Water	H_2O	H
Sulfate	SO_3	$\underline{S}$

3.4 Properties of Cement Compound

Chemical compounds present in cement are given in Table 3.2.

3.4.1 Tricalcium Aluminate, C_3A

It liberates a lot of heat during the early stages of hydration, but it is responsible for setting and has little strength contribution. Gypsum is added to slow down the hydration of C_3A. Cement low in C_3A is sulfate resistant.

3.4.2 Tricalcium Silicate, C_3S

This compound hydrates and hardens rapidly. It is largely responsible for portland cement's early gain of strength.

Table 3.2: Chemical constituents of cement

Compound	Formula	Shorthand form
Tricalcium aluminate	$Ca_3Al_2O_6$	C_3A
Tetracalcium aluminoferrite	$Ca_4Al_2Fe_2O_{10}$	C_4AF
Belite or dicalcium silicate	Ca_2SiO_5	C_2S
Alite or tricalcium silicate	Ca_3SiO_4	C_3S
Sodium oxide	Na_2O	N
Potassium oxide	K_2O	K
Gypsum	$CaSO_4.2H_2O$	$C\underline{S}H_2$

3.4.3 Dicalcium Silicate, C_2S

C_2S hydrates and hardens slowly. It is largely responsible for later strength gain i.e. after one week.

3.4.4 Ferrite, C_4AF

This is a fluxing agent which reduces the melting temperature of the raw materials in the kiln. It hydrates rapidly, but does not contribute much to strength of the cement.

3.4.5 Lime

It is the major constituent of cement. Its exact proportion is important. The excess lime makes the cement unsound and causes the cement to expand and disintegrate. In case of deficiency, the strength of cement is decreased and cement sets quickly. The right proportion makes cement sound and strong.

3.4.6 Silica

It imparts strength to the cement due to formation of di-calcium silicate (2CaO SiO_2 or C_2S) and tri-calcium silicate (3CaO SiO_2 or C_3S). Silica in excess provides greater strength to the cement but, at the same time it prolongs its setting time.

3.4.7 Alumina

It imparts quick setting quality to the cement. It acts as a flux (rate of flow of energy) and lowers the clinkering temperature. Alumina in excess reduces strength of cement.

3.4.8 Iron Oxide

It provides color, hardness and strength. It also helps the fusion of raw materials during manufacture of cement.

3.5 Hydration Process

When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration". Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how Portland cement hardens and gains strength.

The hydration of cement can be thought of as a two-step process. In the first step, called dissolution, the cement dissolves, releasing ions into the mix water. The mix water is thus no longer pure H_2O, but an aqueous solution containing a variety of ionic species, called the pore solution. The gypsum and the cement minerals C_3S and C_3A are all highly soluble, meaning that they dissolve quickly. Therefore, the concentrations of ionic species in the pore solution increase rapidly as soon as the cement and water are combined. Eventually the concentrations increase to the point that the pore solution is supersaturated, meaning that it is energetically favorable for some of the ions to combine into new solid phases rather than remain dissolved. This second step of the hydration process is called precipitation. A key point, of course, is that these new precipitated solid phases, called hydration products, are different from the starting cement minerals. Precipitation relieves the supersaturation of the pore solution and allows dissolution of the cement minerals to continue. Thus, cement hydration is a continuous process by which the cement minerals are replaced by new hydration products, with the pore solution acting as a necessary transition zone between the two solid states.

There are two reasons that the hydration products are different from the cement constituents. One reason is that there is a new reactant in the system: water. Not only does the water facilitate the hydration process by dissolving the cement minerals, but it also contributes ions, in the form of hydroxyl groups (OH^-), to the hydration products. The second reason is the tendency for all processes to approach thermodynamic equilibrium. This dictates that the solid phases that precipitate out of the pore solution are the ones that are the most stable under the current conditions. The stability of a phase is defined by a parameter called the free energy, which can be roughly defined as the amount of chemical and thermal energy contained in the phase. The lower the free energy, the more stable the phase. The cement constituents are formed at temperatures exceeding 1400ºC, because they have the lowest free energy under those extreme conditions. At the much lower temperatures present during cement hydration, the cement constituents are actually quite unstable, meaning that there are many other solid phases that will form preferentially in their place once they dissolve. When one phase is converted into another phase with a lower free energy, there is usually a release of excess energy in the form of heat, this is called heat of hydration.

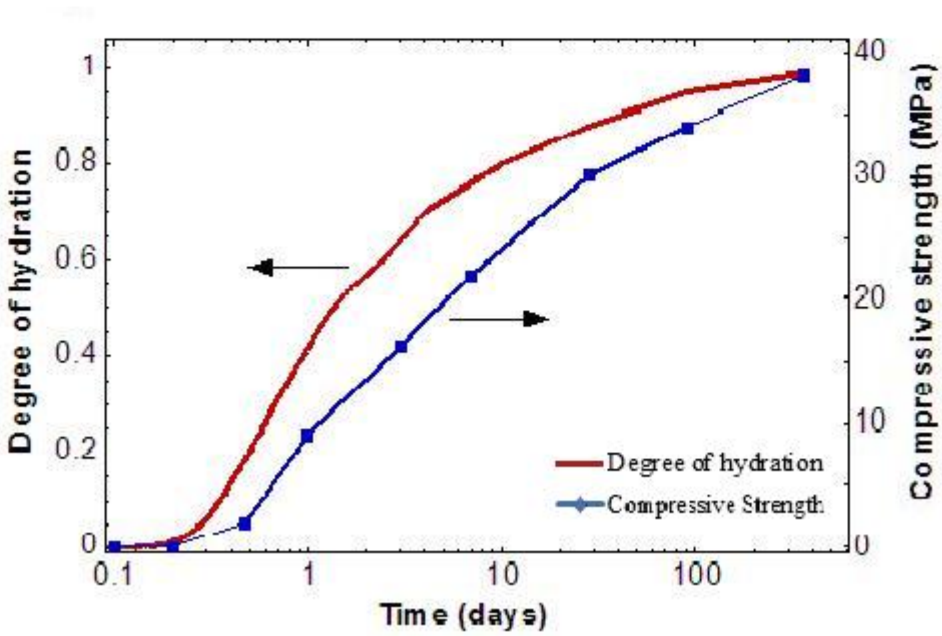


Figure 3.1: Typical development of the degree of hydration and compressive strength of a OPC over time

From figure 3.1 it can be seen that the degree of hydration and the strength track together, particularly at later times. This is because the strength of cement paste depends primarily on the amount of capillary porosity, and the amount of capillary porosity decreases in proportion to the amount of hydration that has already taken place. This decrease occurs because the C-S-H gel phase (including its internal gel pores) occupies significantly more volume than the cement constituents.

In figure 3.1 complete hydration takes place after one year, but this will not always be the case, as many cement pastes will never reach full hydration. Hydration will continue at a slow rate until one of the three following criteria is met:

1) All of the cement reacts. This indicates that the paste has a moderate or high w/c and was cured correctly. While it is the best possible outcome for the given mix design, it does not guarantee high quality concrete as the w/c may have been too high. If the cement contains some large particles, full hydration of these particles may not occur for years.

2) There is no more liquid water available for hydration. If the cement has a w/c less than about 0.4, there will not be enough original mix water to fully hydrate the cement. If additional water is supplied by moist curing or from rainfall, hydration may be able to continue. However, it is difficult to supply additional water to the interior of large concrete sections. If the cement is improperly cured so that it dries out, hydration will terminate prematurely regardless of the w/c. This is the worst-case scenario, as the strength will be lower (perhaps significantly) than the value anticipated from the mix design.

3) There is no more space available for new reaction product to form. When the capillary porosity is reduced to a certain minimal level, hydration will stop even if there is unreacted cement and sufficient water. This is the best possible outcome, and it is only possible if the w/c is less than about 0.4. Not only will the cement paste or concrete have a high strength, but it will also have a low permeability and thus be durable.

3.6 Reactions of Hydration

Reaction of tricalcium silicate:

$$2C_3S + 7H = C_3S_2H_8 + 3Ca(OH)_2$$

Reaction of dicalcium silicate:

$$2C_2S + 7H = C_3S_2H_8 + Ca(OH)_2$$

Reaction of tricalcium aluminate:

$$C_3A + 6H = C_3AH_6$$

$$[C_3A + CaSO_4 . 2H_2O = 3CaO. Al_2O_3. 3CaSO_4. 31H_2O]$$

Calcium Sulfoaluminate

3.7 Pozzolans

Pozzolans are siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts at ordinary temperatures with calcium hydroxide released by the hydration of Portland cement to form compounds possessing cementing properties (C-S-H). The most common pozzolans being fly ash, silica fume, ground granulated blast furnace slag (GGBFS), metakaoline and others.

3.8 Need of Pozzolanic Materials

Pozzolanic materials help to improvise concrete properties. Most beneficial effects of using pozzolans or supplementary cementing material (SCM) are related to the effects they have on the pore structure. Their micro filler effect helps in increasing packing of cementitious particles. As they react with excess of calcium hydroxide to form C-S-H (cementing material), thus replacing porous C-H with useful C-S-H. Due to high specific surface area they densify the ITZ (interfacial transition zone) at the cement-aggregate interface causing a wall effect. Also their use reduces energy consumption and CO_2 emissions when used as partial replacement for cement which additionally is a productive use of industrial waste which may be landfilled otherwise.

3.9 Pozzolanic Reaction

Chemical reaction with calcium hydroxide (lime) and water leads to the formation of cementitious products, like C-S-H.

$$2C_3S + 6H \rightarrow C_3S_2H_3 + 3CH$$

$$2C_2S + 4H \rightarrow C_3S_2H_3 + CH$$

$C_3S_2H_3$: Strength giving phase

CH: No cementitious property

$C_3S + H$	$\longrightarrow$	C-S-H + CH	(FAST)
$C_2S + H$	$\longrightarrow$	C-S-H + CH	(FAST)
Pozzolans + CH + H	$\longrightarrow$	C-S-H	(SLOW)

CHAPTER 4
EXPERIMENTAL PROGRAMME

4.1 Materials

OPC 53 grade cement, flyash (Fl.) and silica fume (SF) were used as cementitious materials. Two sizes of coarse aggregate (20mm down and 10mm down) and natural sand were used. Superplasticizer (SP) used was BASF's Glenium SKY-777. Silica fume as mineral admixture in dry densified form obtained from ELKEM INDIA (P) LTD, Mumbai conforming to ASTMC-1240. Normal tap water was used for mixing and curing purposes.

4.2 Material Testing

4.2.1 Tests on Coarse Aggregate

4.2.1.1 Sieve Analysis/ Fineness Modulus:

This covers the determination of particle size distribution of coarse aggregates by sieving or screening. Coarse aggregates were supplied in the nominal sizes as given in Table 2 of IS: 383-1970 reproduced as Table 4.1. Sieve shaker used for sieving is given in figure 4.1.

Table 4.1: Particle size distribution of coarse aggregates [19]

IS SIEVE DESIGNATION	PERCENTAGE PASSING FOR SINGLE-SIZED AGGREGATE OF NOMINAL SIZE					
	63mm	40mm	20mm	16mm	12.5mm	10 mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)
80mm	100	-	-	-	-	-
63mm	85-100	100	-	-	-	-
40mm	0-30	85-100	100	-	-	-
20mm	0-5	0-20	85-100	100	-	-
16mm	-	-	-	85-100	100	-
12.5mm	-	-	-	-	85-100	100
10mm	0-5	0-5	0-20	0-30	0-45	85-100
4.75mm	-	-	0-5	0-5	0-10	0-20
2.36mm	-	-	-	-	-	0-5

Fineness modulus (FM) for coarse aggregate is determined as follows:

FM= (500+ sum of cumulative % of weight retained)/100

Figure 4.1: Using of Sieve Shaker for sieve analysis

Test result:

Coarse aggregate-I (20mm down)

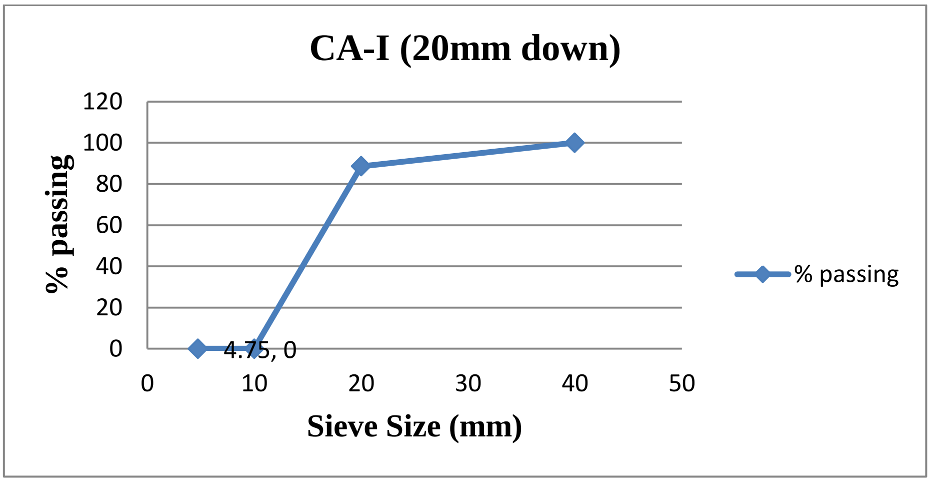
Table 4.2: Sieve analysis reading for CA-I

Sieve size (mm)	Wt. retained	% Wt. retained	Cumulative % Wt. retained	% Passing
40	0	0	0	100
20	114	11.4	11.4	88.6
10	886	88.6	100	0
4.75	0	0	100	0
Pan	0	0	-	-

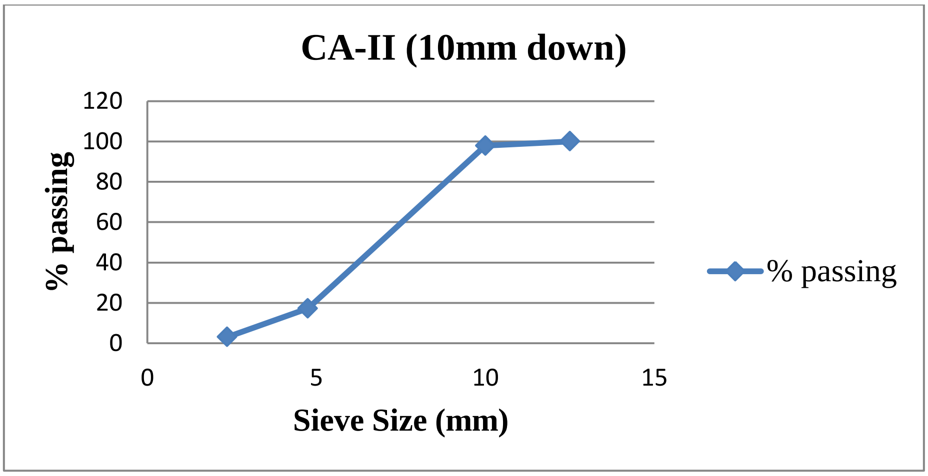
Coarse aggregate-II (10mm down)

Table 4.3: Sieve analysis reading for CA-II

Sieve size (mm)	Wt. retained	% Wt. retained	Cumulative % Wt. retained	% Passing
12.5	0	0	0	100
10	81.2	8.12	8.12	97.88
4.75	806.6	80.66	88.78	17.22
2.36	81.3	8.13	96.91	3.09
Pan	30.9	0	-	-



Graph 4.1: Sieve analysis curve for CA-I



Graph 4.2: Sieve analysis curve for CA-II

Figure 4.2: Coarse Aggregate-I

4.2.1.2 Flakiness Index/Elongation Index:

Weighed sample of aggregate containing minimum of 200 pieces in sieved in accordance with the sieves mentioned in Table V of IS:2386 (Part-1):1963 reproduced as Table 4.4 was taken. Each fraction was gauged in turn for thickness on a metal gauge of the pattern shown in Figure 4.3. The width of the slot used in the gauge was of the dimensions specified in co1umn 3 of Table 4.4 for the appropriate size of material. The total amount passing the gauge was weighed. The flakiness index is the total weight of the material passing the various thickness gauges, expressed as a percentage of the total weight of the sample gauged.

Flakiness Index= (W1/W)*100

Calculated value= 28.3%

For determining elongation index same pattern was followed, here each fraction was gauged individually for length on a metal length gauge of the pattern shown in Figure 4.4. The gauge length used was that specified in co1umn 4 of Table 4.4 for the appropriate size of material. The total amount retained on the gauge was weighed. The elongation index is the total weight of the material retained on the various length gauges, expressed as a percentage of the total weight of the sample gauged.

Elongation Index= (W2/W)*100

Calculated value= 32.8%

Figure 4.3: Metal Guage for calculating Flakiness Index

Figure 4.4: Length Guage for determining Elongation Index

W1= total weight of the material passing the various thickness gauges,
W2= total weight of the material retained on the various length gauges, and
W = total weight of the sample gauged.

Table 4.4: Guage sizes for determining flakiness/elongation index [20]

SIZE OF AGGREGATE		THICKNESS GUAGE*	LENGTH GUAGE†
PASSING THROUGH IS SIEVE	RETAINED ON IS SIEVE		
(1)	(2)	(3) Mm	(4) mm
63mm	50mm	33.90	33.90
50mm	40mm	27.00	27.00
40mm	25mm	19.50	19.50
31.5mm	25mm	16.95	16.95
25mm	20mm	13.50	13.50
20mm	16mm	10.80	10.80
16mm	12.5mm	8.55	8.55
12.5mm	10mm	6.75	6.75
10mm	6.3mm	4.89	4.89

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

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

4.2.1.3 Specific gravity

Adopting Method III of IS:2386 (Part-3):1963 for determining specific gravity using pycnometer bottle, approximately 1 kg of saturated surface dried sample is weighed (A). This sample wascarefully placed in the pycnometer and filled with water till the hole of the apex of the metal cone eliminating trapped air if any. The pycnometer was dried from outside and weighed (B). The contents were emptied and refilled with water in same manner as before and weighed (C). The sample was then dried in an oven at 100±10ºC for nearly 24 hours, it was then air-cooled and weiged (D).

Specific gravity calculated is as follows:

Specific gravity= D/[A-(B-C)]

Calculated Specific gravity (CA-I)= 2.94

Calculated Specific gravity (CA-II)= 2.81

4.2.1.4 Water Absorption

Water absorption is represented as percent of dry weight of sample. From the values of above test water absorption was determined as follows:

Water Absorption= 100 (A-D)/D

Water Absorption (CA-I)= 0.58%

Water Absorption (CA-II)= 0.88%

4.2.1.5 Aggregate Impact Value (AIV) Test:

Aggregate Impact Value (AIV) signifies the toughness of the aggregate. The sample passing through 12.5 mm sieve and retained on 10mm sieve was taken for determining AIV. Aggregates from this sample were filled in three layers using a tamping rod in a cylindrical measure. The net weight (A) of the aggregates filled in the measure was taken.

This measure was kept at the bottom of AIV apparatus and the hammer was lifted and allowed to fall freely for 15 times. The sample from the measure was then sieved from 2.36 mm sieve.

The fraction of sample passing through 2.36mm sieve was then weighed (B). The AIV was then determined as follows:

AIV= 100*B/A

AIV= 17.5%

AIV was taken as the mean of two values. Depending upon the AIV, aggregates are classified as given in Table 4.5 below.

Table 4.5: Classification of aggregates on AIV basis

Aggregate Impact Value	Classification
<10%	Very Strong
10-20%	Strong
10-30%	Satisfactory
>35 %	Weak

4.2.2 Tests for Fine Aggregate/Sand

4.2.2.1 Sieve Analysis/ Fineness Modulus(FM)

The grading of fine aggregates, when determined as described in IS: 2386 (Part I)-1963 was within the limits given in Table 4.6 and was described as fine aggregates Grading Zone I. The test result of sieve analysis of sand is shown in table 4.7 and graph 4.3 given below.
FM of fine aggregates is determined as ∑cumulative % of weight retained/100.

Table 4.6: FINE AGGREGATES [19]

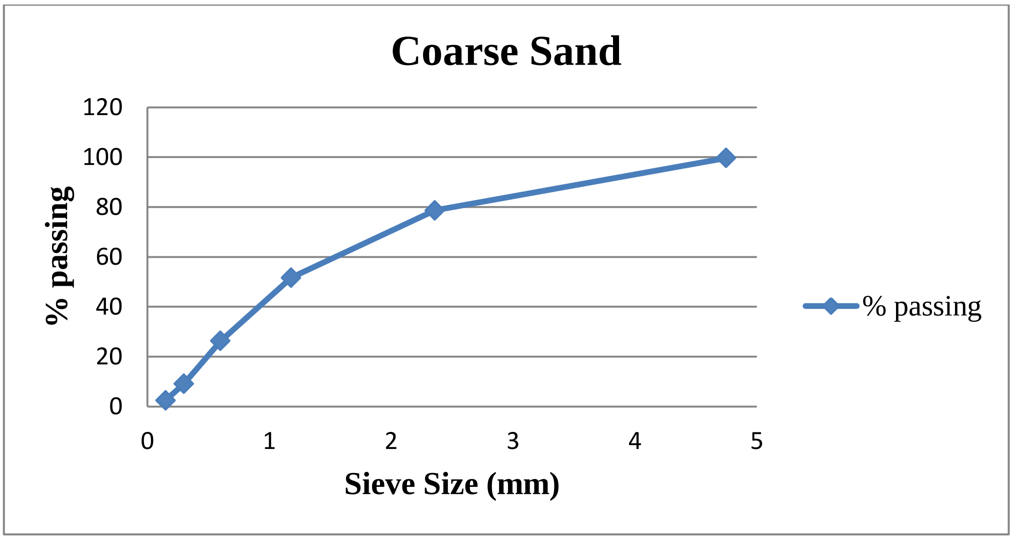
IS SIEVE DESIGNATION	PECENTAGE PASSING FOR			
	GRADING ZONE I	GRADING ZONE II	GRADING ZONE III	GRADING ZONE IV
10mm	100	100	100	100
4.75mm	90-100	90-100	90-100	95-100
2.36mm	60-95	75-100	85-100	95-100
1.18mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Test result:

Table 4.7: Sieve analysis reading of sand

Sieve size (mm)	Wt. retained	% Wt. retained	Cumulative % Wt. retained	% Passing
4.75	22.7	2.27	2.27	97.73
2.36	190.6	19.06	21.33	78.67
1.18	269.7	26.97	48.3	51.7
0.600	253.5	25.35	73.65	26.35
0.300	172.4	17.24	90.89	9.11
0.150	66	6.6	97.49	2.51
Pan	25.1	-	-	-

F.M of sand= 3.34



Graph 4.3: Sieve analysis curve for sand

Figure 4.5: Rejected sand having FM 2.76

Figure 4.6: Coarse sand having FM 3.34

4.2.2.2 Specific Gravity/ Water Absorption

Specific gravity and water absorption for fine aggregates was determined as per Method III of IS:2386 (Part-3):1963 using pycnometer shown in figure 4.7 below.

Figure 4.7: Using of Pycnometer for determining specific gravity.

Specific Gravity= 2.77

Water Absorption= 1.0%

4.2.3 Tests on Cement

4.2.3.1 Fineness of cement

As per IS:4031(Part-1):1996 fineness of cement was measured by sieving it on standard 90 micron sieve. The proportion of cement of which the grain sizes are larger than the 90 micron size was thus determined. Approximately 100 g of cement is sieved through 90 micron sieve. The residue wass weighed and expressed as percent (R1) of the weight of the sample. Process was repeated to obtain R2. Percentage of residue of cement (R) was obtained as mean of R1 and R2.

Fineness of cement calculated was 5% retained on 90 µm sieve.

4.2.3.2 Standard Consistency of Cement

As per IS:4031 (Part-4):1988 the consistency which will permit a vicat plunger having 10 mm dia and 50 mm length to penetrate to a depth of 5-7 mm from bottom of the mould is the standard consistency. It is ability of the fresh mortar to flow. Approximately 400 g of cement was thoroughly mixed with 25% of water with gauging time not exceeding 3-5 minutes. Vicat mould was filled with cement paste and leveled at the top. The plunger was kept close to the top surface of mortar just touching it. Then it was immediately released so as to penetrate in the mortar. This process was repeated with increasing percentage of water till the plunger penetrate to a depth of 5-7 mm from bottom of the mould. Percentage of water (P) by weight of dry cement was calculated as:

$$P=W/C*100$$

W= quantity of water used

C=quantity of cement added

Standard consistency calculated as 29%

4.2.3.3 Initial Setting/Final Setting Time

As per IS:4031 (Part-5):1988 initial setting time is that time period between the time water is added to cement and time at which 1 mm square section needle fails to penetrate the cement paste, placed in the Vicat's mould 5 mm to 7 mm from the bottom of the mould. The cement paste was prepared in same way as for standard consistency test, only the amount of water added was 0.85P of water by weight of cement. P is percentage of water determined from standard consistency test.

Start the stop watch at the instant when the water is added to the cement. This time was recorded as t_1. Then, filled the vicat mould with cement paste and leveled it. Needle was allowed to penetrate in the cement paste. The needle completely pierces the test block. This procedure was repeated i.e. quickly releasing the needle after every 2 minutes till the needle failed to pierce the block for about 5 mm measured from the bottom of the mould. This time was note as (t_2).

$$\text{Initial setting time}=t_2-t_1$$

Calculated Initial setting time= 72 min

Final setting time is that time period between the time water is added to cement and the time at which 1 mm needle makes an impression on the paste in the mould but 5 mm annular attachment does not make any impression. The needle of the Vicat's apparatus was replaced by the needle with an annular attachment. The cement was considered finally set when upon applying the final setting needle gently to the surface of the test block; the needle makes an impression thereon, while the attachment failed to do so. This time was recorded as (t_3)

Final setting time= t_3-t_1

Calculated Final setting time= 266 min

4.2.3.4 Specific Gravity

Specific gravity is defined as the ratio between the weight of a given volume of cement and weight of an equal volume of water. IS:4031 (Part11):1988 was followed to determine specific gravity of cement using Le-Chatelier's flask as shown in figure 4.8. Flask was filled with kerosene and initial reading was noted. Cement was introduced into the flask so as to rise the level of kerosene in flask. Then final reading was noted. Specific gravity was determined as follows:

Specific gravity= mass of cement / (final reading- initial reading)

Calculated Specific gravity= 3.15

4.2.4 Test on Mineral Admixture

4.2.4.1 Sieve Analysis

Sieve analysis was carried out in the similar way. For flyash guidelines from code IS:3812 (Part-1):2003 were adopted.

4.2.4.2 Specific Gravity

Same procedure of calculating specific gravity of cement was followed, adopting the guidelines of IS:4031 (Part-11):1988.

Calculated Specific Gravity of flyash= 1.92

Calculated Specific Gravity of silica fume = 2.20

Calculated Specific Gravity of superplasticizer= 1.10

Figure 4.8: Le Chatelier's flask filled with kerosene for calculating specific gravity of cement.

4.2.5 Chemical Properties

Table 4.8 shows chemical composition of OPC and silica fume.

4.3 Trials

Total eight mixes were designed. One plain mix was cast using OPC, while the other mixes were prepared by replacing 5 to 30 percentages of cement with different mineral admixtures. Mixes were tested for slump value and compressive strength at four curing periods i.e., 7 days, 28 days, 56 days and 90 days. An average of 3 cubes is considered for mean compressive strength.

4.4 Design Procedure and Codal Provisions

The mix designing procedure was carried out using the guidelines provided in IS: 10262-2009 and available literatures on design of HSC.

Table 4.8: Chemical composition

Constituents	Cement	Silica Fume
SiO2	21.08	94.37
Al_2O_3	4.77	0.45
Fe_2O_3	3.22	1.69
CaO	63.89	0.49
MgO	2.23	0.51
SO_3	2.87	0.13
K_2O	0.58	0.59
Na_2O	0.26	0.24
LOI	1.1	1.53
Fineness (Surface Area)	410 m^2/kg	14000 m^2/kg

4.4.1 Setting of Target Mean Strength

The mix has to be proportioned for higher target mean compressive strength f'_{ck}, so that not more than the specified proportion of test results fall below the characteristic strength. The margin over characteristic strength is given by the following relation:

$$f'_{ck} = f_{ck} + 1.65\ s$$

f'_{ck}= target mean compressive strength at 28 days in N/mm^2

f_{ck}= characteristic compressive strength at 28 days in N/mm^2

s= standard deviation

As this study is targeted on design of HSC having compressive strength of the order 90-100 MPa. Sufficient test results for these grades of concrete are unavailable. Therefore, we adopt assumed standard deviation provided in Table 1 of IS: 10262-2009 [21] reproduced here as Table 4.9 given below.

4.4.2 Selection of water-binder ratio

The water binder ratio for the design of HSC is chosen from proposed curve for compressive strength versus water binder ratio [3], from IS: 456- 2000.

Figure 4.9, shows the proposed water binder ratio versus compressive strength relationship. The water binder ratio so chosen is checked against the limiting w/c ratio for the requirements of durability as per Table 5 of BIS: 456- 2000, and the lower of the two values is adopted.

Table 4.9: Assumed Standard Deviation [21]

S. No.	Grade of Concrete	Assumed standard deviation N/mm^2
(1)	(2)	(3)
i)	M10	3.5
ii)	M15	
iii)	M20	4.0
iv)	M25	
v)	M30	5.0
vi)	M35	
vii)	M40	
viii)	M45	
ix)	M50	
x)	M55	

4.4.3 Selection of Water content

Water content of concrete is influenced by a number of factors, like size of aggregate, shape of aggregate, workability, water binder ratio, type and quantity of supplementary cementitious material, type and dosage of superplasticiser and environmental conditions. Use of rounded aggregate and water reducing admixtures will reduce the water demand. Whereas, increased temperature, cement content, slump, water binder ratio, aggregate angularity and a decrease in the proportion of coarse aggregate to fine aggregate will increase water demand.
The quantity of maximum mixing water per unit volume of concrete may be determined from Table 2 of IS: 10262-2009 reproduced as Table 4.10. The water content in Table 4.10 is for angular coarse aggregate and for 25 to 50 mm slump range. The water estimate in Table 4.10

can be reduced by 10 kg for sub-angular aggregate, 20 kg for gravel with some crushed particles and 25 kg for rounded gravel to produce same workability. For any desired workability (other than 25 to 50 mm slump range), the required water content may be established by trial or an increase by about 3 % for every additional 25 mm slump or alternatively by using chemical admixture conforming to IS:9103. Water reducing admixtures can reduce water content up to 20 percent and above depending upon the property of SP and its dosage.

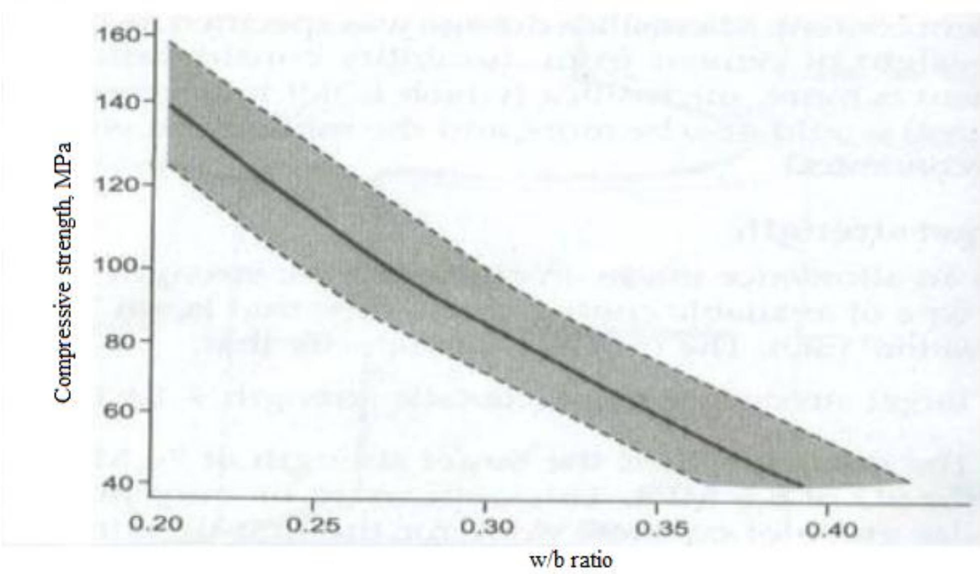


Figure 4.9: Compressive strength and water binder ratio curve

Table 4.10: Maximum Water Content [21]

S.No.	**Nominal Maximum Size of Aggregate**	**Maximum Water Content[1)]**
	Mm	Kg
(1)	(2)	(3)
i)	10	208
ii)	20	186
iii)	40	165

NOTE- These quantities of mixing water are for use in computing cementitious material contents for trial batches.

[1)] Water content corresponding to saturated surface dry aggregate.

4.4.4 Calculation of Binder Content

The binder or cementitious contents per m^3 of concrete is calculated from the w/b ratio and the quantity of water content per m^3 of concrete. Assuming the percentage replacement of cement by SF (5% and 10%) and by Fl. (20%, 25% and 30%) the SF and Fl. content is obtained from the total binder contents. The remaining binder content is composed of OPC. The cement content so calculated is checked against the minimum cement content for the requirements of durability as per table 5 and 6 of BIS: 456-2000 and the greater of the two values is adopted. As this study is mainly focused on design of concrete having compressive strength of the order 90-100 MPa so maximum cement content limit of 450 kg cement per m^3 of concrete has been violated for some trial mixes.

The amount of cement, fly ash and silica fume content used in different mixes is presented in the Table 4.12.

For easy understanding of the content of mixes instead of designating by numbers they are designated by alphanumeric value. The first two letters ie, PC or Fl. or SF tells about the binder material and the last two digits shows the percentage replacement of cement. So PC means it is plain concrete without any replacement of cement, Fl.20 denotes mix in which 20% of cement is replaced by fly ash, whereas SF10 denotes concrete having 10% replacement of cement by silica fume.

4.4.5 Estimation of Coarse Aggregate Proportion

Aggregates of essentially the same nominal maximum size, type and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate per unit volume of total aggregate is used. Approximate values for this aggregate volume are given in Table 4.11. The volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and grading zone of fine aggregate.

4.4.6 Estimation of Fine Aggregate Proportion

After following all the above steps, only thing remains is to determine the quantities of coarse aggregate and fine aggregate. In order to determine their values we first calculate the combined absolute volume of total cementitious material, water and chemical admixture, by dividing their respective masses with their specific gravity and multiplying it with a factor of 1/1000. These values are then subtracted from unit volume of concrete. After this, what left is the absolute volume of coarse and fine aggregates combined. Now this volume is divided depending upon the proportion of coarse aggregate as determined in the previous step. The quantity of coarse and fine aggregates is obtained by multiplying their respective volumes with their respective specific gravity and 1000.

Table 4.11: Volume of Coarse Aggregate per Unit Volume of Concrete for Different Zones of Fine Aggregate [21]

S.No.	**Nominal Maximum Size of Aggregate Mm**	**Volume of Coarse Aggregate per Unit Volume of Concrete for Different Zones of Fine Aggregate**			
		Zone IV	**Zone III**	**Zone II**	**Zone I**
(1)	(2)	(3)	(4)	(5)	(6)
i)	10	0.50	0.48	0.46	0.44
ii)	20	0.66	0.64	0.62	0.60
iii)	40	0.75	0.73	0.71	0.69

In present work, the ratio of coarse aggregate to fine aggregate by volume was kept as 1.5. The ratio of fine aggregate to total aggregate by volume was 0.40. CA-I (20mm down) and CA-II (10mm down) were mixed in the ratio of 0.52/0.48 for combined grading.

4.5 Mix Proportions of the Ingredients

Table 4.12: Mix proportioning of concrete mixes.

Mix	Cementitious Material Kg			CA-I Kg	CA-II Kg	Fine Aggregate Kg	Chemical admixture Kg	Water Kg	w/b ratio
	OPC	FA	SF						
PC	635	-	-	607	551	717	11.43	140	0.22
Fl.20	510	125	-	572	504	690	11.43	135	0.21
Fl.25	445	190	-	569	502	687	11.43	140	0.22
Fl.30	475	160	-	560	494	676	11.43	144	0.226
SF05	600	-	35	591	521	714	11.43	135	0.21
SF10	570	-	65	586	517	708	11.43	140	0.22
Fl.*20	510	125	-	572	504	690	11.43	140	0.22
Fl.20+SF10	445	125	65	560	494	676	11.43	148	0.233

*Fine Fl. (>99%) passing 45 micron sieve.

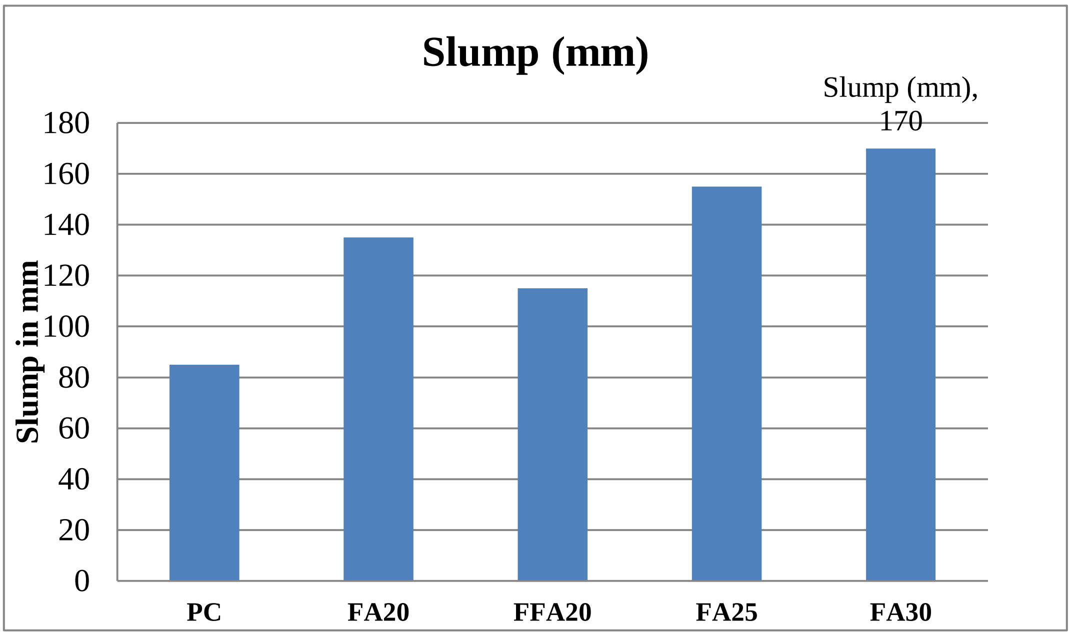
4.6 Results and Discussions

4.6.1 Slump Value

The slump values obtained for various concrete mix follows a definite trend. For the mixes having Fl. as mineral admixture shows an increase in the slump value with an increase in the percentage of replacement of cement. Whereas, a reverse trend is seen to be followed in case of mixes having SF as mineral admixture, with an increase in percentage replacement of cement by SF the slump decreases. Also one thing was noted that for same percentage replacement of cement by Fl. of 20 percent, the slump value is lesser for mix containing fine fly ash. Slump values measured for different mixes are given in table 4.13.

Table 4.13: Slump

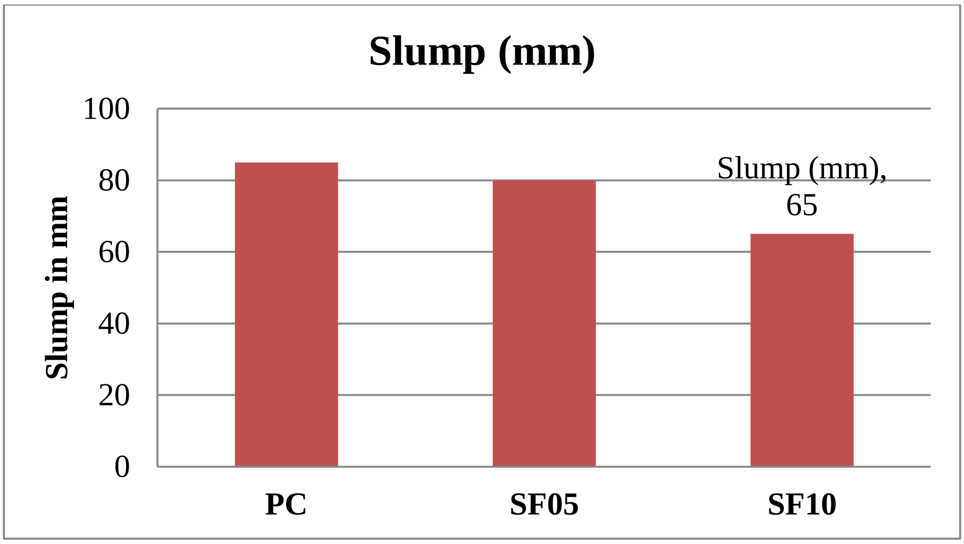
Mix	Water content per m^3 of concrete Liters	Water binder ratio	Slump Mm
PC	140	0.22	85
Fl.20	135	0.21	135
Fl.25	140	0.22	155
Fl.30	144	0.226	170
SF05	135	0.21	80
SF10	140	0.22	65
FFl.20	140	0.22	115
Fl.20+SF10	148	0.233	95



Graph 4.4: Comparison of slump for various fly ash replaced mixes.

With reference to slump values obtained from Table 4.13, graph 4.4 shows comparison of slump for different percentage replacement of cement by Fl. It is observed that the addition of Fl. to concrete increases its workability keeping dosage of superplasticiser constant. But, same replacement with relatively finer flyash gives smaller improvement in workability.

Also, a similar kind of graph is plotted for concrete mixes containing SF as mineral admixture. It can be seen in graph 4.5 that with addition of SF the workability of concrete reduces.



Graph 4.5: Comparison of slump for various silica fume replaced mixes.

4.6.2 Compressive Strength

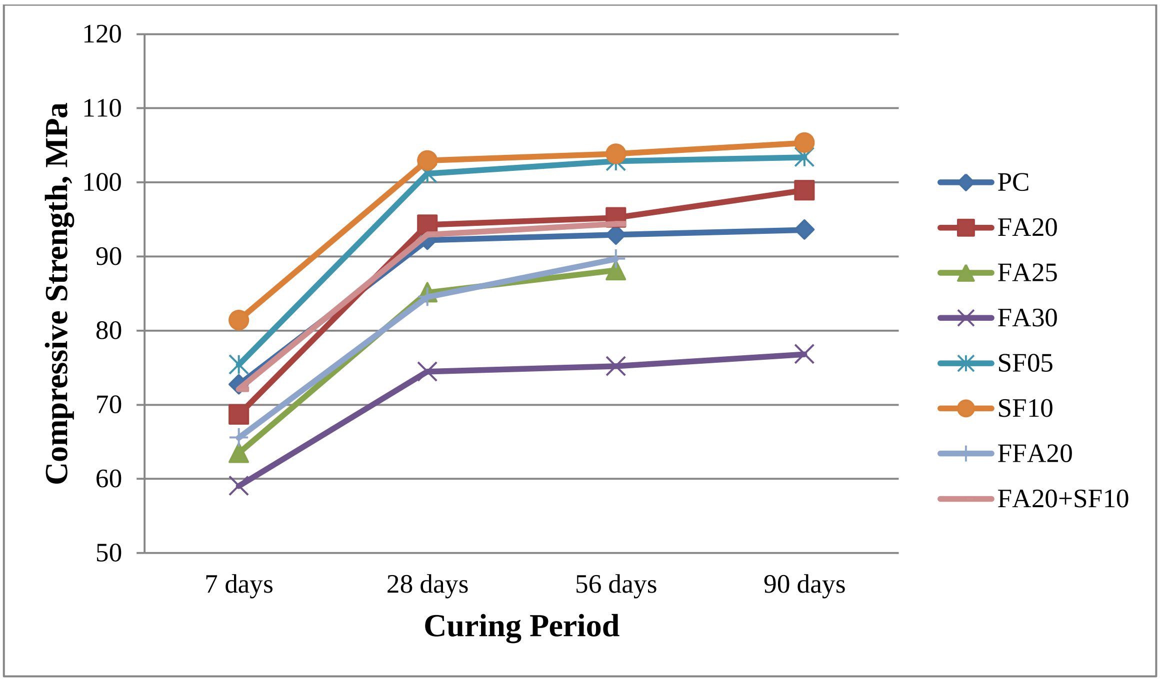
Table 4.14: Comparison of compressive strength at different ages

Mix	7-days Mean Compressive Strength MPa	28-days Mean Compressive Strength MPa	56-days Mean Compressive Strength MPa	90-days Mean Compressive Strength MPa
PC	72.71	92.20	92.93	93.60
Fl.20	68.65	91.70	95.22	98.91
Fl.25	63.48	82.57	88.14	-
Fl.30	59.03	74.45	75.19	76.80
SF05	75.39	101.18	102.85	103.39
SF10	81.40	102.93	103.83	105.32
FFl.20	65.55	84.52	89.67	-
Fl.20+SF10	72.08	92.95	94.39	-

It is observed that for concrete having both Fl. and SF as supplementary cementing material has an intermediate value of slump. This is due to the combined effect of Fl and SF.

Table 4.14 shows the mean compressive strength of all the mixes at different ages. The deviation of the test samples from the mean value is within 10%. The compressive strength results show that using supplementary cementing material having particle sizes smaller than cement, improves particle packing in concrete resulting in an increased overall strength gain. The results show that concrete having Fl. possess lower early age strength but larger gain in strength with time up to 90 days. Whereas, concrete mixes containing SF show early strength gain i.e., up to 28 days.

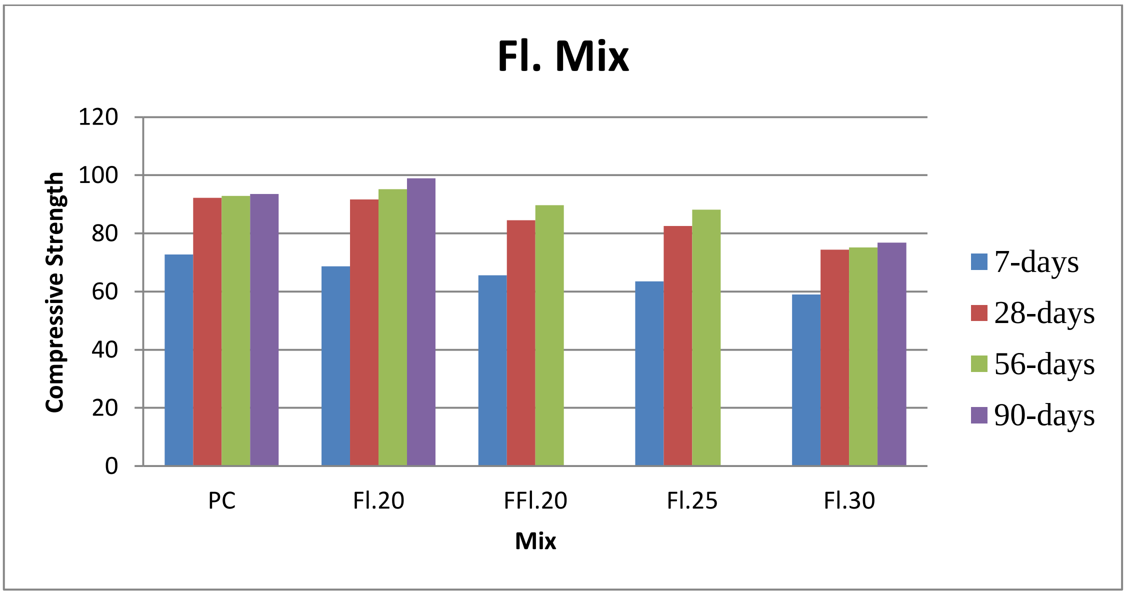
Graph 4.6 shows the gain in compressive strength of different mixes at four different curing periods. On comparing the results for mixes containing Fl., it is found that mix with 20 % replacement shows the maximum gain of strength whereas 30 % replacement shows the least. So based on this study we can conclude optimum percentage of cement replacement by Fl. is obtained to be 20%. Second thing to be noted is that, if same amount of cement is replaced with Fine Fl. (FFl.) the results for workability goes down.



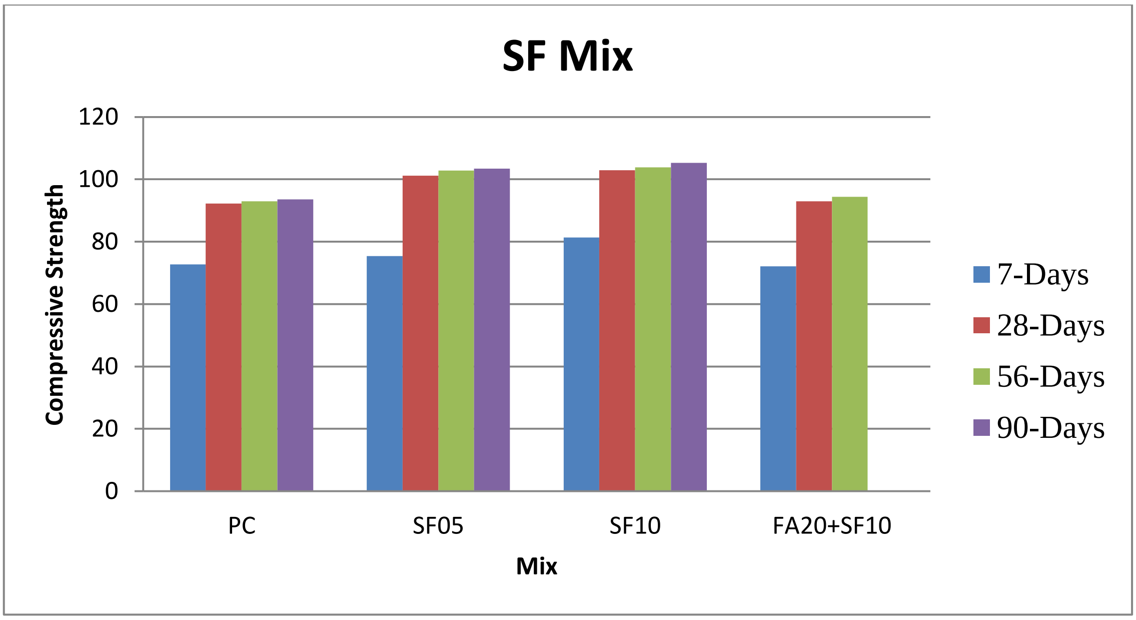
Graph 4.6: Comparison of compressive strength for different mixes at different ages

When we compare the results for mixes containing SF, we observe that both mixes show an early strength gain as well as increased long term strength. However, mix having 10 % SF shows maximum compressive strength at 7 days and comparable value to 5% SF 28 days onwards. But, mix of 10% SF possessed least slump value also.

The results in Table 4.14, graph 4.7 and 4.8 give trend of strength gain at different ages for plain, Fl. and SF concrete mixes.



Graph 4.7: Strength gain of fly ash concrete



Graph 4.8: Strength gain of silica fume concrete

4.6.3 Cost Analysis

From practicability point of view it is essential to conduct a cost analysis of all the mixes. In order to determine the cost for HSC mixes the market values of the materials, as shown in Table 4.15 were considered:

Table 4.15: Material price

Material	Market price	Cost per kg
Cement	275 Rs./bag of 50 kg	5.5
SF	900 Rs./bag of 25 kg	36
Superplasticizer	Variable	100
CA-I	600 Rs./m^3 (1500 kg/m^3)	0.40
CA-II	500 Rs./m^3 (1550 kg/m^3)	0.32
Sand	1200 Rs./m^3((1650 kg/m^3)	0.73

Table 4.16 illustrates the comparison of 7 days, 28 days, 56 days and 90 days mean compressive strength and cost of different concrete mixes per cubic meter. Fly ash is available at very cheap price so its price is not considered in calculation instead an approximate value of 100 Rs. is added per cubic meter of concrete.

Though from strength point of view SF10 gives the highest result at 7 days and comparable strength to SF05 at 28 days onwards but it is not at all economical. FA20 mix can be considered as most feasible HSC mix from all the aspects considering strength, workability and cost as well. If early high strength is required then SF mix and comparable strength to PC at 7 days with higher later strength then ternary blended concrete is the next best option.

Table 4.16: Cost comparison

Mix	7-days Mean Compressive Strength MPa	28 days mean compressive strength	56-days Mean Compressive Strength MPa	90-days Mean Compressive Strength MPa	Cost Rs./m^3
PC	72.71	92.20	92.93	93.60	5745.00
Fl.20	68.65	91.70	95.22	98.91	5008.00
Fl.25	63.48	82.57	88.14	-	4812.00
Fl.30	59.03	74.45	75.19	76.80	4633.00
SF05	75.39	101.18	102.85	103.39	6794.00
SF10	81.40	102.93	103.83	105.32	7601.00
FFl.20	65.55	84.52	89.67	-	5008.00
Fl.20+SF10	72.08	92.95	94.39	-	5775.00

CHAPTER 5
CONCLUSION

5.1 Conclusions

Based on the findings of experimental work conducted on various concrete mixes the following conclusions have been drawn:

1. The optimum percentage of Fl. replacement as mineral admixture for maximum compressive strength of HSC is 20 percent.

2. With increase in percentage of Fl. replacement upto 30%, the workability of mix increases for constant dosage of superplasticizer.

3. Early age strength gain decreases in Fl. concrete, however long term strength gain is high.

4. The optimum percentage of replacement of cement by SF from the point of view of maximum compressive strength is 5%. 10 % SF gives higher early age strength only.

5. Workability of concrete mix reduces with increasing percentage of SF.

6. Rapid early strength gain is observed in concrete mixes containing larger quantity of SF.

7. Ternary blended concrete containing 20% FA and 10% SF with cement content of 445 kg/m^3, achieved compressive strength equivalent to mix having cement content of 635 kg/m^3 with even higher workability.

8. Considering technical feasibility, practicability and economy Fl.20 mix is the most appropriate option for HSC.

9. IS: 456-2000 recommends up to M55 grade concrete with maximum cement content of 450 kg/m^3 while one can develop a concrete of >90 MPa with this cement content.

5.2 Future Scope

In this study prime focus has been laid on the compressive strength and workability aspect of HSC. Still other properties such as durability, modulus of elasticity, initial surface absorption, permeability and few others remain to be investigated. Also, other supplementary cementing materials like metakaolin, rice husk ash, waste fiber glass and others can be utilized in order to improve the effectiveness of concrete.

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