DESIGN AND EXPERIMENTAL INVESTIGATION ON HIGH STRENGTH CONCRETE USING FLYASH AND SILICA FUME

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ABSTRACT

This study presents the design and results of experimental work on compressive strength and workability of High Strength Concrete (HSC) using flyash and silica fume as mineral admixtures following guidelines of IS: 10262-2009. The aim of study was to design high strength concrete having compressive strength of above 90 MPa and good workability by varying percentage of two different mineral admixtures.

The work focussed on concrete mixes having a constant total binder content of 635 kg/m3 at constant dosage of super-plasticizer. The compressive strength tests were conducted up an age of 90 days. Total eight mixes were cast having 0, 20%, 25%, and 30 % flyash and 5% and 10% silica fume. One mix contained fine flyash in order to investigate its effect on properties of concrete. Apart from these, one ternary blended concrete mix having both flyash and silica fume together with 20% and 10% respectively was also studied.

The findings of this research indicate that both flyash and silica fume play a significant role in the long term gain of strength in concrete. Flyash reduces the early age strength gain whereas silica fume sue to its high reactivity, rapidly enhances the early strength gain in concrete. On one hand, addition of flyash increases the workability of mix while on the other hand addition of silica fume follows a reverse trend. Also the ternary blended concrete mix produced satisfactory results with intermediate workability and compressive strength comparable to plain mix having cement content of 635 kg/m^3.

Keywords: high strength concrete, flyash, silica fume, ternary blend concrete, workability and compressive strength.

Introduction

The use of concrete as structural material is favoured by its mechanical properties, mainly compressive strength because other properties are related with it. Hence, compressive strength of the concrete is the most important parameter to assess its quality. High Strength Concrete (HSC) mixes are generally characterised by low water/binder ratio, high consumption of cement and presence of various chemical and mineral admixtures, which are used to improve the workability of concrete at low water/binder ratio and to give supplementary strength by reacting with liberated free lime on hydration of cement, in presence of moisture at ambient temperatures.

The cost of land is going higher and higher, therefore providing closed space at affordable price can be achieved only by multi-storeyed buildings. As the height of building increases, use of high strength concrete becomes unavoidable. Because large member sizes of conventional concrete not only consumes more concrete means reducing the usable space but also increases self weight of the structure. For a building of specified floor area and type of use, fixes its total imposed load, while use of High Strength Concrete (HSC) reduces self weight and seismic weight of structure. This reduction in self weight is not only requires smaller size of members and lighter foundation for the building but also reducing the seismic force (disturbing force) during an earthquake. In other words, one can say that for tall buildings use of High Strength Concrete is mandatory.

In such situations, one should not only be able to produce High Strength Concrete but also economically and with greater confidence. So in present time, it is not sufficient to say that many persons have already produced it, therefore one is not required to produce it again. But, it is the need of time that all of us should be able to produce it at smallest cost, of smaller variability and with greater confidence.

It is possible to make concrete of compressive strength up to 120 MPa by improving the strength of cement paste, which can be controlled through the choice of good aggregate, water content, water/binder ratio, type and dosage of admixtures.

Literature Review

Rashid and Mansur [1] gave a review of literature on the requirements of ingredient materials for production of high strength concrete (HSC) along with the results of their experimental study on achieving HSC. In their experimental study, the targeted strengths of concretes were from 60MPa to 130 MPa. The variables considered by them were water-binder ratio (from 0.34 to 0.20) and super-plasticizer binder ratio (from 0.37% to 2.95%).

Zain et. al. [2] investigated possibility of developing High Performance Concrete (HPC) using silica fume (SF) at relatively high water cement ratio (i.e. 0.45 and 0.50). The test specimens were air and water cured. The mechanical properties like compressive strength, modulus of elasticity and initial surface absorption of hardened concrete were determined. They found that SF concrete subjected to dry air at 35^0C after 14 days of initial water curing produced the highest compressive strength and dynamic modulus of elasticity when continuously cured under water at 20^0C.

Vinayagam [3] formulated a simplified mix design procedure for HPC by combining BIS and ACI code procedures of mix design and available literature on HPC. Based on this, mixes of compressive strength of 80 MPa and 100 MPa were arrived at. These mixes were tested experimentally for compression, split tension, flexure and workability. The study revealed that optimum percentage of cement replacement by SF is 10% for achieving maximum compressive, split tensile and flexural strengths and elastic modulus. The ratio of 7days to 28 days compressive strength was varying from 0.75 to 0.80. The use of SF in concrete reduces workability.

Brooks et. al. [4] studied the effect of silica fume (SF), metakaolin (MK), flyash and ground granulated blast furnace slag (GGBFS) on setting times of high strength concretes using the penetration resistance method. The effect of shrinkage reducing admixture (SRA) on setting time of normal and high strength concrete was also investigated. They concluded that general effect of SF, MK, flyash and GGBFS is to retard the setting time of high strength concrete. SRA has negligible effect on setting time of normal strength concrete but has a significant retarding effect when used in combination with super-plasticizer in high strength concrete. Increasing level of SF, MK, flyash and GGBFS has higher retardation in setting time of high strength concrete.

Mazloom et. al. [5] analysed short and long term mechanical properties of high strength concretes of varying level of silica fume. They fixed water/binder ratio and binder contents and studied workability, development of compressive strength, secant modulus of elasticity, strain due to creep, shrinkage, swelling and moisture movement. They concluded that a concrete of slump 100 ± 10 mm with higher replacement of cement with silica fume tends to require higher dosage of super-plasticizer. Also, 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 class F fine flyash, which was passing 99% on 45μ sieve to produce workable high strength concrete. The cement replacement by the flyash was 0, 10 and 15%. The mixtures were tested for workability and strength. At 10% replacement of cement by flyash, it was possible to reduce the mixing water by 35% to produce a concrete of similar workability. At 15% replacement level, there was a rapid reduction in the workability of concrete. The concrete at 10% replacement exhibited higher early strength followed by an excellent development of strength over time. It demonstrated 20% higher strength with reference to control concrete.

Alves et. al. [7] studied the influence of different mixing methods on production of HSC. Four different methods were chosen to execute in accordance with the criteria of practicability, cost, material consumption and technical suitability. These methods were IPT/ EPUSP method, the Mehta/ Aitcin method, the Toralles Carbonari method and the Aitcin method. The study concluded that there is a significant difference between producing HSC as per HSC specific proportioning methods and proportioning of conventional concrete. Material consumption per cubic meter of concrete, particularly cement varies considerably from one method to another. Also concerning cost per cubic meter of HSC.

Del Viso et.al. [8] studied the shape and size effects of specimens on the compressive strength of HSC. Cube and cylindrical specimens of different sizes were prepared and tests were performed at a single axial strain rate of 10^{-6} per second. The study revealed that post-peak behaviour in cubes is milder as compared to that of cylinders. In cylindrical specimens, a main inclined fracture surface is nucleated, while in cubes, spalling of lateral sides leading to hourglass shaped failure mode is observed. The size effect in cubes is more prominent and large sizes resist less stress.

Oner et. al. [9] carried out study on development of strength containing flyash and determined optimum use of flyash. A total of 28 mixes were proportioned. Four control mixes of 250, 300, 350 and 400 kg/m^3 of cement content were kept as base and six different percentages of cement replacement by flyash were studied. The research concluded that strength of mix increased up to a certain optimum percentage of flyash replacement and thereafter decreased.

Bhanja and Sengupta [10] developed a mathematical model to predict 28-days compressive strength of silica fume concrete using statistical methods. Strength results of 26 concrete mixes were analysed, which were having water/cement ratio between 0.30 to 0.42 and silica fume between 5 to 30%.The validity of model was checked with test results of previous researchers also.

Zhou et. al. [11] studied the 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 day compressive strength of about 90 MPa with normal aggregate was found to be drastically reduced, as expected by the weaker aggregates and also about 9% by the stronger aggregates.

Naik and Bruce [12] presented results of research conducted on a precast/ prestressed concrete plant to identify optimum mix proportions for production of high early strength concrete with high flyash contents. Compressive strength, workability and water demand results are presented. Concrete mix using type C flyash up to 30% replacement can be used to produce high early strength concrete for precast/ prestressed products.

Theoretical Approach

There are four main complex oxides present in cement, which are tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A) and tetracalcium alumino ferrite (C_4AF). The first two complex oxides contribute to strength of cement. Of these first two, tricalcium silicate contributes to early age strength while dicalcium silicate contributes to later age strength. The variation of these two complex oxides controls rate of gain of strength in plain concretes. Higher the grade of cement means larger the percentage of tricalcium silicate in it. In cements, even in unhydrated form, some free lime is available.

High Strength Concrete (HSC) needs more quantity of cement for production of a unit cubic meter of concrete in comparison of conventional concrete. In HSC, we take care of gain of later age strength. On hydration, tricalcium silicate liberates more free lime in hydrated form than the dicalcium silicate as given below:

$$2\,C_3S + 6\,H = C_3S_2H_3 + 3\,CH$$
$$2\,C_2S + 4\,H = C_3S_2H_3 + CH$$

Where C, S, H, $C_3S_2H_3$ and CH represents CaO (lime), SiO_2 (silica), H_2O (water), calcium silicate hydrate gel (a strength giving compound) and Ca $(OH)_2$ i.e. hydrated lime respectively.

This liberated free lime along with available free lime of unhydrated form of cement makes the total free lime available in concrete. The higher cement content in HSC provides larger content of total free lime in the concrete. Therefore, taking the benefit of this total free lime in HSC improves the efficiency of cement in HSC.

Pozzolanas are siliceous or siliceous and aluminous materials that may or may not have cementitious property, but in finely grounded form and in presence of moisture react with calcium hydroxide (i.e. hydrated free lime) at ambient temperature. Fineness of these materials accelerates the pozzolanic reactivity means finer a pozzolanic material faster is reaction. The most commonly used pozzolanic materials are flyash, silica fume, metakaolin, ground granulated blast furnace slag and others. The pozzolanic reaction is given below:

$$\text{Pozzolana } [2.SiO_2] + 3\ CH = C_3S_2H_3 \text{ or C-S-H}$$

Where C-S-H is calcium silicate hydrate gel, which gives strength to concrete.

From the above, it is clear that one will get more additional strength from pozzolanic reaction, if one is using high grade cement that means more tri-Calcium Silicate in it.

Experimental Investigation

Materials

Ordinary Portland Cement (OPC) 53 grade conforming to IS: 269-2015 [13] along with flyash and silica fume was used, latter as cementitious materials. Two size of coarse aggregate (i.e. 20 mm down and 10 mm down) along with natural sand were used as aggregates. Super-plasticizer (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 ASTM C-1240 [14] was used. Normal tap water was used for mixing and curing purposes.

Materials testing

Sieve analysis tests were conducted on both type of coarse aggregates and results are given in Tables 1 and 2. CA-1 and CA-2 were mixed in 1: 0.908 proportions. Flakiness index and elongation index (as shown in Figs. 1 and 2) of the coarse aggregate were determined in accordance with IS: 2386(Part 1)-1963 [15] and were found as 28.3% and 32.8% respectively. The specific gravity and water absorption of coarse aggregate was also determined in accordance with IS: 2386(Part3)-1963 [16] and was found as 2.878 and 0.72% respectively. The impact value of the aggregate was found as 17.5%.

Table - 1 Sieve analysis test results for coarse aggregate (CA-1)

Sieve size (mm)	Weight retained (g)	% Weight retained	Cumulative % weight 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	-	-

Table - 2 Sieve analysis test results for coarse aggregate (CA-2)

Sieve size (mm)	Weight retained (g)	% Weight retained	Cumulative % weight retained	% passing
12.5	0	0	0	100
10	81.2	8.12	8.12	91.88
4.75	806.6	80.66	88.78	11.22
2.36	81.3	8.13	96.91	3.09
Pan	30.9	3.09	-	-

Fig. 1 Metal gauge for flakiness index

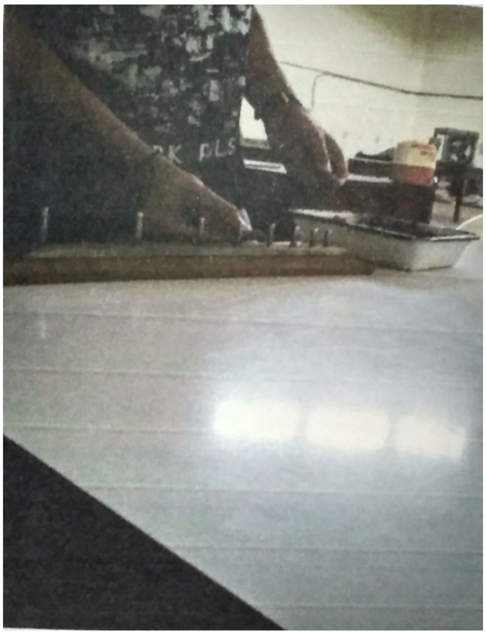

Fig.2 Length gauge for elongation index

The grading of fine aggregate was determined in accordance with IS: 2386 (Part 1)-1963 and was found as grading zone I in accordance with IS: 383- 2016 [17]. The sieve analysis test results of fine aggregate are given in Table 3. A view of fine aggregate is shown in Fig. 3. Specific gravity and water absorption (Fig. 4) of the aggregate were determined in accordance with IS: 2386(Part 3) – 1963 and were found as 2.77 and 1.0% respectively.

Fineness of cement was determined in accordance with IS: 4031 (Part 1)-1996 [18] and residue found on 90μ sieve was 5%. Standard consistency of cement was determined in accordance with IS: 4031(Part 4)-1988 [19] and was found as 29%. Initial and final setting times of cement were determined in accordance with IS: 4031(Part 5)-1988 [20] and were found as 72 minute (> 30 minute) and 266 minute (< 600 minute). Specific gravity of cement was determined by Le Chatelier's flask in accordance with IS: 4031 (Part 11)-1988 [21] and was found as 3.15.

Fig. 3 Fine aggregate having F.M. 3.34

Fig. 4 Use of Pyconometer for specific gravity

Table-3 Sieve analysis test results of fine aggregate

Sieve size (mm)	Weight retained (g)	% Weight retained	Cumulative % weight 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	48.30	51.70
0.6	253.5	25.35	73.65	26.35
0.3	172.4	17.24	90.89	9.11
0.15	66	6.60	97.49	2.51
Pan	25.1	-	-	-
Fineness modulus = Σ cumulative % of weight retained / 100 = 3.34				

Flyash was conforming to IS: 3812 (Part 1)-2003 [22]. Specific gravity of mineral admixtures were determined in accordance with IS: 4031 (Part 11)-1988 and were found as 1.92 and 2.20 for flyash and silica fume respectively, while specific gravity of super-plasticizer was 1.10, as provided by the manufacturer.

Chemical compositions of OPC and silica fume are given in Table -4.

Table-4 Chemical compositions of the cement and silica fume

Name of constituent	Cement	Silica fume
SiO_2	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
Loss on ignition	1.10	1.53
Fineness (specific surface)	$410 m^2/kg$	$14000 m^2/kg$

Mix design

As the study was focussed on the design of HSC having compressive strength of above 90 MPa for which sufficient test results were not available. Therefore, highest value of standard deviation was adopted from Table 1 of IS: 10262-2009 [23] to achieve the target mean strength from the characteristic strength of the mix.

Water binder ratio

The water binder ratio for the design of HSC was chosen from proposed curve for compressive strength versus water binder ratio [3] and from IS: 456-2000 [24] with reference to durability, smaller of the two was adopted.

Water content

Water content of concrete is influenced by a number of factors like size of aggregate, shape of aggregate, required workability, water binder ratio, type and quantity of supplementary cementitious material, type and dosage of super-plasticizer and environmental conditions. Use of super-plasticizer reduces the water demand. Whereas, increased temperature, cement content, slump, aggregate angularity and decrease in water binder ratio and in the proportion of coarse aggregate to fine aggregate increase water demand. The quantity of maximum water per unit volume of concrete was determined from Table 2 of IS: 10262 - 2009 corresponding to angular coarse aggregate and for 25 mm to 50 mm slump range. Adjustments in quantity of water were made for required slump of 50 mm to 100 mm and use of super-plasticizer.

Calculation of binder content

The binder or cementitious contents per m^3 of concrete were calculated from already decided water/binder ratio and the quantity of water content per m^3 of concrete. Assuming the percentage replacement of cement by silica fume (5% and 10%) and by flyash (20%, 25% and 30%), the quantity of silica fume and flyash were determined from total binder content. The remaining binder content was OPC. The cement content so calculated was checked against the requirement of minimum cement content from durability in accordance with IS: 456-2000 and greater of the two was adopted. As this study was mainly focussed on design of HSC of compressive strength above 90 MPa, so maximum cement content limit of 450 kg/m^3 in concrete has been dis-regarded for some trial mixes due to its applicability up to M55concrete as referred in IS: 456-2000..

Estimation of coarse aggregate proportion

Aggregate essentially of the same nominal maximum size, type and grading produce concrete of satisfactory workability, if it is used for specified volume of coarse aggregate, in a unit volume of concrete. Approximate values for this aggregate volume corresponding to nominal maximum size and grading zone of fine aggregate are chosen from Table 2 of IS: 10262-2009.

Estimation of fine aggregate proportion

After following all above steps, now determination of quantities coarse aggregate and fine aggregate remains only. In order to determine their values, combine absolute volume of total cementitious material, water and chemical admixture were calculated by dividing their respective masses with their specific gravity and multiply it with a factor of 1/1000. These values were then subtracted from unit volume of concrete. After this, what left were the absolute combined volumes of coarse and fine aggregates. Thereafter, this volume was divided, depending upon the proportion of coarse aggregate as determined in previous step. The quantities of coarse and fine aggregates were determined by multiplying their respective volume with their respective specific gravity and 1000.

Mix proportions

Total eight mix proportions were investigated in the present study. One control mix and seven other mixes were designed for various percent of cement replacement with different cementitious materials. For easy understanding of the content of mixes, instead of designating by numbers, they were designated by alphanumeric values. The first two letters i.e. PC or Fl or SF of FF tells about the binder material and last two digits show the percentage replacement of cement. So PC means plain concrete without any replacement of cement, Fl20 denotes the mix in which 20% of cement is replaced by flyash, whereas SF10 denotes concrete having 10% replacement of cement by silica fume and FF20 denotes a mix in which 20% cement replaced with fine flyash (i.e. >99% passing from 45 micron sieve). The details of quantities required per m^3 of concrete for all mixes are given in Table 5.

Table-5 Details of quantities required for various mixes

Mix	Cement (kg/m^3)	Flyash (kg/m^3)	Silica fume (kg/m^3)	Water/ binder	Water (kg/m^3)	Chemical admixture (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate-1 (kg/m^3)	Coarse aggregate - 2 (kg/m^3)
PC	635	-	-	0.220	140	11.43	717	607	551
Fl20	510	125	-	0.210	135	11.43	690	572	504
Fl25	475	160	-	0.220	140	11.43	687	569	502
Fl30	445	190	-	0.226	144	11.43	676	560	494
SF05	600	-	35	0.210	135	11.43	714	591	521
SF10	570	-	65	0.220	140	11.43	708	586	517
FF20	510	125	-	0.220	140	11.43	690	572	504
Fl20 + SF10	445	125	65	0.233	148	11.43	676	560	494

Test Results

Slump

Slump values obtained for various concrete mixes follow a definite trend as shown in Table-6. For the mixes having flyash as mineral admixture show an increase in the slump values with an increase in the percentage of replacement of cement. Whereas, a reverse trend is followed in case of mixes having silica fume as mineral admixture, with an increase in percentage replacement of the cement by silica fume, the slump decreases., It was also noted that for same percentage of replacement of cement by flyash of 20%, the slump value is lesser for mix containing fine flyash.

It is observed that the replacement of cement with flyash in concrete increases its workability keeping dosage of super-plasticizer constant. But, same replacement with relatively finer flyash gives smaller improvement in workability. While, replacement of cement with silica fume in concrete decreases its workability despite of keeping dosage of super-plasticizer constant.

It is also observed that concrete having both flyash and silica fume as cement replacement has an intermediate value of slump.

Compressive strength

Compressive strength of concretes was determined by testing of 150 mm cube specimens at specified ages after curing them in water. Table-6 shows mean compressive strength of all mixes at different ages. The variations of individual specimens were within 10% of mean values.

Cost analysis

From adoptability point of view, it is essential to have a cost analysis of all the mixes. In this regard, to determine the cost of all high strength concrete mixes, the market value of constituent materials were considered. The cost of cement, silica fume, super-plasticizer, coarse aggregate-1, coarse aggregate-2 and fine aggregate were considered as Rs. 275 per bag of 50 kg, Rs. 900 per bag of 25 kg, Rs. 100 per kg, Rs. 600 per m^3, Rs. 500 per m^3 and Rs. 1200 per m^3 respectively. Flyash is available at free of cost, so only Rs. 100 per cubic meter of concrete were added against its transportation cost.

Table-6 Test results

Mix	Slump (mm)	Mean compressive strength (MPa)				Cost (Rs./m^3)
		7-days	28-days	56-days	90-days	
PC	85	72.71	92.20	92.93	93.60	5745.00
Fl20	135	68.65	91.70	95.22	98.91	5008.00
Fl25	155	63.48	82.57	88.14	*	4812.00
Fl30	170	59.03	74.45	75.19	76.80	4633.00
SF05	80	75.39	101.18	102.85	103.39	6794.00
SF10	65	81.40	102.93	103.83	105.32	7601.00
FF20	115	65.55	84.52	89.67	*	5008.00
Fl2+ SF10	95	72.08	92.95	94.39	*	5775.00

* Results not available.

Discussion

In plain concrete (PC) mix, quantity of water required in concrete is used in hydration of cement and wetting the surface of aggregates to reduce surface friction on aggregates. The latter use of water control workability of concrete. As the cement is replaced with flyash in subsequent concrete mixes (Fl20, Fl 25 and Fl30), the water used by the replaced cement is available in concrete, which is larger than the quantity of water required to wet the surface of flyash, hence improvement in workability of flaysh concrete is recorded. Higher the replacement of cement by flyash (like in Fl30), highest the slump is recorded. But, if the same percent of cement is replaced with conventional and relatively finer flysah (Fl20 and FF20), concrete prepared with finer flyash (i.e. FF20) is showing relatively smaller slump due to larger surface area of finer flyash.

Silica fume is very fine in comparison to flyash, therefore, even 5% replacement of cement with silica fume reduces slump of concrete with reference to plain concrete, which means the quantity of water required to wet the surface of silica fume particles is larger than the water required for the hydration of replaced quantity of cement. Hence slump of silica fume concrete reduced. Higher the replacements of cement with silica fume in concrete, larger the reduction in slump.

Compressive strength test results show that using supplementary cementitious material having particle size smaller than cement, improves particle packing in concrete resulting in an increased overall strength gain. The results also show that concrete having flyash possess lower early age strength but larger gain in strength with time up to 90 days. Whereas, concrete mixes containing silica fume show early strength gain i.e. up to 28 days.

Table-6 shows gain in compressive strength of different mixes at four different curing periods. On comparing the results for mixes containing flyash, 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 that optimum percentage of cement replacement by flyash is obtained as 20%. The next point is that if same amount of cement is replaced with fine flyash, the results for workability and compressive strength both go down.

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

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

Conclusions

1. The optimum percentage of cement replacement by flyash, as mineral admixture for maximum compressive strength in High Strength Concrete is 20%. Flyash replacement beyond this level and up to 30% level, increases workability of the mix only for a constant dose of super-plasticizer.
2. Cement replacement by flyash decreases early rate of gain of strength along with increase in long term gain of strength.
3. Optimum percentage of cement replacement by silica fume is 5%, while 10% replacement gave higher early age (i.e. rapid) strength only. Increase in percentage level of silica fume in concrete reduces workability of the concrete.
4. In a ternary blended concrete, containing 20% flyash and 10% Silica fume with cement content of 445 kg/m^3, a comparable compressive strength along with better workability was achieved, otherwise which could be achieved with a cement content of 635 kg/m^3.

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