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A Review on the Effect of Partial Replacement of Cement by Silica Fume on Hardened Concrete

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Abstract:
Nowadays high strength and high performance concrete are being widely used in various civil engineering practices. Most applications of high strength concrete have been in high rise buildings, long span bridges and some special structural applications. The use of high strength concrete would result in both technical and economical advantage. In high strength concrete it is necessary to reduce the water binder ratio, which in turn will increase the binder content. Superplasticizers are used to achieve the desired workability. There are two types of mineral admixtures which are commonly mixed into the Portland clinker or blended directly with cement nowadays. They can be categorized as crystalline, which are also known as hydraulically inactive additions and pozzolanic which are hydraulically active additions. Silica fume is one of the popular pozzolans used in concrete to get improved properties. The use of silica fume in conjunction with superplasticizers has become the backbone of high strength and high performance concrete. Silica fume is very reactive pozzolan, which is used in concrete because of its fine particles, large surface area and high SiO_2 content. A detailed experimental investigation has been carried out to study the effect of silica fume in conjunction with superplasticizers on the strength parameters of concrete. The investigation revealed that the use of silica fume improved the mechanical properties of high strength concrete and thus may be used as a partial replacement of cement.

Key words: *High strength concrete, silica fume, water binder ratio, compressive strength, mix proportions etc.*

1. Introduction

Concrete production exists around the globe and is one of the leading construction material, essentially man made stone that has become a more versatile and universally recognised tool to build wealth. Concrete is a widely used structural material which essentially consists of a binder and a mineral filler. It has the unique distinction of being the only construction material which is manufactured actually on the site, whereas other materials are merely shaped and fabricated and eventually assembled on site. Ever since the time of the Romans, there has been a continuous effort by the research workers in the field of cement and concrete technology to produce better quality cement resulting in concretes in overall improved quality. The introduction of reinforced concrete as an alternative to steel construction, in the beginning of the 20th century, necessitated the development and use of low and medium strength concretes. In keeping with the demands of the nuclear age, high density concrete has been successfully used for the radiation shielding of highly active nuclear reactors. Considerable progress has been achieved in the design and use of structural light weight concretes, which have the dual advantage of reduced density coupled with increased thermal insulation. With the present state of knowledge in the field of concrete mix design, it is possible to select and design concrete capable of resisting heat, sea water, frost and chemical attack arising out of industrial effluents.

When the concrete was first adopted as a structural material during the nineteenth century, compressive strength was perhaps the only criterion in the proportioning of a concrete mix. The concept of durability, workability and other factors influencing the mix proportions, as they are understood now, are of comparatively recent origin. The strength of concrete was supposed to improve with the increase in the quantity of cement and with better compaction. High strength concrete refers to concrete that has a uniaxial compressive strength greater than the normal strength concrete obtained in a particular region.

High strength and high performance concrete are being widely used throughout the globe and in the production of these concretes it is necessary to reduce the water/binder ratio with the subsequent increase in the binder content. High strength concrete refers to good abrasion, impact and cavitation resistance. The deterioration and premature failure of concrete structures such as marine structures, concrete bridge deck etc. has lead to the developement of high performance concrete. The high performance concrete is defined as the high-tech concrete whose properties have been altered to satisfy specific engineering properties such as high workability, very high strength, high toughness and high durability to severe exposure condition.

Nowadays silica fume is almost invariably used in the production of High Performance Concretes. In future, high range water reducing admixtures (Superplasticizers) will open up new possibilities for the use of such material as partial replacement of cement to produce and develop high strength concrete, as some of them are much finer than cement. The existing literature is rich in information on silica fume concrete and after performing a detail review of the research papers published over the last two decades, the objective of the present study was framed. The present investigation is an effort towards developing a better insight into the isolated effect of silica fume on the different strength parameters of silica fume concrete over a wide range of water cementitious material ratio ranging from 0.30 to 0.42 and silica fume replacement percentages of 0, 5, 10 and 15 by weight of total binder with high range water reducing admixtures for optimizing its effect on concrete.

The results indicate that there is a remarkable increase in the compressive strength of concrete with respect to control on replacement of cement by silica fume. The optimum level of replacement depended on the water cement ratio and age of testing and it was obtained in the range of 10-12%.

2. Aims and Objectives

The use of silica fume in combination with a superplasticizer is nowadays a usual way to obtain high strength concrete. The effect of silica fume in concrete have attracted the attention of researchers throughout the world.

Based on the guidelines of the previous work and need for further research to explore the ever expanding field of silica fume concrete, the following objectives are outlined:

- To study the isolated effect of silica fume in concrete keeping other mix design factors almost constant. Cement will be replaced by silica fume over a wide range of water/binder ratios and replacement percentages. As the mix design factors remains almost unchanged, the changes in concrete properties will occur primarily due to silica fume replacements. Since the SP contents of all the mix will be kept constant, to eliminate the interference of workability, the compaction energy will be varied for obtaining proper compaction. The time of compaction will vary, more for stiff concretes and less for flowing concretes.
- To determine the influence of microsilica on the compressive strength of concrete, rate of evolution of strength and percentage gains with respect to control concrete.

3. Significance of the Present Research Work

There are many important parameters which needs to be explored in detail. The isolated effect of silica fume in concrete and the optimum silica fume replacement percentage still calls for detailed investigations to ensure the maximum utilization of silica fume in concrete. The present work aims at a deeper insight into the effect of cement replacement by silica fume in concrete over a wide range of water-cementitious material ratios and silica fume replacement percentages.

4. Materials and Procedures

This section describes the characteristics of the materials used in the present investigation. The reason for the selection of the materials are also mentioned.

- **Cement:** Cement used was 43 Grade Ordinary Portland Cement (Manufacturer's Name- Ultra Tech) conforming to IS:12269-1987.
- **Silica Fume:** Silica Fume (Grade-920D) was obtained from Elkem India Private Limited, Mumbai, India.
- **Fine Aggregates:** For the production of strong durable concrete, good quality sand should be used. Due to incorporation of silica fume, the volume of fines in the concrete will be high. Use of Zone II sand has been found to be beneficial with regard to workability. Due to scarcity of Zone II sand in this eastern part of India, sand of Zone III as per IS: 383 was used for controlling the workability of resultant mixes.
- **Coarse Aggregates:** Though aggregates smaller than 12.5 mm is recommended for HSC, 20 mm coarse aggregates are the most commonly used aggregate for the variety of applications in the general concrete construction. Hence to cater for the application in most of the works dealing with HSC, 20 mm graded aggregates have been taken into consideration. 12.5mm aggregates and 20mm aggregates are mixed in the ratio of 50:50 for obtaining maximum packing density.
- **Water:** Potable Water was used in the present investigations as per IS:456.
- **Superplasticizers:** Conplast SP-430 manufactured at Bangalore was used as a water reducing agent to achieve the required workability. It is available in brown liquid instantly dispenable in water. Conplast SP-430 complies with IS:9103 and BS:5075 Part-3 and ASTM-C-494 Type "F" as a high range water reducing admixture. It is a Sulphonate Napthalene Polymer instantly dispersible in water, having specific gravity 1.22.

The reasons for the selection of the ingredients are discussed below:

- Cement: Though in the present investigation no particular strength level was targeted, yet, to reach high strength levels, high strength cement having average 28 days strength of 43MPa was used.
- Coarse Aggregates: For production of high strength concrete smaller size aggregates should be used for effective bond between cement paste and aggregates. Hence 12.5mm aggregates and 20mm aggregates should be used in the ratio of 50:50 to obtain maximum packing density.
- Fine Aggregates: Zone II sand was used to control the workability of the resultant mixes.
- Silica Fume: A high quality very active silica fume, supplied by Elkem India Private Limited, Bombay, was used.
- Superplasticizers: Superplasticizers are almost invariably used in the production of High Strength Concrete with silica fume. Due to incorporation of a considerable amount of silica fume (cement was replaced by silica fume @0 to 15%) a

high dosage of superplasticizer was required as silica fume is extremely hydrophilic. Conplast SP-430 (Sulfonated Napthalene Formaldehyde Condensate) was used to improve the cohesiveness and slump.

5. Experimental Procedure

The present research is aimed at investigating the effect of silica fume on the properties of concrete in the fresh and hardened state. Concrete at diffferent water/binder ratio ranging from 0.30 to 0.42 will be prepared. At each water/binder ratio, cement will be replaced by silica fume @0 to 15%. All the concretes will be tested in the fresh states as per relevant Indian Standards and their properties will be determined. Accordingly the effect of silica fume on cement replacements will be determined. The workability of the silica fume concretes depends on a host of parameters. The present investigation is aimed to determine the isolated effect of silica fume on concrete as a result of which the mix variables like quality of ingredients, mix proportions, curing conditions, dosage of SP etc. have been kept constant. The fundamentals of the present investigation is not to arrive at a particular strength or workability but to study the effect of silica fume on the rheological properties of concrete and to determine the optimum silica fume replacement percentage to maintain the desired workability, so as to satisfy most of the modern structural applications. Therefore the effect of cement replacement by silica fume was studied over a wide range of water/binder ratio (0.30 to 0.42) and over a wide range of cement replacements (0-15%).

6. Mix Proportion

According to Shah and Ahmad (1994) for proportioning of high strength concretes, mostly purely empirical procedures based on trial mixtures are used and the trial mix approach is best for proportioning high strength concretes. Any mix proportioning method for High Strength Concrete is yet to be universally accepted. The Indian Standard- "Recommended Guidelines for Concrete Mix Design"(IS-10262) is meant for the design of low to medium strength concretes but does not include the design of concrete mixes when pozzolans and admixtures are used. Therefore for arriving at the reference mix, the basic principles on which high strength concrete mix should be based were considered and the proportions of a number of mixes incorporating silica fume as reported in the literature were reviewed. Since the strength of silica fume concretes depend on a host of parameters, in order to study the effect of silica fume only, the others were to be kept constant. Hence the mix proportion as well as the dosage of SP were to be kept constant as in the reference mix. For High Strength Concrete the content of cementitious material is higher ranging from 500-650 kg/m^3 (Shah and Ahmad,1994). For the present investigation the binder content will be maintained at 525 kg/m^3. Coarse aggregate and fine aggregate were maintained at a ratio of 60:40 for obtaining the maximum packing density. The detailed mix proportion is presented in the table 01:

Mixes	W/B	Cement (Kg/m^3)	Silica Fume		Aggregates (Kg/m^3)		Water (Kg/m^3)
			%	(Kg/m^3)	Fine	Coarse	
SFC 01	.30	525	0	0	724	1086	157
SFC 02		498	5	26.2	720	1080	
SFC 03		472	10	52.5	716	1075	
SFC 04		446	15	78.7	712	1069	
SFC 05	.34	525	0	0	701	1052	178
SFC 06		498	5	26.2	698	1047	
SFC 07		472	10	52.5	694	1041	
SFC 08		446	15	78.7	690	1035	
SFC 09	.38	525	0	0	679	1019	199
SFC 10		498	5	26.2	675	1013	
SFC 11		472	10	52.5	672	1008	
SFC 12		446	15	78.7	667	1001	
SFC 13	.42	525	0	0	656	985	220
SFC 14		498	5	26.2	653	979	
SFC 15		472	10	52.5	649	973	
SFC 16		446	15	78.7	645	968	

Table 1: Detailed Mix Proportion

7. Specimens

The scheme of the experimentation spanned over 4 water-binder ratios, 4 silica fume replacement percentage at each of the 4 water-binder ratios. Hence a total of 16 mixes were to be evaluated. For the determination of compressive strength 150x150x150 mm cube specimens have been used.

8. Results and Discussion

In the present study, a detailed investigation was performed on the strength parameters of concrete over a range of water binder ratio. Silica Fume was used as a partial replacement of cement at different levels varying from 0 to 15%. Compressive strength test was carried out to investigate the mechanical properties of high strength concrete.

9. Hardened Concrete

In the present investigation compressive strength test were performed on silica fume concrete. For determination of strength at any particular age at least three specimens were tested. A total of 144 specimens were tested for the present experimental investigation spanning over 4 water-binder ratios (0.30, 0.34, 0.38 and 0.42). The database thus generated was analyzed to develop a better insight in to the effects of microsilica on concrete over a wide range of water cementitious material ratios and silica fume replacements.

9.1. Compressive Strength

Strengths were measured at 7, 28 and 90 days on samples of 150x150x150 mm cube specimens. The values of the compressive loads at failure at age levels of 7, 28 and 90 days have been presented in table. The tables depict the failure loads at various water cementitious material ratios (0.30, 0.34, 0.38 and 0.42) and at different silica fume replacement levels (0, 5, 10 and 15% by weight of cement). The corresponding compressive strengths (MPa) have been calculated and are presented in table 02.

W/B Ratio	Binder (Kg/m^3)	Silica Fume %	Compressive Strength (MPa)		
			7 Days	28 Days	90 Days
0.30	525	0	43	60	63
		5	46	66	70
		10	54	76	81
		15	45	65	68
0.34	525	0	38	53	60
		5	40	62	66
		10	48	68	71
		15	40	61	65
0.38	525	0	32	45	53
		5	35	53	58
		10	38	60	64
		15	35	58	62
0.42	525	0	28	42	48
		5	33	46	53
		10	37	52	59
		15	36	49	57

Table 2: Compressive Strength Results

9.2. Discussion

In order to explore the various aspects of silica fume concrete, the results of the present investigations will be analyzed in different sections as follows:

- Effect of silica fume on the compressive strength at different age levels.
- Effect of water-cementitious material ratios on the compressive strength at different ages.
- Variation of compressive strength with age.
- Rate of gain in compressive strength.
- Optimum silica fume replacement percentage.

9.3. Effect of Silica Fume on the Compressive Strength of Concrete

The 7 day compressive strength on 150x150x150 mm cube specimens have been plotted with respect to silica fume percentage as shown in the figure 01. The strength values at different water/binder ratios have been plotted at each silica fume replacement level. The figure shows that there is an increasing trend in the compressive strength as the silica fume content increases. This is clearly depicted in all the graphs for all the water/binder ratios and for all types of specimens. But at higher percentages of silica fume the trend takes a decreasing trend. For all the water cement ratios, compressive strength increased continuously from 0% to 10% silica fume replacement levels. For the minimum water/binder ratio of 0.30, maximum strength is obtained at 10% replacement level. Beyond that percentage the strength decreases at 15% replacement levels. Maximum 7 day compressive strength at 10% silica fume content was obtained at 54 MPa, which was reduced to 45 MPa at 15% replacement level for the minimum water binder ratio of 0.30. This effect is noted for all the specimens. At such a low value of water binder ratio and high percentage replacement of silica fume, the mix becomes very hard to compact. Hence the mixes might have suffered from improper compaction resulting in strength reduction.

For water cementitious material ratio of 0.34 and above the compressive strength of concrete increased upto 10% silica fume content. Even at high silica fume content, concrete mixes with water binder ratios of 0.34 and above had good workability (as indicated by the slump and compaction factor values) and as such achieving proper compaction was not difficult. At higher water/binder ratios, cement replacement by 10% silica fume has a beneficial effect on the 7 day compressive strength of concrete. At 15% replacement level the compressive strength fell below that at 10% but remained higher than control. A large proportion of the pozzolanic action of the silica fume takes place as early as 3 days. At a high water/binder ratio, a high percentage of silica fume results in a better pore structure by filling the voids and greater degree of hydration than the same percentage at a lower water/binder ratio.

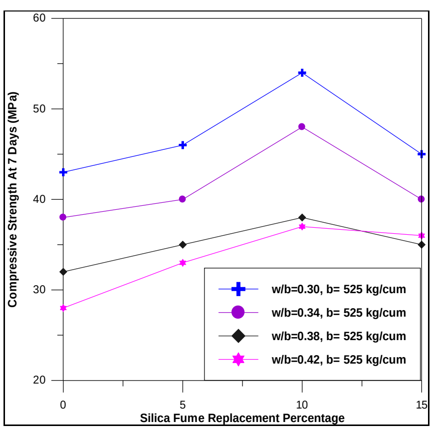
Therefore from the present results it can be concluded that the 7 day compressive strength of concrete can be improved by the replacement of cement by silica fume upto 10% replacement level. This significant gain in the compressive strength at the 7 day stage can be primarily attributed to the filler effect, as at the early stages it is the filler effect which enhances the concrete strength and not the pozzolanic effect.

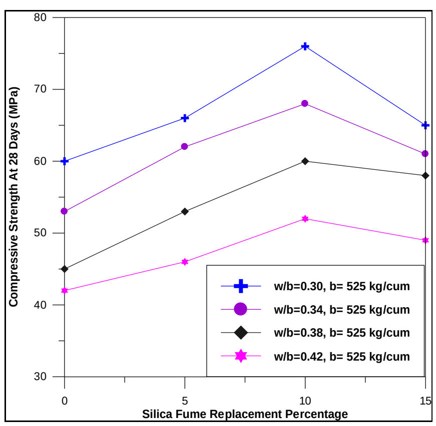
The 28 days compressive strengths have been plotted and presented in figure 02. The relationship between compressive strength and silica fume replacement percentage at the different water/binder ratio exhibit a common trend as expected. At the lowest value of the water/binder ratio i.e. 0.30, the compressive strength increased continuously with respect to control up to 10% replacement level where the maximum value was reached. Thereafter the strength decreased at higher percentage i.e. 15% replacement level. But even at 15% replacement level, the strength was higher than that of control. At the intermediate water/binder ratio i.e. 0.34 and 0.38, compressive strengths exhibit a continuously increasing trend up to 10% silica fume replacement. But after attaining the maximum value at 10%, the strengths fell at 15% replacement level. The strengths of concrete at higher values of water/binder ratio i.e. 0.42, had a similar increasing trend like the lower water/binder ratio concretes. Even at 15% replacement level, the strength of silica fume concrete is higher than the corresponding control concrete.

The 90 days compressive strengths have been presented in figure 03. Results obtained are similar to those at 28 day level for all the specimens at all water cemtitious material ratios. At all the water/binder ratio i.e. 0.30, 0.34, 0.38 and 0.42, maximum strength occurs at 10% replacement level. The 90 days strength (moist cured up to 28 days and then air cured) have been found to be always higher than the corresponding 28 days strengths (moist cured). Goldman and Bentur (1989) have reported that though air curing results in a somewhat lower strength as compared to continuous moist curing, air curing is not detrimental to the strength of silica fume concrete. This was attributed to the fact that the influence of silica fume takes place quite early, during the period of 1 to 28 days. Iravani (1996) reported that silica fume ultra high strength concrete is less sensitive to drying than high strength concrete without silica fume.

It has been very well established by different researchers all over the world that replacement of cement by silica fume has a remarkable efffect on the compressive strength of concrete. Specialists throughout the world have put forward different optimum percentages and have established their research findings but they are yet to reach a unique solution. The present research findings indicate that the optimum replacement percentage (for maximizing the compressive strength) depends on the water/binder ratio values and the age at which the strength is measured. As the water binder ratio increases, greater degree of hydration takes place. Also at higher replacement levels, the extra silica fume will be useful in filling up the voids, thus resulting in a better pore structure. Also at higher age levels greater degree of hydration takes place. Hence the amount of silica fume required for maximizing the concrete strength will depend on the water/binder ratio and the age at which the strength is measured. Similar observations were obtained by Yogendral et al.(1991) and Khedr and Abou-Zeid (1994).

However, optimum dosage of silica fume depends on a host of parameters like type of cement, cement content, mix proportions, temperature of curing etc.





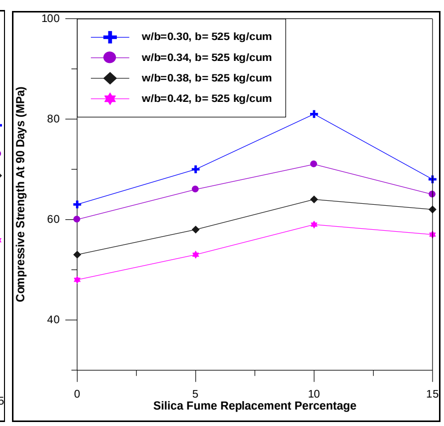


Figure 1: Compressive Strength At 7 Days with Silica Fume Replacement %
Figure 2: Compressive Strength at 28 days with Silica Fume Replacement %
Figure 3: Compressive Strength at 90 days with Silica Fume Replacement %

9.4. Effect of Water Binder Ratios on the Compressive Strength

It is observed that as the water/binder ratio increases, the compressive strength of the concrete decreases. This is valid for all the specimens. It is also observed that at a particular water/binder ratio as the silica fume content increases, the compressive strength also increases. For all the cases even with 15% silica fume replacement level, the 7 day compressive strength has been found to be higher than that of the control concrete (i.e. 0% silica fume). At all the water/binder ratio i.e. 0.30, 0.34, 0.38 and 0.42 the maximum strength has been achieved with 10% silica fume replacement. This is true for all the mixes and all the specimens. For lowest water/binder ratio i.e. 0.30, the 7 day compressive strength at 10% replacement level was found to be 54 MPa with respect to 43 MPa for control mix. In this context it may be mentioned filler action of silica fume mainly contributes to the early compressive strength development.

The 28 day strengths almost exhibit the same trend for all types of specimens tested. At all the water/binder ratio maximum compressive strength is obtained at 10% silica fume replacement. Thereafter the strength decreased at 15% silica fume replacement percentage. It is also observed that at higher water binder ratio of 0.38 and 0.42, even at higher silica fume replacement level i.e. 15%, the mix becomes much more amiable to compaction. From the figure it is also observed that at all water/binder ratio, as the silica fume content increases, the compressive strength also increases. Upto 10% silica fume replacement, for all water/binder ratio, the lines are non intersecting and parallel to each other showing a increasing trend. However at higher percentage of silica fume replacement, the curves shows a gradual decreasing trend. The optimum percentage for strength maximisation (for 28 days strength) varies from 10 to 15% depending on the water/binder ratio of the concrete. Similar observations were obtained by Khedr and Abou-Zeid (1994) and Toutanji and El-Korchi (1995). This proves the authenticity of the experimentally obtained results of the present investigation.

The compressive strength values for 90 days strength are presented in table 02. The strength of silica fume concretes at all water/binder ratios and all percentage replacements have yielded higher strengths than 28 days at 90 days. The trend of compressive strength is similar to those at 28 days.

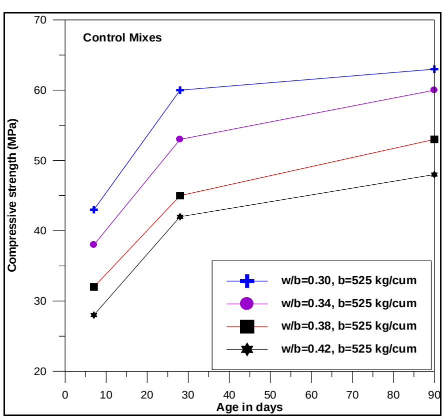
9.5. Variation of Compressive Strength with Age

The compressive strength at 7, 28 and 90 days are plotted with respect to age for all the concretes and are presented in the figures 4, 5, 6 and 7. At a particular water-cementitious materials ratio the plots for different types of specimens are presented separately. All the specimens just after demoulding were immersed in fresh water and cured. The 7 and 28 days specimens were tested after removing from the water. The 90 days specimens were removed from water after 28 days from casting and air cured till tested. From the figures 4, 5, 6 and 7 it has been found that the slopes of the lines connecting the 7 and 28 days strength are always higher than the corresponding slopes between 28 and 90 days. This indicates that the strength increase between 7 and 28 days is higher than that between 28 and 90 days. Concrete was moist cured for 28 days and thereafter air cured, most of the pozzolanic reaction occurred within 28 days. Silica fume has been introduced as cement replacement material at replacements ranging ffrom 0 to 30%. Even at 7 day level in all the cases, the silica fume concretes have strengths higher than that of the control. The 28 days strength values of silica fume concretes are always higher than the corresponding control concretes. Similar type of curing was performed for all the concretes. Therefore it can be concluded that the effect of silica fume is quite significant at 28 day level. Sabir (1995) reported that the strength developement for silica fume concrete is faster than that of the control concretes up to 28 days.

For water-binder ratio of 0.30, figures 4, 5, 6 and 7 indicate that at higher percentages of silica fume, especially at 15%, increase in strength from 7 to 28 days is remarkably high, indicating that at these high percentages, the 7 days strength is lower but 28 days strength increased drastically. For such concrete, early strength get considerably reduced. At water-binder ratio of 0.30, the 7 days strength of control and 15% silica fume concretes were 43 MPa and 45 MPa respectively, whereas at 28 days and 90 days the same values were 60 MPa, 65 MPa and 63MPa and 68 MPa respectively. At high percentage of silica fume the rate of gain of strength after 28 days is considerably reduced. An increase in the strength of silica fume concrete occurred up to 10%, but thereafter at higher percentage replacement, the strength got reduced. It is also observed from the figures, that for all the specimens at all the ages , 5% of silica fume causes a significant increase in the compressive strength with respect to control. This implies that at lower water/binder ratio, lower percentage of silica fume are more beneficial towards the developement of compressive strrength.

At water-binder ratio of 0.34, 0.38 and 0.42, the figures show a similar trend in the developement of compressive strength. The strengths have increased up to 10% silica fume replacement at all the ages for all the specimens. At 15% silica fume replacement, the strength got reduced.

The figures 4, 5, 6 and 7 shows the variation of compressive strength with age at different silica fume replacement percentage.



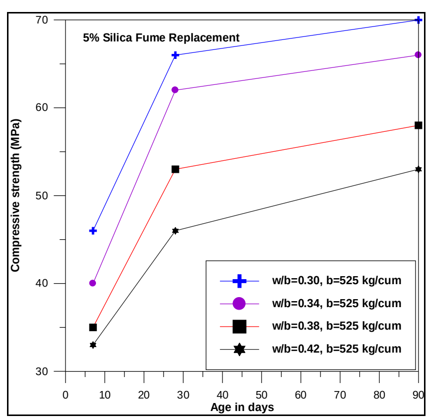
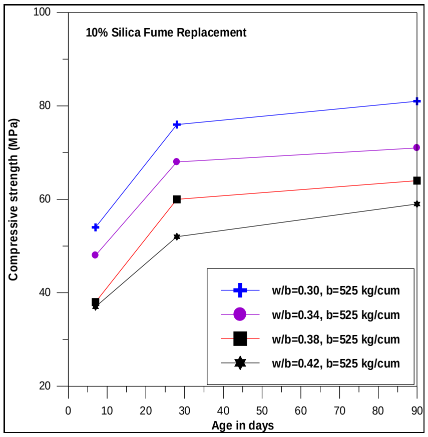


Figure 4: Variation of compressive strength with age for control concretes

Figure 5: Variation of compressive strength with age at 5% silica fume replacement level



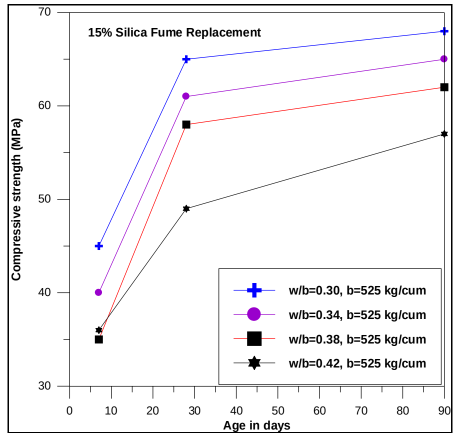


Figure 6: Variation of compressive strength with age at 10% silica fume replacement level
Figure 7: Variation of compressive strength with age at 15% silica fume replacement level

9.6. Rate of Gain in Compressive Strength

At any particular water-binder ratio, the percentage gain in strength at any age level at any silica fume content has been determined.

At water-binder ratio 0.30, in the present investigation, the rate of gain in compressive strength from 7 days to 28 days is maximum for 15% silica fume replacement level being around 45%. The 7 day and 28 day compressive strength for 15% silica fume replacement are 45 MPa and 65MPa respectively. Also it is observed that for control concretes the rate of gain in compressive strength from 7 days to 28 day is around 40%. The average rate of gain in compressive strength from 7 days to 28 days, for w/b ratio of 0.30 has been found to be 42%. However after 28 days, the rate of gain in strength up to 90 days is dramatically reduced, being maximum for 10% silica fume replacement i.e.7%.

Similarly for water-binder ratio of 0.34, the rate of gain in compressive strength from 7 days to 28 days is maximum for 10% silica fume replacement level, being 55%. For 15% replacement level, the rate of gain in strength is reduced to 40%. Ganesh Babu and Surya Prakash (1995) have reported that the efficiency of silica fume decreases at higher replacement levels. The 7 day and 28 day compressive strength for 10% silica fume replacement are 40 MPa and 62 MPa respectively. The average rate of gain in compressive strength from 7 days to 28 days for w/b ratio of 0.34 has been found to be 47%. However after 28 days, the rate of gain in compressive strength is found to be reduced drastically, the average rate being around 7%.

For water-binder ratio of 0.38, the rate of gain in compressive strength from 7 days to 28 days is maximum for 15% silica fume replacement level, being around 65%. The average rate of gain in compressive strength from 7 days to 28 days for w/b ratio of 0.38 has been found to be 54%. However after 28 days, the rate of gain in compressive strength follows a similar trend, the average rate being only around 10%.

For w/b ratio of 0.42, the average rate of gain in compressive strength from 7 days to 28 days is around 40%.

From the above discussions, it can be concluded that maximisation of concrete strength with silica fume incorporation has mostly occurred within the range of 7 to 28 days. After 28 days the rate of gain in compressive strength, for all the specimens and at all w/b ratios, is relatively insignificant.

9.7. Optimum Silica Fume Replacement Percentage

Different researchers have reported different silica fume replacement percentage as optimum for obtaining the maximum strengths of concretes.

Yogendran et al.(1987) worked with silica fume concrete at constant water-binder ratio of 0.34 at silica fume replacements ranging from 0-25%. The SP content was increased with higher silica fume content to maintain a constant slump. The cementitious material was fixed at 500 kg/m^3. The compressive strength was found to increase continuously with increasing amounts of silica fume and maximum occurred at 15% for all ages (i.e. 7, 28, 56 and 91 days).

Hooton (1993) investigated the properties of concrete with a total cementitious material content of 400 kg/m^3 and a constant water-cement ratio of 0.35 keeping the coarse and fine aggregates almost constant. Cement was replaced by silica fume @ 0, 10, 15 and 20% at variable dosages of SP for maintaining a constant slump. 7 day compressive strength attained maximum at 20% though at 15% silica fume content the strength was marginally lower. The 28 day and 56 day (moist cured) samples attained maximum strength at 15% silica fume replacement.

The optimum silica fume replacement percentage for maximising strength was found to be different. In the present investigation, it can be concluded that maximisation of concrete strength with silica fume incorporation has mostly occcurred for 10% silica fume replacement level. According to Neville (1994) superplasticizers do not alter fundamentally the strength of hydrated cement paste. The main effect is due to a better distribution of cement particles, and consequently their better hydration. To determine the optimum silica fume replacement percentage that causes maximisation of strength, the mix proportions and superplasticizer content were kept constant. Hence the variation in concrete properties occurred primarily due to variation in the silica fume replacement percentage.

For the mixes with similar mix proportions and constant dosages of SP, strengths obtained with inccreasing amounts of silica fume will be a function of silica fume only, provided proper compaction can be achieved and other parameters (curing, temperature, w/b ratio etc.) are kept constant. The present research work is a humble effort in this regard. The behaviour of silica fume concrete has been studied over a wide range of w/b ratios i.e. at 0.30, 0.34, 0.38 and 0.42 and silica @ 0, 5, 10 and 15% has replaced cement. At any w/b ratio, the mix proportions were kept constant, only cement was replaced by silica fume. The SP content also remained constant with increasing percentage of silica fume replacement resulting in variable workabilities. Since other parameters remained almost unchanged, the effect of silica fume on concrete properties and the optimum silica fume content required for maximizing strength at any constant w/b ratio has been determined.

10. Conclusion

It may be concluded that the use of silica fume is a necessity in the production of high strength concrete.

- From the study it has been observed that maximum compressive strength is noted for 10% replacement of cement with silica fume.
- Maximization of strength by incorporating silica fume has been obtained for the minimum water/binder ratio of 0.30. For 10% silica fume replacement percentage, the strength at 28 days is 27% higher with respect to control concrete.
- As the silica fume concrete is more compact and thereby more durable in nature and hence with some degree of quality control, it may be used in those places of construction where there is a chance of chemical attack, frost action etc.
- Lastly with good quality control, high early strength can be achieved in Silica Fume concrete which may be useful in various structural constructions such as high rise buildings, bridges etc

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12. References

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