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Experimental Investigation of Silica Fume Based Fibre Reinforced Concrete with Chemical Admixtures

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ABSTRACT

There is always a concern on the interaction between various mineral and chemical admixtures with fibre reinforced concrete. To find a suitable concrete material by using all these substances, firstly study the interaction among them and their effects on the strength of that concrete. Thus, in this study an experimental test was conducted on silica fume based fibre reinforced concrete with chemical admixtures. The main intention of this study was to find effect of fibre reinforced concrete prepared with mineral admixture on various chemical admixtures. The mineral admixture used was silica fume, fibre used was dramix steel fibre and the chemical admixtures used were accelerator, super-plasticizer and air-entraining agent. The optimum dosage of these admixtures with and without including silica fume and steel fibre was found out and tests were conducted on 3, 7 and 28 days. The results indicated that addition of accelerator with silica fume and steel fibre increased the compressive strength significantly with a marginal increase in tensile strength. On the addition of super-plasticizer with silica fume and steel fibre, a greater reduction in w/c ratio could be achieved without compromising the strength. In the combination with air-entraining agent, the strength was affected faintly at the initial stage but in later stage, the expected strength was attained.

Key words: Silica fume, chemical admixtures, steel fibre

INTRODUCTION

The usage of the composite material “Reinforced Cement Concrete” in structures like dams, bridges, apartments, commercial buildings etc., is found to be more economical and feasible for engineers. Today engineers have moved to the next phase in preparing concrete by adding many ingredients (chemical and mineral) with it. Hence, an experimental investigation is carried out on a composite material such as silica fume based concrete and the effectiveness of their combination in that concrete is determined. As cement can’t be entirely replaced by silica fume it is replaced by 0, 5, 10 and 15% by weight of cement to find the optimum content. Also discontinuous discrete steel fibres are added with this composite material by 0, 0.5, 1 and 1.5% in volume fractions to find its optimum content. The purpose of adding silica fume and steel fibre to this mix is to increase the strength, crack resistance (Nili and Afroughsabet, 2012), strain capacity and toughness parameter of concrete (Ezeldin and Balaguru, 1992; Koksal *et al*., 2008). To this certain chemical admixtures are also added in order to enhance other properties of concrete such as early gain in strength, improved workability etc. The chemical admixtures include Accelerator (AC), Super-plasticizer (SP) and Air-entraining Agent (AEA). They are added in three categories (5, 10 and 15 mL kg^{-1} of cement) to find the optimal dosage that can be added to this high performance concrete.

Depending upon the type and properties of admixture, certain properties of concrete can also change (Sahmaran *et al*., 2006) and so careful consideration in studying the properties of admixture, interaction between the admixture and constituent particles (Jolicoeur and Simard, 1998; Hanehara and Yamada, 1999) are done before adding them to concrete. However, both chemical and mineral admixtures may affect the setting time of concrete. Sangeetha (2011) in her study on the compression and impact strength test on glass fibre reinforced concrete with various combinations of admixtures like (super-plasticizer+accelerator+air-entraining agent, super-plasticizer+retarder+air-entraining agent and super-plasticizer+water-proofing compound+air-entraining agent) showed that different combinations of admixtures increases the compressive and Impact strength considerably particularly the combination "SP+R+AEA" showed good result both in compression and impact test.

Thus, in this study an attempt has been made in preparing and evaluating the properties of high performance fibre reinforced concrete with optimal replacement of cement by silica fume, optimum addition of steel fibre and chemical admixtures without affecting other properties of concrete.

MATERIALS AND METHODS

Cement: Locally available OPC 43 grade was used in this study. The cement was tested for its physical properties such as specific gravity, initial setting time and final setting time and were found to be 3.12, 60 and 450 min, respectively.

Aggregate: Locally available river sand passing through 4.75 mm and retained on 2.36 mm sieve was used as fine aggregate. The specific gravity and fineness modulus of sand are 2.65 and 3. Crushed granite passing through 20 mm and retained on 10 mm sieve were used as coarse aggregate. The specific gravity and fineness modulus of 20 mm aggregate were 2.7 and 6.5, respectively, the water absorption of 3%.

Water: Ordinary portable water was used for mixing and curing purposes.

Hooked end steel fibres: Dramix steel fibres were used in this study. The diameters of 0.5 mm and length of 30 mm with an aspect ratio of 60 were used. The yield strength of the steel fibre is 1100-1380 Mpa.

Admixtures: Accelerator, super-plasticizer, air-entraining agent and mineral admixture include specific gravity of 2.26.

Concrete mixing, casting and curing procedure: The dry cement, sand and coarse aggregates were mixed for 60 sec in a laboratory mixer. The mixing continued for another 60 sec about 80% of total water were added. The mixing was continued for another 60 sec and the fibres were then fed continuously to the mixer for a period of 2-3 min. Finally, the exact quantity of super-plasticizer was diluted with the remaining water and the mixing was continued for an additional 2 min.

Before use, the moulds were properly coated with mineral oil, casting was carried out in three different layers and each layer was compacted well manually. Based on the quantity of mix the specimens such as cubes and cylinders were casted. The casted specimens were demolded after 24 h and kept in water curing until the time of test.

Methodology: Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative quantities with the object of producing as economically as possible concrete minimum properties notable consistent strength and durability. In this study, a High Performance Concrete of grade M60 was considered. The nominal mix proportion of 1:0.56:1.89: 0.28 water cement ratio was considered for this study. The water cement ratio is arrived from the slump test. Six numbers of concrete casting moulds of size 100×100×100 mm were made. They were checked for dimension on both the directions and on the diagonals and casted to find the compressive strength of the specimen in parallel and perpendicular sides to the direction of compaction. Two cylindrical mould of size 100 mm diameter and 200 mm height are made, checked for dimension and casted to find the split tensile strength of concrete. To obtain the effective dosage of admixtures on high performance concrete, the admixtures were added in three different dosages 5, 10 and 15 mL kg^{-1} of cement. The concrete cubes that are made with accelerator were labeled as AC-1, AC-2 and AC-3 for 5, 10 and 15 mL kg^{-1} of cement, respectively. Similarly super-plasticizer specimens were labeled as SP-1, SP-2 and SP-3 by adding 5, 10 and 15 mL kg^{-1} of cement, respectively. The specimens made with air-entraining agent were labeled as AEA-1, AEA-2 and AEA-3 for 5, 10 and 15 mL kg^{-1} of cement, respectively. In case of concrete cubes made with Super-Plasticizer, the water-cement ratio was reduced by 10% (from 0.28-0.252) and then added with three different dosages as mentioned above. During the preparation of concrete mix, the water quantity is divided approximately into two parts and the admixtures were added with the second part so that the interaction of admixtures with the water will be more effective than adding it with the first part. Subsequently after this silica fume was replaced for cement by 5, 10 and 15% and labelled as SF-1, SF-2 and SF-3, respectively. After determining the optimal content, steel fibre was added to this by 0.5, 1 and 1.5% by volume fraction and labeled as S-1, S-2 and S-3 correspondingly. Finally, combined specimens were casted with the effective dosages of silica fume and steel fibre with every chemical admixture. They were labeled as SFSA for the combination with accelerator, SFSS for the combination with super-plasticizer, SFSE for the combination with air-entraining agent and their response to compressive and tensile strength was found in 3, 7 and 28 days. All specimens were removed from the mould after giving a minimum period of 24 h as setting time and cured in the curing tank. The specimen was then taken from the tank and allowed for surface drying for a minimum period of 5-6 h before testing. It was then placed in ASTM compressive testing machine and tested the load was applied at the rate of 2.9 kN sec^{-1}. The test was conducted on 3, 7 and 28 days.

RESULTS AND DISCUSSION

The following results are inferred from the experiment for the compressive and split tensile strength of the concrete specimens and they are tabulated.

The compressive strength and the split tensile strength of concrete cubes made with various dosages of accelerator say AC-1, AC-2 and AC-3 on different days of curing are shown in Table 1 and 2, respectively. It is found that the compressive strength on 3 days test gives a very good result compared relatively to those of 7 days test and 28 days test. This is because, when accelerator is added to the concrete mix, it increases the initial setting time, thereby enhancing the strength at the beginning stage. Moreover, there is a gradual raise in the compressive and tensile strength for AC-1 to AC-2 in 3 day test itself from 22.55-27.73 Mpa (in compression) and from 2.99-3.35 Mpa (in tension). But for AC-3 the strength begins to reduce from AC-2 (27.73-26.84 Mpa in compression and from 3.35-3.24 Mpa in tension) because further increase in the quantity of

Table 1: Compressive strength of the concrete cube specimen casted with chemical admixtures (accelerator, super-plasticizer and air-entraining agent)

	Compressive strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	16.95	35.96	60.28
AC-1	22.55	38.81	61.95
AC-2	27.73	42.55	65.87
AC-3	26.84	41.02	63.68
SP-1	18.26	37.91	61.52
SP-2	21.29	40.54	64.18
SP-3	21.16	40.45	63.87
AEA-1	17.16	38.66	62.14
AEA-2	20.82	42.33	63.87
AEA-3	19.38	41.54	63.21

The suffix 1, 2, 3 represents three different dosages (5, 10 and 15 mL kg^{-1} of cement) of addition of Accelerator (AC), Super-plasticizer (SP) and Air-entraining Agent (AEA), Control Concrete (CC)

Table 2: Split tensile strength of the concrete cylinder specimen casted with chemical admixtures (accelerator, super-plasticizer and air-entraining agent)

	Split tensile strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	2.48	2.91	3.18
AC-1	2.99	3.41	4.02
AC-2	3.35	4.46	4.73
AC-3	3.24	4.32	4.51
SP-1	2.52	2.84	3.17
SP-2	3.64	3.79	4.59
SP-3	3.53	3.76	4.92
AEA-1	2.34	3.22	3.91
AEA-2	2.92	3.68	4.73
AEA-3	3.08	3.84	4.66

The suffix 1, 2, 3 represents three different dosages (5, 10 and 15 mL kg^{-1} of cement) of addition of Accelerator (AC), Super-plasticizer (SP) and Air-entraining Agent (AEA)

accelerator is not making the concrete to gain its strength; instead making the concrete more rigid during mixing itself and resulting in decrease on the strength parameter. Finally among all of them AC-2 gave a good initial setting time, desired workability and a better strength in compression. The relative percentage strength attainment when compared to that of controlled concrete is 46, 70, 109% at 3, 7 and 28 days, respectively. This is higher than AC-1 which gives 37, 64, 102% at 3, 7 and 28 days and AC-3 which gives 44, 68, 105% at 3, 7 and 28 days.

Table 1 and 2 also shows the compressive and split tensile strength of concrete cubes made with various dosages of super-plasticizer say SP-1, SP-2 and SP-3 against different days of curing. It is found that the compressive strength on 3 days and 7 days gives a good result, whereas, for 28 days it gives a moderate result. When super-plasticizer is added to the concrete mix, it provides flocculation and flow-ability to the concrete mix. For a smaller quantity, it gives a poor dry mix and as a result the strength is increased but workability is decreased. This is apparent from the mix of SP-1 where the workability was very much low. For higher quantity it gives a flowing concrete with a moderate strength and for greater quantity it causes segregation with deterioration in strength of concrete. This can be seen from the increase in strength on both compression and tension for SP-1 and SP-2 from 61.52-64.18 Mpa and from 3.17-4.59 Mpa. For the mix SP-3 the workability was high and so the compressive strength began to reduce from 64.18-63.87 Mpa on 28 days. Hence, in SP-2 though the mix was little wet, desired workability and strength is achieved `than SP-1 and SP-3, where in SP-1 there is a lower workability and in SP-3 there is a higher workability. Here, the relative percentage strength attainment in compression for SP-2 compared to Controlled Concrete is 35, 67, 107% on 3, 7 and 28 days greater than SP-1(which gives 30, 63, 102% on 3,7 and 28 days) and SP-3 (which gives 35, 67, 106% on 3,7 and 28 days).

Further to this, the compressive strength and the split tensile strength of concrete cubes made with various dosages of air-entraining agent say AEA-1 AEA-2 and AEA-3 against different days of curing are also shown in Table 1 and 2. It is found that the compressive strength on 3 days gives a poor result of 17.15, 20.82 and 19.38 Mpa in compression and 2.34, 2.92 and 3.08 Mpa in tension for all three specimens whereas 7 day and 28 day gave a very good result. This may be due to the fact that air-entraining agent has the tendency to decrease the strength (though it increases the durability) at initial stage. Hence when added to the concrete mix, it shows an initial decrease in the strength but at a later stage it reached around 63 Mpa after the voids are completely filled with the air-bubbles, giving a satisfactory results. Compared to AEA-1, AEA-2 gives a better strength of 63.87 Mpa (in compression) and 3.91 Mpa (in tension) at the final stage and also better than AEA-3 which gives a marginal difference of 63.21 Mpa. Moreover, the slump of AEA-3 was found to be high than AEA-1 and AEA-2 since the air-entraining agent has the tendency to form a coagulant bubbles during mixing itself and so a soapy layer was formed around the constituent material. The setting time for AEA-3 is also more compared to others. Hence, AEA-2 has performed well among them giving a relative percentage strength attainment of 35, 70, 106% on 3, 7 and 28 days compared to that of controlled concrete, whereas, the relative percentage of AEA-1 and AEA-3 are 28, 64, 103 and 32, 69, 105%, respectively on 3, 7 and 28 days.

The compressive strength and the split tensile strength of concrete cubes made with various percentage replacement of silica fume for cement (labeled as SF-1, SF-2 and SF-3) on different days of curing are shown in Table 3 and 4. It is found that the strength on SF-2 gives a better value in compression (61.52 Mpa) and slightly lesser value in tension (4.28 Mpa) compared to that of SF-1 (which gives 60.83 Mpa in compression and 4.92 Mpa in tension) and those of SF-3 (giving only 57.99 Mpa in compression and 3.91 Mpa in tension). This is because of the degree of replacement of silica fume. When silica fume was added to the concrete mix with certain amount of replacement for cement, there is some change in degree of bondage between the constituent particles. The fact is that silica fume won't offer as much effective bondage as that of cement as

Table 3: Compressive strength of the concrete cube specimen casted with mineral admixture (silica fume)

	Compressive strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	16.95	35.96	60.28
SF-1	16.47	36.50	60.83
SF-2	17.05	37.18	61.52
SF-3	14.91	34.81	57.99

The suffix 1, 2, 3 represents three different dosages (5, 10 and 15 mL kg^{-1} of cement) of replacement of the mineral admixture (silica fume)

Table 4: Split tensile strength of the concrete cylinder specimen casted with mineral admixture (silica fume)

	Split tensile strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	2.48	2.91	3.11
SF-1	3.84	4.37	4.92
SF-2	3.13	3.97	4.28
SF-3	2.34	3.22	3.91

The suffix 1, 2, 3 represents three different dosages (5, 10 and 15 mL kg^{-1} of cement) of replacement of the mineral admixture (silica fume)

Table 5: Compressive strength of the concrete cube specimen casted with steel fibre

	Compressive strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	16.95	35.96	60.28
S-1	24.08	45.97	71.72
S-2	24.81	46.28	72.53
S-3	23.22	45.10	69.89

The suffix 1, 2, 3 represents three different volume fractions (0.5, 1 and 1.5%) of the steel fibre

Table 6: Split tensile strength of the concrete cylinder specimen casted with steel fibre

	Split tensile strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	2.48	2.91	3.11
S-1	3.39	4.83	6.92
S-2	3.97	5.67	7.95
S-3	3.86	5.08	7.41

The suffix 1, 2, 3 represents three different volume fractions (0.5, 1 and 1.5%) of the steel fibre

mentioned earlier but has the ability to bind with the constituent materials (Pawade *et al*., 2011). SF-3 got a quite decrease in strength from 17.05-14.91 Mpa in compression and 3.13-2.34 Mpa in tension at the initial stage itself. From the texture of the tested specimen, the bonding nature of silica fume can be inferred. The relative percentage strength attainment of SF-1 and SF-3 compared to that of controlled concrete are only 27, 61, 101 and 25, 58, 96%, respectively on 3, 7 and 28 days whereas the relative percentage strength attainment for SF-2 was 29, 62, 103% on 3, 7 and 28 days. Hence, only at certain percentage replacement, the strength got increased.

Table 5 and 6 shows the compressive and the split tensile strength of concrete cubes made with various volume fraction of steel fibre i.e., S-1, S-2 and S-3 against different days of curing. It is found that the compressive strength and tensile strength of these specimens are greater than other specimens. Among these S-2 gives a better value of 72.53 Mpa in compression and 7.95 Mpa in tension than S-1 (which gives 71.72 Mpa in compression and 6.92 Mpa in tension) and S-3 (which gives 69.89 and 7.41 Mpa in tension). From this it was evident that increase in the volume fraction of steel fibres will increase the strength considerably but they are also subjected to corrosive action at the surface. So, this was the reason that the strength of S-3 is slightly affected than S-2. Also fibres are randomly distributed in the specimen and so the resistance against the compressive forces on all the direction will be of more or less equal magnitude. Another hold back of adding excess fibres to the mix was that it bonds separately with the mortar content in a certain region (balling effect) and uniform distribution of fibres was limited to certain extent. Although, concrete cubes made with steel fibre gives a higher split tensile strength at the initial stage itself (3.39, 3.97 and 3.86 Mpa) than other type specimens due to the ductile property of the fibre (Foster and Attard, 2001) which prevents the specimen bisecting into two halves and keeping them tightly without splitting it away. This was evident from the texture of the broken specimen.

The compressive strength and the split tensile strength of the combined specimen for the optimum proportion of all constituent materials are shown in Table 7 and 8. This includes optimum replacement of silica fume and optimal addition of steel fibres with accelerator, super-plasticizer and air-entraining agent. Among all, the combination CC+SF+S+AC (i.e., silica fume+steel fibre+accelerator) gives a much greater strength of 81.48 Mpa in compression and 7.58 Mpa in tension on the 28 day test result showing that the achieved tensile strength is approximately 9-10% of the compressive strength. The main reason is due to the early setting effect by the accelerator, effective resistance against load by the steel fibres and with a percentage replacement of silica fume. In case of CC+SF+S+SP specimen (i.e., silica fume+steel fibre+super-plasticizer) the mix gives a better workability due to the addition of super-plasticizer when compared to other mixes and it was inferred that this combination is still more effective for a further small decrease in the w/c ratio. Though the strength of concrete is not as much as that of the first specimen, a higher value of 79.87 Mpa in compression and 7.01 Mpa in tension is obtained on 28 days. Speaking about the specimen CC+SF+S+AEA (i.e., silica fume+steel fibre+air-entraining agent), it gives a good result at its initial stage itself (22.19 Mpa in compression and 3.97 in tension) because the steel

Table 7: Compressive strength of the combined concrete cube specimen casted with steel fibre, mineral admixtures (silica fume) and chemical admixtures

	Compressive strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	16.95	35.96	60.28
CC+SF+S+AC (SFSA)	25.51	43.66	81.48
CC+SF+S+SP (SFSS)	23.43	41.29	79.87
CC+SF+S+AEA (SFSE)	22.19	40.73	79.78

The combination of Controlled Concrete (CC) with that of silica fume (SF), Steel Fibre (S) and different chemical admixtures say Accelerator (AC), Super-plasticizer (SP) and Air-entraining Agent (AEA)

Table 8: Split tensile strength of the combined concrete cube specimen casted with steel fibre, mineral admixtures (silica fume) and chemical admixtures

	Split tensile strength (Mpa)		
Specimen label	3 Days	7 Days	28 Days
CC	2.48	2.91	3.11
CC+SF+S+AC (SFSA)	4.61	6.43	7.58
CC+SF+S+SP (SFSS)	4.22	6.22	7.01
CC+SF+S+AEA (SFSE)	3.97	6.82	7.15

The combination of Controlled Concrete (CC) with that of silica fume (SF), Steel Fibre (S) and different chemical admixtures say Accelerator (AC), Super-plasticizer (SP) and Air-entraining Agent (AEA) fibre compromised the effect of air-entrainment which will affect the strength of concrete and also made the concrete durable for a longer period. On 28 days test result the strength has reached considerable upto 79.78 Mpa in compression and 7.15 Mpa in tension.

CONCLUSION

From the result of this experimental investigation, the following conclusions were made on accelerator, air-entraining agent, super-plasticizer, silica fume and steel fibres.

The optimum dosage of accelerator for this high performance (HPC) concrete was found to be 10 mL kg^{-1} of cement. In case of excess quantity the strength began to reduce but the initial setting time increased considerably.

The optimum dosage of air-entraining agent for this high performance concrete was found to be 10 mL kg^{-1} of cement. In case of excess quantity, the durability of concrete was enhanced but it also lead to detrimental effect on strength parameter.

The optimum dosage of super-plasticizer for this high performance concrete was found to be 10 mL kg^{-1} of cement. However, adding the next higher quantity (upto 15 mL), the strength was not greatly affected. But excess quantity has made the concrete increase its flow-ability, leading to segregation of constituent particles.

The optimum dosage of steel fibre for this high performance concrete was found to be 1% per volume of concrete. On the other hand, further increase in the percentage is leading to balling effect and there by causing patches of fibre group together making the concrete to form "honey comb".

The optimum dosage of silica fume for this high performance concrete was found to be 10% kg^{-1} of cement. Further increase of silica fume is leading to deterioration of strength gradually down.

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