FRESH AND MECHANICAL PROPERTIES OF HIGH STRENGTH SELF-COMPACTING CONCRETE MODIFIED WITH FLY ASH AND SILICA FUME

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Abstract- The effects of Fly Ash (FA) and Silica Fume (SF) on the fresh and mechanical properties of high-strength self-compacting concrete (HSSCC) are examined in this research. Slump, J-ring, and L-box tests are used to study fresh properties, while compressive strength, split tensile test, and flexural test are used to investigate mechanical properties. This research is based on the previously published research and selected the optimum percentages of supplementary cementing material (SCMs) for FA and SF. The concrete mixture consists of total of seven mixes: control mix (CC), M1 (5%SF and 0%FA), M2 (5%SF and 10%FA), M3 (5%SF and 20%FA), M4 (5%SF and 30%FA), M5 (5%SF and 40%FA) and M6 (5%SF and 50%FA). The study indicates that adding up to 5% SF and 20% FA to HSSCC mixes improves the fresh qualities of the mixtures. On all ages, the mechanical parameters of HSSCC, such as compressive strength, flexural strength, and split tensile strength, are shown to be higher than the control. In comparison to control mixtures at the appropriate ages, the addition of SF and FA at the optimum dose (5% SF and 20% FA) results in a rise in compressive strength, flexural strength, and split tensile strength. It is concluded that 5% SF and up to 20% FA mixes show improvement in the fresh properties as well as mechanical properties of HSSCC while further increment of FA decreases the fresh and mechanical properties of HSSCC.

Keywords- Workability, Supplementary Cementing Material, Compressive Strength, Flexural Strength, Split Tensile

1 Introduction

The amount of CO2 produced into the atmosphere by the cement production industry can be reduced by including SCMs and efficiently using cement clinker [1]. Silica Fume (SF), Ground Granulated Blast Furnace (GGBF), Bentonite (BE), Fly Ash (FA), and other SCMs with pozzolanic properties can partially substitute cement to lessen the cement's harmful effects on the environment while still meeting industrial demands [2]- [6]. Many studies have employed SCMs to produce more sustainable, effective, and durable concrete because most SCMs tend to increase concrete's durability by thinned the interfacial transition zone (ITZ) [7]. The use of natural pozzolans in concrete has gotten special attention due to their unique properties which include low heat of hydration, low permeability, higher content of SiO2, and enhancement in the ultimate strength of concrete [8] . Supplementary cementing material (SCMs) is one of the solutions to minimize the consumption of natural raw material for cement, energy consumption reduces the negative impacts on the environment. Different researchers use SCMs to investigate fresh properties and harden properties to study the fresh and mechanical performance of concrete [9]. The pozzolanic material can also be added during the manufacturing process of cement at different proportions. L.T.B Uzal studies the manufacturing of laboratory-based blend Portland cement with the addition of natural volcanic pozzolanic material. An experimental study is limited to material from two volcanic sources by 55% replacement at the different grinding times. The blend cement improves compressive strength and reduces the ability of alkali-silica expansion [11].

Fly ash is a byproduct which is obtained in the form of fine powder when pulverized coal is burned in power plants. FA is a pozzolanic material, which is a mixture of aluminous and silicious materials that forms cement when mixes with water.

When fly ash is mixed with lime and water, it forms a material that resembles Portland cement. Fly ash is therefore suited for usage as a primary component in several construction materials, such as mixed cement, hollow blocks, and mosaic tiles. When added to the concrete mix, fly ash increases the strength and improves segregation of the concrete and makes it easier to pump [8]. Fly ash is divided into two categories: Class F and Class C. Class F is more typically used for structural concrete since it has a low calcium percentage and, in most circumstances, a carbon content of less than 5% [10]. Class C fly ash is primarily composing of high-calcium fly ashes containing less than 2% carbon. To enhance the mechanical and durability properties of cement, silica fume is employed in a predetermined proportion as a partial replacement. Through pozzolanic reaction, the addition of the right amount of SF (up to 12%) greatly reduced the strength loss of lightweight concrete (LWC) mixtures and increased compressive strength [11]. The results reveal that the mechanical strength of rich fly ash rubberized SCC is marginally improved by the addition of SF [12][13].Using scanning electron microscopy found that employing SF and FA in concrete reduced porosity and produced dense concrete, which decreased permeability [14]. Another study discovered that the pozzolanic reaction's production of calcium silicate hydrate gel (C-S-H) increased the mechanical and durability of concrete [15].

The purpose of this study is to assess the fresh and hardened properties of HSSCC incorporating SF and FA. The novelty of this research program is that I have used different proportion of SF and FA that is I have used 5% SF throughout the mix and FA with the increment of 10% for each mix in order to evaluate the Fresh and mechanical properties then develop a comparison between control mix and the mixes with SF and FA and select the optimum percentages of SF and FA for HSSCC.

2 Experimental Work

2.1 Materials used

The major binding ingredient is ordinary Portland cement (OPC) type I, follow by ASTM C150. OPC has a specific gravity of 3.1, with starting and final setting times of 45 and 330 minutes, respectively [15]. FA and SF are used as SCMs. In Table 1, properties of OPC, FA and SF are shown.

Table 1 Properties of OPC, FA and SF

Chemicals	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_3	LOI
OPC	17.9	-	10.7	3.60	-	1.8	62.8	0.9	1.4	-	0.9
Fly Ash	50.8	1.45	15.75	8.61	-	4.17	11.31	3.08	1.99	-	2.74
Silica fume	94.5	-	0.09	0.10	-	0.43	0.23	-	0.93	-	2.7

The concrete samples are mixed and cured with tap water. The addition of both SCMs cause a reduction in workability. The water-to-cement ratio is maintained constant for all mixtures. To get the require slump, the dosage of the superplasticizer is adjusted. Fine aggregate (FA) is used from the Lawrencepur source in Pakistan. Coarse aggregate (CA) from Margalla hills source is used in concrete. The coarse aggregate size limit is 12 mm. Table 2 lists the characteristics of FA and CA.

Table 2 Properties of fine Agg. and Coarse Agg.

	FA	CA
Sp. Gravity	2.70	2.65
Water Absorption (%age)	1.3	0.54
Loose Density (Kg/m^3)	-	1412
Rodded Density (Kg/m^3)	-	1550
Fineness Modulus	2.99	-

2.2 Methodology and Mix Design

This research program has been divided into three phases. In first phase material has been chosen. In second phase mix design has been made. In third and last phase mixing and costing has been done, after mixing fresh properties has been measured, and for mechanical properties costing has been done.

To evaluate the fresh and mechanical qualities of concrete, seven different mix proportions are adopted. Mixes include Control Concrete (CC) mix, M1 (5%SF and 0%FA), M2 (5%SF and 10%FA), M3 (5%SF and 20%FA), M4 (5%SF and

30%FA), M5 (5%SF and 40%FA) and M6 (5% SF and 50%FA). The optimum percentage for partial replacement of SF and FA was selected based on previous research [16] [17].

HSSCC mix designs are created using EFNARC acceptance criteria and SF and FA as partial replacements of cement. Various mix proportions with constant water-to-binder ratio (W/B) 0.30, 5% constant SF and FA contents 10% increment other than control mix, sand content (743 kg/ m^3) and coarse aggregate (878 kg/m^3) as reported in Table 3, are used in this experimental plan. The binary mixes tagged as M1, M2, M3, M4, M5, and M6 contain same dosages of SF (i.e., 5%) along with different dosages of FA (i.e., 10%, 20%, 30%, 40%, and 50%) respectively. The dosage of super plasticizer is adjusted according to required slump.

Table 3 Mix Proportions

Mix No.	Mix ID	W/B Ratio	W	C	SF		FA		Fine Agg.	Coarse Agg.	Admixture	
			kg/m^3	kg/m^3	%	kg/m^3	%	kg/m^3	kg/m^3	kg/m^3	%	kg/m^3
1	CC	0.30	142.2	474	-	-	-	-	743	878	1.4	6.636
2	M1	0.30	142.2	450	5	24	0	0	743	878	1.4	6.636
3	M2	0.30	142.2	402.6	5	24	10	47.4	743	878	1.4	6.636
4	M3	0.30	142.2	355.2	5	24	20	94.8	743	878	1.4	6.636
5	M4	0.30	142.2	307.8	5	24	30	142	743	878	1.5	7.10
6	M5	0.30	142.2	260.4	5	24	40	190	743	878	1.6	7.584
7	M6	0.30	142.2	213	5	24	50	237	743	878	1.6	7.584

2.3 Sample preparation

Yielding of all the batches of ingredients is done by weight. The ingredients are mixed in an electric concrete mixer and revolved at a rate of 30 rev/min. To get the desire workability, Viscocrete-3110 superplasticizer (SP) is used in the concrete mixes. Different samples are prepared for different tests. To get the average value of each testing result, three samples are prepared and tested. Hardened properties of concrete are investigated by performing mechanical and durability tests. According to ASTM C39, a 150x300 mm cylinder is used to measure compressive strength, and tensile strength is tested using a split test according to ASTM C496/C496M, while flexural strength is tested using 150x150x700mm size beam samples according to ASTM C293 standard method [18] [19]. The slump test, J-ring test, and L-Box test are used to determine the fresh property, to accord with ASTM C1611, ASTM C1621, and ASTM C1611 standard method tests, respectively [20] [21].

3 Results and discussion

3.1. Fresh properties

The fresh properties testing is carried out for two main reasons. The first is to determine whether the concrete is self-compacting, and the second is to assess the deformability or consistency of the concrete to calculate the necessary mixture proportioning if the concrete lacks sufficient self-compatibility. There is no segregation or bleeding in any of the blends, according to the results. In table 4 there are the results of the fresh properties tests that were obtained in this study.

Table 4 Fresh properties of HSSCC

Type of Test	CC	M1	M2	M3	M4	M5	M6
Slump Flow Diameter (mm)	715	725	735	737	720	710	705
J-Ring Hight	12	11	10	10.5	12.5	13	13.5

H_{in}-H_{out} (mm)							
J-Ring Flow Diameter (mm)	700	710	715	720	75	695	680
L-Box ratio	0.92	0.94	0.95	0.96	0.92	0.82	0.78

3.1.1. Slum flow test

The workability of each mix (with a constant water-binder ratio) is determined using the slump test according to ASTM C1611 [18]. Slump values for varying percentages of FA and SF are tried to keep constant. Dosage of SP (by %age weight of binder) reflected that workability is reduced by adding FA and SF. The results show that adding FA and SF greatly boosts workability up to the optimum limit, after which there is a decrease in workability. The require dosage of SP for the FA and SF mix is more as compared to that of the control mix, showing a comparatively severe effect of FA as compare with that of SF in reducing workability. However, FA and SF mix, being highest replacement value among un-strengthen mixes are use a combatively high dosage of SP. The workability results of all the mixes are discarded in figure 1. Because of the fine particle size of FA and SF are compared to cement particles, a reduce slump is value experienced after the optimum limit. The particle shape of FA and SF are spherical. Due to its spherical nature, FA and SF show better workability at lower percentages than higher percentages of FA and SF which is under other studies [22].

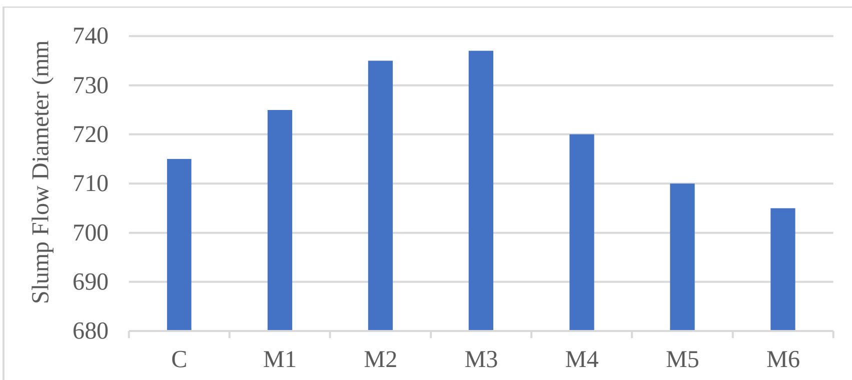
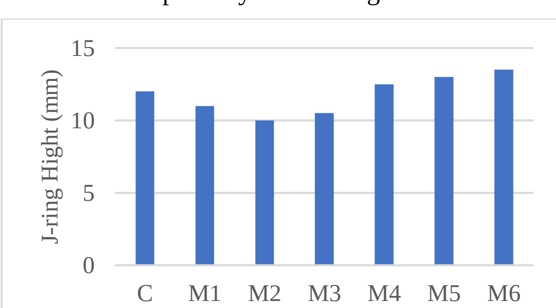


Figure 1: Slump Test Results

3.1.2. J-ring test

HSSCC's capacity to pass is determined by the J-ring test. The capacity of the HSSCC to pass through congest reinforcement and small holes without vibrating is referred to as passage ability [21].

During the J-ring test, the diameter of the concrete and the height difference between the concrete inside and outside of J-ring bars are measured. As shown in table 1, the height differences between the various blends vary over the ranges. Because of the reduce viscosity and share stress, M1, M2, and M3 have the lowest values (11 mm, 10 mm, and 10.5 mm, respectively), allowing the concrete to flow more easily. Besides that, as shown in figure 2a, all mixes having lower percentages of FA and SF have lower values than those containing larger percentages of FA and SF, and all mixes containing SF and FA had lower values than the control mix. In addition, the concrete's diameter was measured. And, as demonstrated in figure 2b, a higher percentage of SCMs at optimum doses have a larger diameter than a higher percentage of SCMs in HSSCC. This could be because FA and SF have a lower specific gravity than cement-only concrete. J-ring flow diameter acceptability values range from 580 to 780 mm, and J-ring height Hin-Hout ranging between 0-15mm.

a) 

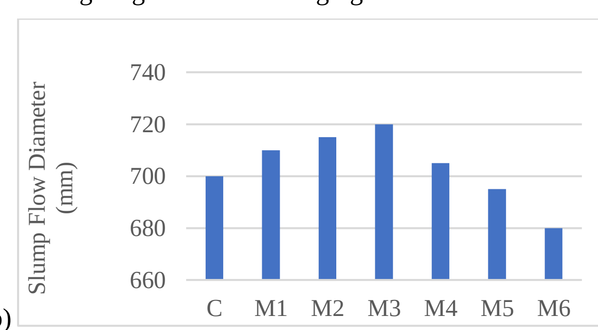
b) 

Figure 2: J-Ring Test, a. J-Ring Hight Results, and b. J-Ring Flow Diameter Results

3.1.3. L-box test

To determine the concrete's capacity to fill, pass, and resist segregation this test is carried out. The L-box test is often used to measure the ability of HSSCC to pass reinforcement blocks when it is subjected to them. [21]. The L-box value grow as the FA and SF powder concentrations approach the optimum limit (5% SF and 20% FA), This can be related to lowering concrete viscosity and increasing yield value. Because of the high viscosity and sharing resistance, adding more powder reduce the L-box ratio compared to the control mix, as illustrate in figure 3. To determine L-box results, the heights of the concrete at both ends of the device (H1 and H2) are measured. The L-box has an acceptance ratio of 0.75 to 1.

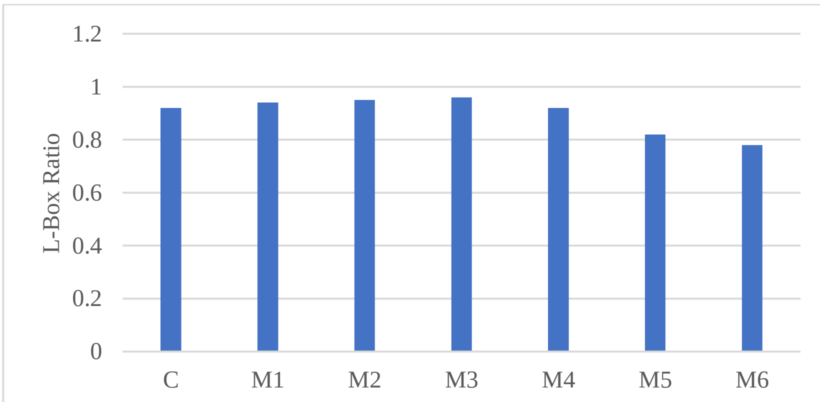


Figure 3: L-Box Ratio results

3.2. Mechanical Properties
3.2.1 Compressive strength

It's one of the most crucial parameters for determining concrete's uniaxial load-carrying capacity. It is determined using an ASTM C39 concrete cylinder [19]. The specimens are tested at 7, 14, and 28 days after curing in water. Table 5 and Figure 4 demonstrate the compressive strength results of HSSCC mixtures. The lowest compressive strength is 28.54 MPa for M6 mix with 5% SF and 50% FA after 7 days, while the highest compressive strength is 50.45 MPa for M3 mix with 5% SF and 20% FA after 28 days. FA and SF has a considerable impact on the HSSCC's strength and strength developed properties, as shown by the overall results.

Table 5 compressive strength values of HSSCC

Compressive Strength (MPa)							
Age (Days)	**CC**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
7	30.14	30.24	38.67	39.97	33.84	30.95	28.54
14	39.35	39.46	44.38	45.50	36.92	35.52	34.28
28	43.70	43.93	49.95	50.45	42.48	39.42	36.49

HSSCC mixtures containing 5% SF and 20% FA (M3) have better compressive strength than other mixes after 28 days of testing. Furthermore, the results show that when the percentage of FA and SF substitution rises, the compressive strength of HSSCC with FA and SF rises until it reaches specified limits, beyond which it begins to drop. As 5%SF and 20% FA are mixed, the compressive strength of concrete increase by 16% and 15%, respectively, at 14 and 28 days, when compared to the control mix. The increase in concrete compressive strength is due to the pozzolanic interaction of FA and SF with cement [20]. FA and SF may have bridged the matrix and aggregates by boosting interfacial properties and lowering stress concentrations in the cross-section [17] [22]. The research shows that mixing substantial doses of SF and FA mixes lower compressive strength when compared to an optimum mix, but that strength is improved when compared to a control mix.

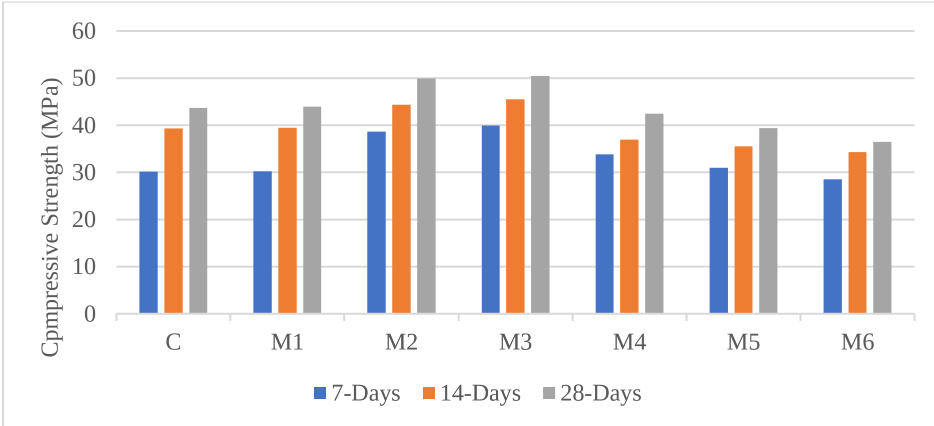


Figure 4: Compressive strength development of HSSCC mixture

3.2.2 Flexural Strength

Figure 5 presents the difference in flexural strength of concrete specimens. The study shows that concrete beams containing 10% and 20% dosages of FA in mixes somehow contribute toward flexural strength, however, the higher dosage of FA mixes exhibited low flexural strength. The increase flexural strength could be attributed to SF adherence to the matrix and improved bond quality, which is prevented crack propagation [23]. On the other hand, the percentage reduction in flexural strength of a concrete beam with the addition of FA after defined limits.

The results show that three mixes of HSSCC registered high flexural strength than the control mix (CC) by 5%, 7%, and 5.12% for M1, M2, and M3 respectively while the other three mixes with higher dosages of SCMs registered lower values by 14%, 16%, and 27% for M4, M5, and M6 respectively. HSSCC with 5% SFand10% FA (M2) register the higher flexural strength compared with all mixes.

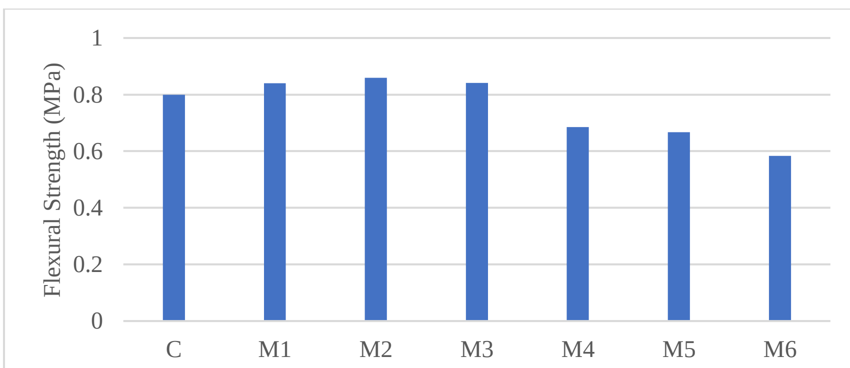


Figure 5: Flexural Strength HSSCC at 28 days

3.2.1 Split tensile test

The split tensile strength of concrete is measured using 150mm x 300mm concrete cylinders in accordance with ASTM C496/C496M-17 (ASTM C496/C496M 17 2011) specifications. The cylinder is placed horizontally inside the loading plates and two splitters are attached to these pates. The purpose of these splitters is to confine the load for splitting the concrete cylinder. The loading rate is adjusted to 1300 N/S. Study shows that mixing of FA and SF in concrete mixes adversely affects the split tensile strength of HSSCC concrete. In table 6 there are the results of the split tensile test that are obtained in this study.

Table 6 Split Tensile Strength Values

Split Tensile Strength (MPa)							
Age (Days)	**CC**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**
14	13.01	13.14	13.89	14.10	10.82	10.05	7.65
28	15	15.06	15.62	16.86	12.19	11.09	9.04

It is observed that concrete specimens containing dosages of SF and FA up to optimum limits exhibited higher resistance to load which is 8% and 12.4% higher in M3 (5% SFand20%FA) mix at 14 days and 28 days respectively as shown in figure 6. However, specimens with larger doses of SF and FA have lower tensile strength than control concrete, which are 41% and 39% lower at 14 and 28 days, respectively, in M6 (5% SFand50%FA) mix.

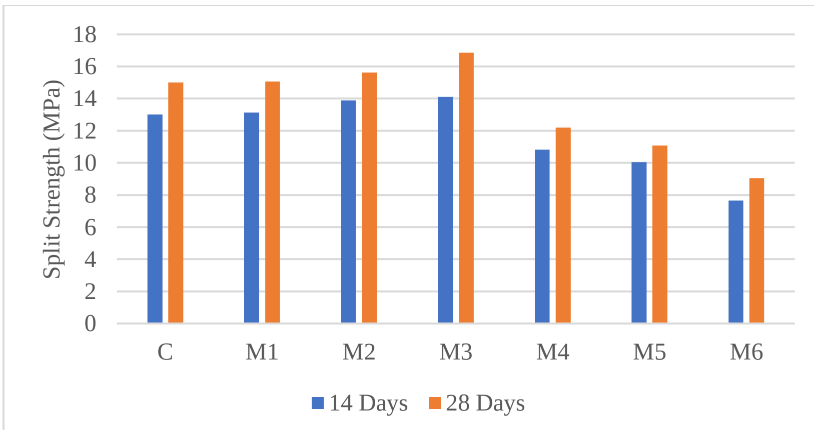


Figure 6: Split tensile strength development of HSSCC

4 Conclusion

SCMs (Silica Fume and Fly Ash) were used to partially substitute cement in concrete in this investigation. SCMs' impacts on concrete parameters like compressive strength, flexural strength, and the split tensile strength were investigated. From the experimental results, it was concluded that,

1. Adding SF and FA to high-strength self-compacting concrete increases its workability up to the optimal limit when the water-to-binder ratio is kept constant (5%SF and 20%FA). This is due to the FA content in the concrete mix. The greater surface area of the SF content causes a decrease in workability after the optimum limit.
2. Fresh characteristics of HSSCC which is indicated J-ring test and L-box test including FA and SF are better than the control mix. This is owing to the decreased viscosity and shear stress, which allow the concrete to flow more easily. This is because SF and FA particles have a lower specific gravity and are spherical in shape.
3. HSSCC mixes including SF and FA have better compressive strength than the control mix, but the compressive strength decreased as the SCMs replacement level increased, such HSSCC have 15% higher and 16% lower compressive strength of M3 and M6 mixes, respectively, at 28 days than control mix. Higher compressive strength of M3 mix is because of SF, it has more silica content which has cementitious properties and the lower compressive strength of M6 is due to low hydration of silica content.
4. Flexural strength of HSSCC including SCMs is 7.37% greater for M2 mix than the control mix. The increase flexural strength could be attributed to SF adherence to the matrix and improved bond quality, which is prevented crack propagation.
5. Split tensile strength of HSSCC containing SF and FA exhibited higher tensile strength which is 12.4% higher for M3 mix than control mix at 28 days. This is also pozzolanic effect of SF.

Thus, it is determined that the maximum SF and FA concentrations that can be employed to enhance the mechanical and fresh properties of HSSCC are 5% and 20%, respectively. The further increment of FA will decrease the mechanical and fresh properties of HSSCC.

Acknowledgement

The authors are appreciative to the editor and all reviewers for suggesting improvements to the paper, and they are grateful for the attentive review and constructive suggestions by the anonymous reviewers.

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