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Durability and Strength Properties Self-Compacting Mortars with High-Calcium Fly Ash and Silica Fume

Yüksek Kalsiyumlu Uçucu Kül ve Silis Dumanı İçeren Kendiliğinden Yerleşen Harçların Durabilite ve Dayanım Özellikleri

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Abstract

This paper aims to investigate the strength properties and durability of self-compacting mortars (SCMs) produced from C class fly ash (FA) and silica fume (SF) as mineral admixtures. SCMs were produced from the binary mixes of FA and SF by replacing Portland cement with 10%, 20%, and 30% by weight of C class fly ash (FA) and 6%, 10%, 14% by weight of silica fume (SF). The water-to-binder (w/b) ratio ranges from 0.37 to 0.48. A sum of 7 different mixtures with 630 kg/m3 binder were prepared to observe SCMs behavior in fresh and hardened conditions. Mini slump flow diameter, viscosity and mini V-funnel flow time tests were performed to assess the fresh properties of SCMs containing FA and SF. Specimens of 40x40x160 mm were produced and cured at the age of 7, 28 and 180-day for compressive and tensile strength tests and 50 mm cube specimens were prepared and cured at 28 days for durability tests (porosity and density). The results indicated that the compressive strength of binary mixes of FA reduces as the content of FA increases. Binary mix of SF10 reaches the highest tensile strength at the age of 180 days.

Keywords: Self-compacting mortar, Silica fume, Fly ash, Fresh properties, Strength properties, Durability

Öz

Bu çalışmada, C sınıfı uçucu kül (ÜK) ve silis dumanı (SD) 'den üretilen kendiliğinden yerleşen harçların (KYH) mukavemet özelliklerini ve dayanıklılıklarını araştırmayı amaçlamaktadır. KYH 'ler, Portland çimentosu yerine ağırlıkça % 10,% 20 ve% 30 oranında C sınıfı uçucu kül (FA) ve % 6,% 10,% 14 oranında silika dumanı (ağırlıkça) ikame ederek ÜK ve SD' lı ikili karışımlar üretilmiştir. Su/bağlayıcı (s/b) oranı 0.37 ila 0.48 arasında tutulmuştur. 7 farklı karışım toplam bağlayıcı miktarı 630 kg/m3 olan KYH ın taze ve sertleştirilmiş koşullarda davranışını incelemek için hazırlanmıştır. UK ve SD içeren KYH'ların taze özelliklerini ölçmek için mini slump çapı, viskozite ve mini V-huni akış süresi testleri gerçekleştirilmiştir. Basınç ve çekme dayanımlarını incelemek için 40x40x160 mm boyutunda numuneler 7, 28 ve 180 günlük suda kür edilmiş ve test edilmiştir. Durabilite özelliklerini incelemek için 50 mm boyutunda küp numuneler üretilmiş ve 28 gün suda kür edildikten sonra ve porozite ve görünür yoğunluk değerleri bulunmuştur. UK den üretilmiş ikili karışımlarının basınç dayanımının UK içeriği arttıkça azaldığını gözlenmiştir.%10 ikameli UK den üretilmiş nümünler 180 günlük kür sonucunda en yüksek çekme mukavemetine ulaştığı görülmüştür.

Anahtar Kelimeler: Kendiliğinden yerleşen harç, Silis dumanı, uçucu kül, Taze özellikler, Dayanım özellikleri, Durabilite

1. Introduction

Mineral admixtures replace cement in mortar mixtures and in some concrete types such as lightweight concrete, reactive powder, compacted cylinders and self-compacting concrete to enhance the mechanical properties and durability due to pozzolanic and/or self-cementing effects (Mardani-Aghabaglou et al. 2014). When mineral admixtures are examined, workability of fresh concrete, strength and durability of hardened concrete are the most interested features. Fly ash and silica fume are the most widely used mineral additives in concrete/mortar. Fly ash has very positive effects on concrete, such as reducing water demand and hydration heat, reducing bleeding and obtaining satisfactory durability (Wang et al. 2012). Silica fume is utilized as a mineral admixture to produce high performance

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concrete (HPC) instead of cement. It is stated that adding silica fume which is an effective pozzolanic material in concrete/mortar produces a more impermeable pore and discontinuous structure then the ordinary Portland cement. The hydration rate at early age resulting from the release of alkalis and OH- ions into pore fluids is also increased by the replacement of silica fume (Mardani-Aghabaglou et al. 2014, Zhu et al. 2013, Felekoglu et al. 2006). Furthermore, the benefits of using mineral admixtures in concrete are protecting nature and providing economy. Self-compacting concrete (SCC) which offers benefits in workability, reduces labour costs and high strength compared to conventional concrete has recently emerged as a new concrete technology and its use has increased rapidly over the last three decades and reflected in the number of published works. Self-compacting mortar (SCM) exhibits similar mechanical and durability properties to SCC and can be used to examine the performance mechanisms of the SCC (Sahmaran et al. 2006). Mortar forms the basis of SCC workability properties and these properties can be evaluated with SCMs. In fact, evaluating the properties of the SCMs is an integral part of the SCC design (Sahmaran et al. 2006, Domone et al. 1999). Super plasticizing and/or viscosity regulators which reduce water at high levels in SCC/SCM production are used (Sonebi 2004, Mohamed 2011, Silva et al. 2015). While the use of superplasticizer maintains fluidity, it ensures the stability of the fine-content mixture and thus obtains resistance against bleeding and separation. The addition of fly ash and silica fume to SCC decreases the amount of superplasticizer required to provide a similar slump flow as compared to mixtures produced only from Portland cement (Mohamed 2011, Yahia et al. 1999). Wongkeo et al. (Wongkeo et al. 2012) pointed out that the compressive strength of the autoclave cured binary and ternary mixes of mortars incorporating FA and SF. They concluded that the compressive strength of the binary mixes of mortar with FA had a tendency to reduce with increasing FA content and revealed a lower compressive strength than the control specimens. On the other hand, binary mixes of SF had improved the compressive strength and when compared to control specimens, the compressive strength had a higher value. Poon et al. (Poon et al. 1997) did research on the effects of various curing regimes on the pore structure and respective properties of mortars containing FA. They found that the interfacial zone between the pastes and the aggregates was improved by F class fly ash. Another study of Wongkeo et al. (Wongkeo et al. 2014) explored chloride resistance and compressive strength of SCC , which contains binary and ternary mixes of C class fly ash and silica fume. The study revealed that the compressive strength of SCC at 3, 7, 28 and 90 days of age generally declined. However, the compressive strength of ternary mixes of fly ash and silica fume showed better performance after 7 days with respect to binary mixes of fly ash for the same content. Leung et al. (2016) studied sorptivity of SCC containing F class fly ash and silica fume. The research indicated that fly ash and silica fume considerable decreased the sorptivity of SCC at a w/b ratio of 0.38. Siddique (2013) showed that sorptivity of SCC mixes increased as the bottom ash content get increased. In this study, standards issued by EFNARC were utilized (Kunther et al. 2013). According to EFNARC; workability of self-compacting concrete can be provided with filling capability, suitable viscosity determined by the flow rate, the ability to pass through the narrow section and the separation resistance (Karatas et al., Kunther et al. 2013). Limiting amount of coarse aggregate is common method to achieve the high fluidity of SCC/SCM. The main goal of the paper is to examine the mechanical characteristics of self-compacting Mortars (SCMs) at different curing times (7, 28 and 180 days) and durability properties at the age of 28 days. For this purpose, Binary mixtures of SCMs were prepared and produced by replacing Portland cement with different replacement contents of C class fly ash (FA) silica fume (SF). A sum of 7 different mixtures with 630 kg/m^3 binder were prepared to observe SCMs behavior in fresh and hardened conditions. The w/b ratio ranges from 0.37 to 0.48. Hardened properties were evaluated by 7, 28 and 180 days of compressive strength and flexural strength tests. Mini slump flow diameter, viscosity and mini V-funnel flow time tests were performed to assess the fresh properties of SCMs containing FA and SF. In addition, durability Porosity and apparent density) characteristics of SCM samples cured at 28 days were also evaluated.

2. Materials and Method

The study aimed to explore the strength properties and durability of SCMs by using binary combinations of fly ash and silica fume at water curing at the age of 7, 28, and 180 days . 40x40x160 mm specimens were manufactured from different fly ash and silica fume replacement ratio for compressive and tensile testing of SCMs. The mini V-funnel flow and mini slump flow tests recommended by EFNARC (EFNARC 2002) were carried out to assess the characteristics of fresh properties of SCM. In addition, viscosities of fresh mortars were also measured. Furthermore, Porosity and apparent density were determined on 50 mm cube samples exposed to water curing for 28 days.

2.1. Materials

Ordinary Portland cement (CEM I 42.5N) was used to produce the seven different SCM mixtures. Class C fly ash (FA) got from Soma Thermal Power Plant and silica fume (SF) obtained from Antalya Electro Metallurgy Enterprise were used as mineral additives. The properties of cement and mineral additives are tabulated in Table 1.

The fine aggregates used in the mixtures were natural river sand having specific gravity, fineness modulus and water absorption of 2.63 gr/cm^3, 3.29 and %1.91 respectively. The maximum particle size of sand was 4.00 mm. (Figure 1) In addition, a modified polycarboxylate-based polymer type superplasticizer (SP) is required to achieve a suitable workability with a low water/ binder (w /b) ratio.

Table 1. Properties of Portland cement, fly ash and silica fume.

Chemical Components (%)	PC	FA	SF
SiO_2	21.12	38.34	91.0
Al_2O_3	5.62	16.69	0.58
Fe_2O_3	3.24	5.11	0.24
CaO	62.94	27.62	0.71
MgO	-	1.60	0.33
SO_3	2.3	4.44	-
Na_2O	-	-	-
K_2O	-	-	-
CI	-	-	-
Loss in ignition	3.52	0.79	1.84
Physical Properties			
Specific Gravity (g/cm^3)	3.1	2,50	2,2
Specific Surface Area (cm^2/g)	3490	1343	96,5%< 45μm

Table 2. Properties of superplasticizer.

Material structure	Modified polycarboxylates based polymer
Density (gr/cm^3)	1.06
pH	3 – 7
Freezing point (°C)	-4
Clor content % (TS EN 934-2)	< 0.1
Alcali content % (TS EN 934-2)	<3

2.2. Mix Proportions and Fresh Mortar Tests

A sum of 7 different mixtures containing 630 kg/m^3 binder, including the control sample, were prepared to observe the characteristics of the SCM in fresh and hardened states. Mini slump flow diameter, mini V-funnel flow time and viscosity tests were performed to assess the fresh features of SCMs containing FA and SF. SCMs were produced by replacing Portland cement with 10%, 20%, and 30% by weight of C fly ash (FA) and 6%, 10%, 14% by weight of silica fume (SF). The mixing ratios of the produced mortars for 1 m^3 by weight) are given in Table 3. The SCMs are designed to give a slump flow diameter of 240-260 mm obtained by modifying the SP quantities. Experimental batches were fabricated for each mix to obtain the recommended sump flow diameter. V-funnel flow time and slump flow diameter were obtained as per EFNARC recommendations. The number after each letter FA and SF indicates the amount of each mineral admixture in the mortar. For example, the FA10 mortar consists of 10% fly ash.

2.3. Production of Test Specimens

For this work, in all the mixes, cement, mineral additives and sand were first mixed for 1 min. Then, SP and water were poured and mixed for extra 4 min. The workability of fresh mortar was achieved by V-funnel tests and mini slump as per EFNARC standards. The compressive and flexural tensile strengths were conducted on 160 x 40 x 40 mm prisms after 7, 28 and 180 days in water curing. For durability tests, 50 mm cube samples, cured in water for 28 days, were used.

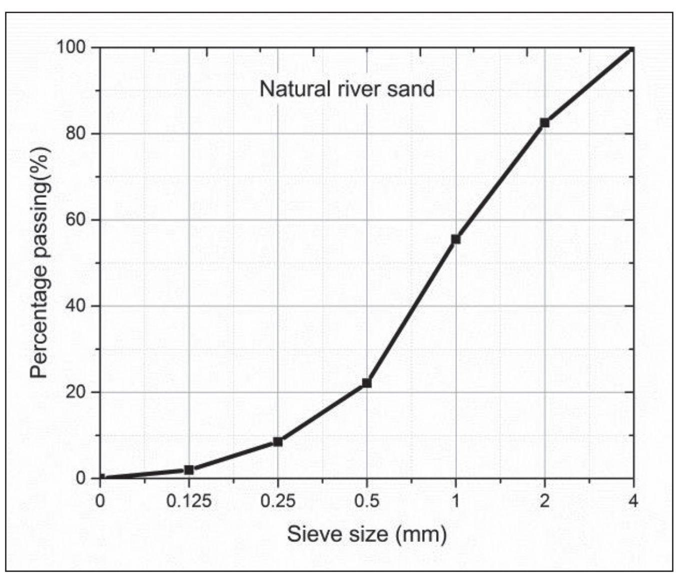

Figure 1. Particle size distribution of natural river sand.

Table 3. Mix proportion of mortars (kg/m³)

Mix Code	Amount of Ingredient (kg/m³)						
	Binder			Sand	SP*	w/b(by volume)	w/b (by mass)
	PC	FA	SF				
Control	630	0	0	1306.24	7.00	1.21	0.39
FA10	567	63	0	1271	7.00	1.24	0.41
FA20	504	126	0	1238	7.00	1.27	0.43
FA30	441	189	0	1154	7.00	1.39	0.48
SF6	592.2	0	39	1324	8.00	1.13	0.37
SF10	567	0	58.5	1282	8.00	1.17	0.40
SF14	541.8	0	78	1240	8.00	1.22	0.42

* ***SP** = superplasticizer.*

2.4. Curing of Test Specimens

All specimens that are produced from seven different mixes are exposed to water curing which is performed in the water tank at the temperature of 20±2°C for the duration of 7, 28 and 180 days after they are kept in laboratory conditions for 24 h until demoulding.

2.5. Test Methods

2.5.1 Workability and Rheological Tests for Fresh Mortar

The V-funnel flow test and mini slump flow test were conducted according to EFNARC (2002) while measuring workability of SCM. In the mini slump flow test, the truncated cone was filled with mortar on a flat plate and lifted upwards. The diameter was evaluated by averaging the two vertical dimensions of the mortar. In the V-funnel flow test, the bottom outlet was opened to allow the mortar to flow out after fully filling the funnel with mortar. The V-funnel flow time was the time (t) between the opening of the bottom outlet from the beginning of the light and outlet of funnel. The workability values of SCMs were considered according to EFNARC (2002) acceptance criteria with 24-26 cm and 7-11 s for slump-flow diameter and V-funnel flow time, respectively. Viscosity was measured with a rotational viscometer. This was done at different rotational speeds. The fresh mortar was put into the bowl of the viscometer (Benabed et al. 2012). Viscosity values were calculated immediately after mixing, at rotational speeds of 1, 2.5, 5, 10, 20, 50, 60 and 100 rpm.

2.5.2. Compressive and Flexural Strength Tests

After the first fresh mortar test is completed, the mortars are cast into a 40x40x160 mm steel moulds, after 24 hours, they were demoulded. After demoulding, specimens were subjected to water curing at a temperature of (20 ± 2) C until the age of testing. The compressive and flexural strength tests were realized as per ASTM C109 (ASTM C109, 2007) at 7, 28 and 180 days, in four series of 40x40x160 mm prismatic specimens obtained from each of 7 mixtures. Initially, the tests were performed for tensile strength resulting in two halves then they were used for compressive strength tests (Rao et al. 2015). The compressive strength and tensile strength tests were conducted on a testing machine having a capacity of 250 kN in compression and 150 kN in bending.

2.5.3 Porosity and Apparent Density Tests

Porosity and apparent density of SCMs were measured at the age of 28 days as per ASTM C642 (ASTM 1997). For the porosity and density tests, the cubes were weighed under water (W_2) and in the saturated surface-dry (W_3) condition (Chen et al. 2013, Galle 2001). Each specimen was then dried until reaching a constant weight at 105 ° C in a carbon dioxide free oven (W1). The weight difference between water saturated and oven dry conditions was utilized to determine the porosity clarified as the percentage volume of the bulk specimen. The values were determined using Eqs. (1 and 2). The results were the average of three samples (Figure 2).

$$\textit{Porosity (\%)} = \frac{W3 - W1}{W3 - W2} \times 100 \quad (1)$$

$$\textit{Apparent Density} = \frac{W1}{W1 - W2} \quad (2)$$

3. Results and Discussion

3.1. Fresh-State Properties

Relative slump and relative V-funnel time values are presented in Table 4. It is obvious that SCM mixtures ensured EFNARC (2002) recommendation for relative slump and relative funnel speed. When relative slump and

Table 4. Mini-cone slump-flow and mini V-funnel test results.

	Control	FA10	FA20	FA30	SF6	SF10	SF14
Mini-cone slump-flow (mm)	250	257	256	251	252	251	250
Relative slump	5.30	5.60	5.60	5.30	5.40	5.30	5.30
Mini-V-funnel (s)	10.20	10.10	10.40	10.80	10.90	10.90	10.80
Relative V-funnel	1.0	1.0	1.0	0.9	0.9	0.9	0.9

relative funnel speed values are examined, it is seen that all the values are in the reference range. SF mixes have generally low relative slump values. SCMs with 6% of SF are much more cohesive than mortars made only with Portland cement. Table 4 shows the relative funnel speed values that are between 0.9-1.4 as suggested by EFNARC (2002) (Turk 2012, Felekoglu et al. 2006). The relative funnel speed of binary mixes of FA10 and FA20 is higher that all binary mixes and almost the same as the control mix. It can be concluded from Table 4 that the workability of binary mixes of FA is better that the other mixes of SCMs except FA30. Viscosity measurements were also made for all mortars. The viscosity development of SCMs containing binary mixtures of FA and SF evaluated at various rotational speeds is plotted in Figure 3. With increasing rotational speed of the rotary tip across the mortars, the viscosity of all SCMs decreased and the viscosity curves showed an asymptotic approach towards the X axis. When Figure 3 is examined, the viscosities of SCMs decrease regularly by increasing the rotational speed from 1 rpm to 100 rpm. As seen in Figure 3, the viscosities of FA-containing mortars are considerably higher than those of control mixture and SF-containing mortars. As the content of FA in binary mixes increases, the viscosity values also increase. The viscosity values of the mortars containing SF are also higher than the control sample. As shown in Figure 3, the viscosity values decrease as the SF content increases in the mortar. As the angular velocity increases, the viscosity values of the mixtures containing SF are higher than control mortar and mortars with FA. The energy required to bring about a flowing consistency can be said to be lower for mortars with FA than for mortars containing SF with binary mixes at high speeds.

3.2. Hardened Properties

Compressive strength and tensile strength, especially for samples containing FA, are very low for all mineral additives levels at an early age of curing. However, with the increasing curing time, the compressive strength and tensile strength of all SCM samples increased.

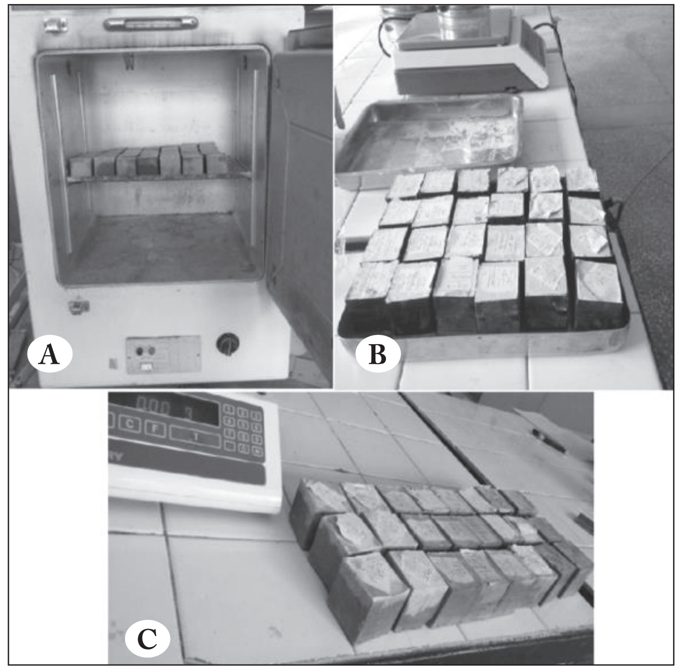

Figure 2. A) Specimens in the oven **B)** Specimens in the desiccator **C)** Water absorbed specimens after 24 h.

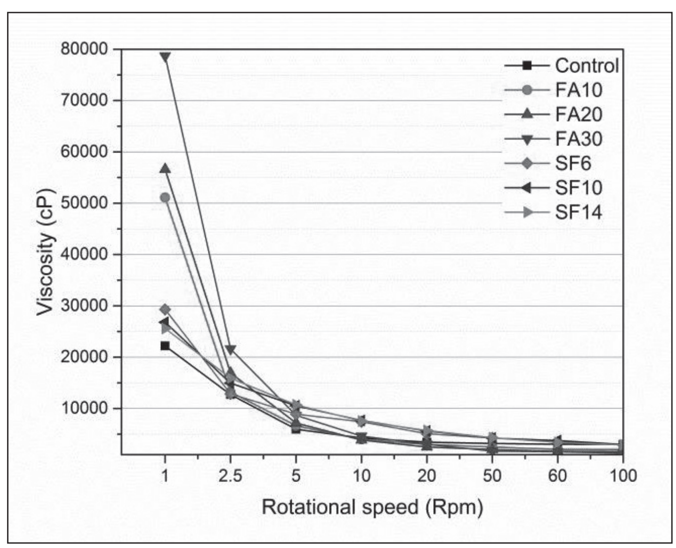

Figure 3. Viscosity of SCMs containing binary mixes of FA and SF.

3.2.1 Compressive Strength

The variation of compressive strength of all mixes of SCMs at the age of 7, 28 and 180d were in the range of 23.13–83.32 MPa, while the lowest value belongs to binary mix of FA30 at the age of 7 days and the highest value belongs to binary mix of FA10 at the age of 180 days as indicated in Figure 4. Variation of compressive strength of all SCMs at the age of 7, 28 and 180 days is plotted in Figure 4. The compressive strength increases gradually while the curing time increases and it reaches the highest value of 83.32 MPa for the binary mixes of 10% of FA at 180 days. The compressive strength of binary mixes of FA reduces as the content of FA increases up to 30% which has the lowest value in all SCMs. FA10 and SF6 performed well in the binary mixes of SCMs. The slow pozzolanic reaction and the dilution effect of FA caused the decrease in compressive strength of the FA blended of SCMs. Binary mixes of SF have higher compressive strength than binary mixes of FA. This can be explained that SF has a larger pozzolanic reaction and micro-fill effect (Wongkeo et al. 2014). The filler effect and the pozzolanic reaction of SF have conduced a denser microstructure and thus an increase in compressive strength. In addition, SF-blended mixtures have a greater effect on compressive strength than the control and FA blends, since the smaller particle size and the higher specific surface area of SF cause more pozzolanic reaction than FA (Wongkeo et al. 2010). A lot of research has come to the conclusion that hardening has slowed down by the replacement of FA (Turk 2012, Aprianti et al. 2016, Wong et al. 1999).

Replacement of 10% PC by FA enhances the compressive strength of SCMs but further increase in FA content leads to a reduction in compressive strength. On the contrary, addition of SF generally increases the concrete strength. This reduced strength for FA concrete and the enhanced strength for SF concrete were also reported by other researchers (Tasdemir 2003, Dinakar et al. 2008, Hassan et al. 2012). Since the average particle size of FA is higher than that of SF, the pores in the paste and interfaces are not completely filled, therefore excessive use of FA leads to a lowered strength. However, the strength development in SF series is due to the pozzolanic reaction (Leung et al. 2016)

3.2.2 Flexural Tensile Strength

Figure 5 indicates the tensile strengths of SCMs in binary mixes of SF and FA relative to that of the control mix at water curing at the age of 7.28 and 180 days. The values of tensile strength of all mixes of SCMs were in the range of 4.49–10.40 MPa. The lowest value belongs to binary mix of FA30 at the age of 7 days and the highest value belongs to binary mix of SF10 at the age of 180 days. As plotted in Figure 5, flexural tensile strength of SF14 performed the best at the age of 28 days. Binary mix of SF10 reaches the highest tensile strength at the age of 180 days. The flexural tensile strength of all binary mixes of SCMs increases as the curing periods increases. The biggest increment occurs for the mix of SF10 whose tensile strength increases 17.64% as curing period changes from 28 days to 180 days.

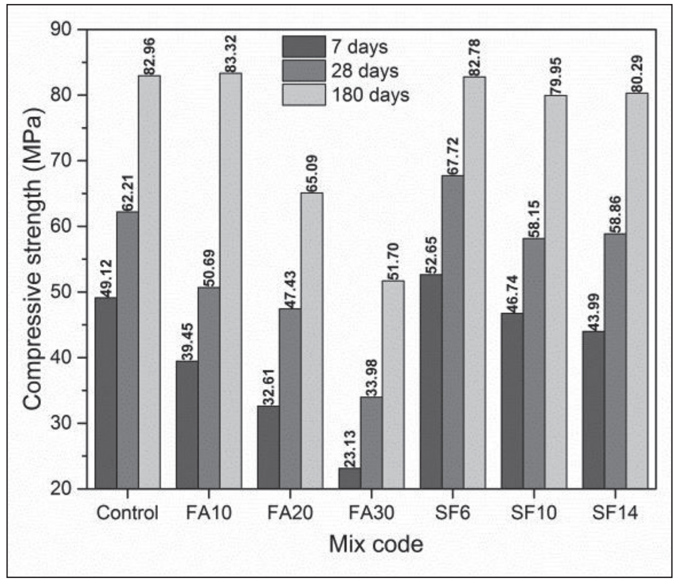

Figure 4. Compressive strength of SCMs of all mixes at the age of 7, 28 and 180 days.

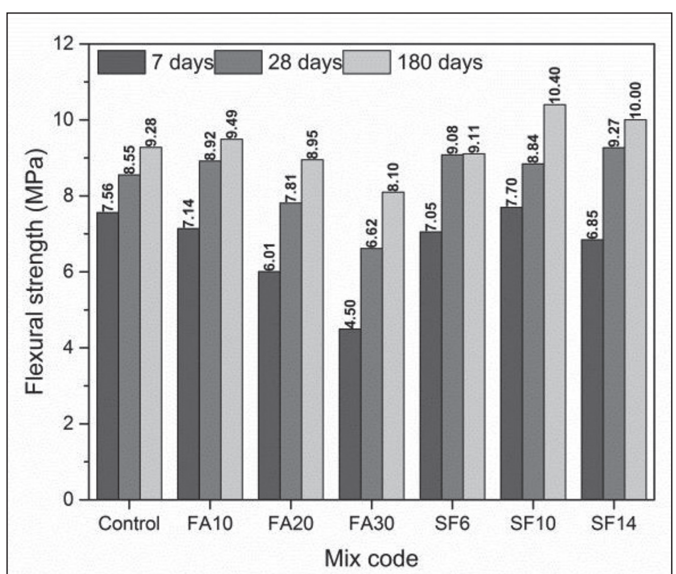

Figure 5. Flexural tensile strength of SCMs of all mixes at the age of 7, 28 and 180 days.

Binary mixes of SCMs containing FA have a decreasing tensile strength with the increasing FA content. The flexural strength of SCMs incorporating high content of FA is lower than control specimens. The reduction of the flexural strength of binary mixes of the SCMs containing FA is due to the slow pozzolanic reaction and the dilution effect. FA is also a bit coarser so the reaction is a bit slow (Turkel et al. 2009). Binary mixes of SCMs with SF10 and SF14 have higher tensile strength than the control and FA mixes of SCMs. The reason for this can be explained that SF has a larger pozzolanic reaction and micro-fill effect (Wongkeo et al. 2014). The ratio of w/b also affects the flexural strength of FA mixes of SCMs adversely. FA30 has the lowest tensile strength with the highest w/b ratio of 0.48 as compared to other binary mixes of FA and SF. This may be attributed to increasing pore content and due to higher w/b ratio. Figure 6 shows the variation of compressive and flexural strengths with respect to FA replacement at the age of 28 days. As shown in Figure 6, there is a good correlation between the compressive and flexural strengths of SCMs mixes with respect to the replacement ratio of FA. Figure 7 plots the variation of compressive and flexural strengths with respect to SF replacement at the age of 28 d. As seen in Figure 7, the correlation of compressive strength with respect to SF replacement ratio is not good as compared to that of FA.

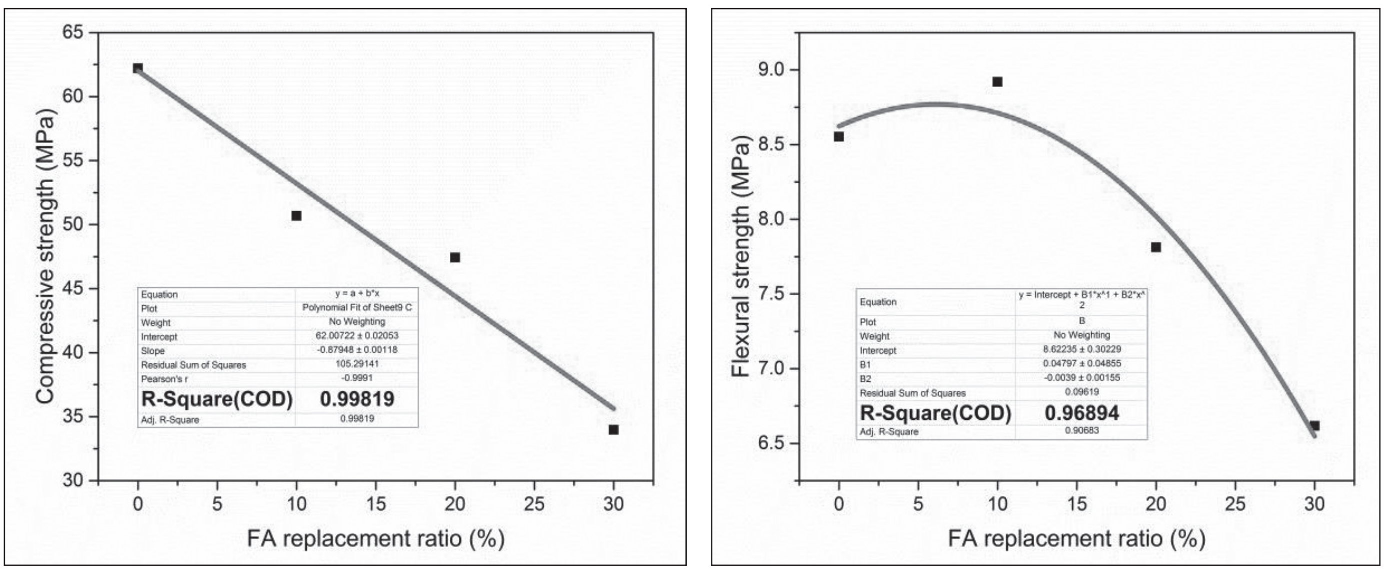

Figure 6. Variation of compressive and flexural strengths with respect to FA replacement at the age of 28 d.

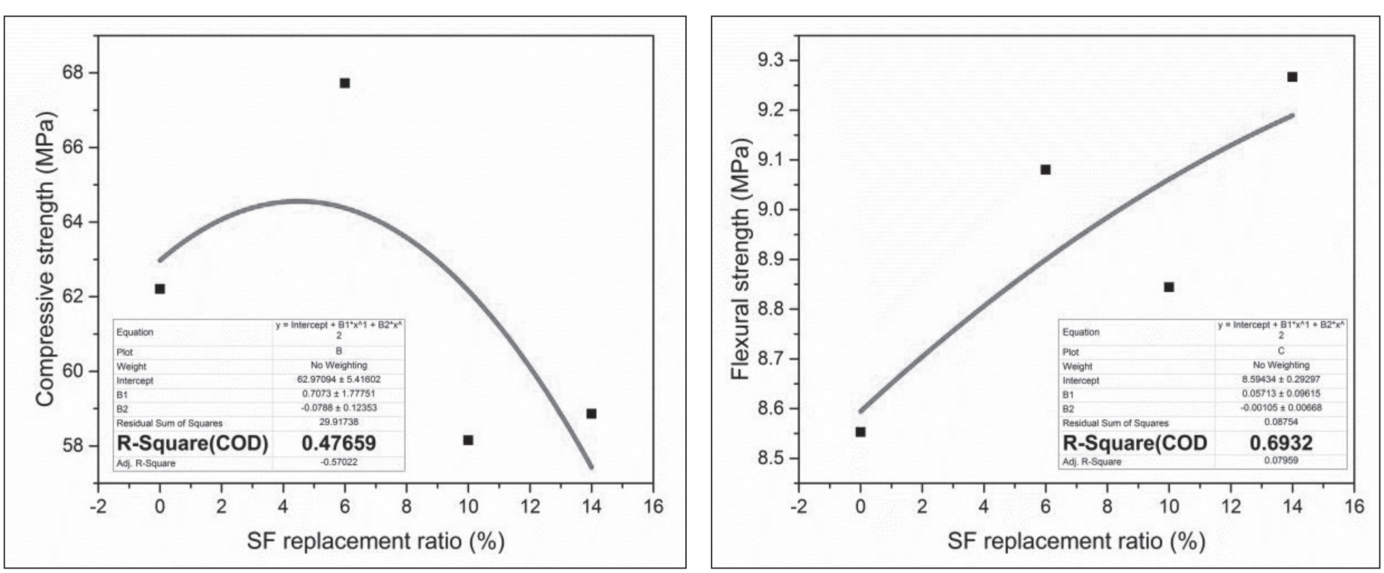

Figure 7. Variation of compressive and flexural strengths with respect to SF replacement at the age of 28 d.

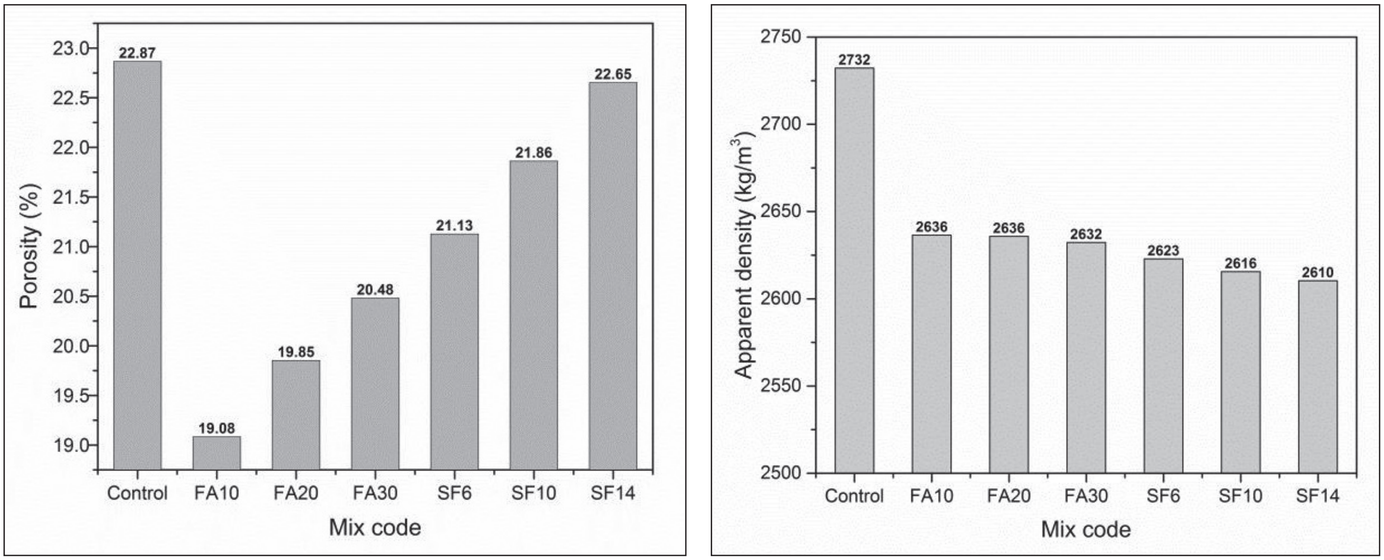

Figure 8. Porosity and apparent density of all mixes of SCMs at the age of 28 d.

3.2.3. Porosity and Apparent Density

Figure 8 shows the porosity and apparent density of all binary mixes of SCMs at the age of 28 days. The porosity water absorption provides additional information about pore volume and connectivity (Torres et al. 2009). The control specimens have the highest porosity as compared to all binary mixes of SCMs. The porosity of binary mixes of SCMs containing FA increases as the content of FA increases. This can be expressed as the cement dilution effect and slow pozzolanic reaction of FA. The same trend occurs for the binary mixes of SCMs incorporating SF which has high pozzolanic reaction and filler effect. SF14 has the highest porosity in all binary mixes SCMs with FA and SF. Pitroda et al. (Pitroda et al. 2013) has also come to the conclusion that increasing trend of capillary water absorption and porosity with increasing replacement level of OPC with FA (Hossain et al. 2016, Pitroda et al. 2013). The density of control specimens has the highest density as compared to binary mixes of FA and SF at the age of 28 days. Similar to porosity variation in binary mixes of SCMs, a slight reduction occurs in the density of SCMs. Variation of porosity and apparent density of SCMs with respect to FA replacement ratio is seen in Figure 9. As shown in Figure 9b, the porosity decreases parabolically up to about 18% FA replacement then porosity increases as FA replacement increases up to 30%. Variation of density of SCMs with respect to FA replacement at the age of 28 days is given in Figure 9a. The density decreases parabolically up to about 21% FA replacement then porosity increases as FA replacement increases up to 30%. Variation of porosity and apparent density of SCMs with respect to SF replacement ratio is seen in Figure 10. There is a good correlation between the density and porosity with respect to SF replacement ratio. As shown in Figure 10a, the density of SCMs decreases parabolically up to the content of about 22% of SF then increases as the content of SF increases. The porosity variation is also parabolic and decreases to the content of about 17% of SF then increases.

4. Conclusion

This paper presents an experimental study to specify the strength characteristics and durability of SCMs produced from the binary mixes of FA and SF. The following findings that are based on the obtained results from this study can be drawn:

- All of the concrete mixes examined provide satisfactory fresh self-compacting properties, In addition, the FA series performed better with workability properties when compared to the SF series. The viscosities of FA-containing mortars are considerably higher than those of control mixture and SF-containing mortars
- The compressive strength increases gradually while the curing time increases and it reaches the highest value of 83.32 MPa for the binary mixes of 10% of FA at 180 days Binary mix of SF10 reaches the highest tensile strength at the age of 180 days.
- The density of control specimens has the highest density as compared to binary mixes of FA and SF at the age of 28 days.

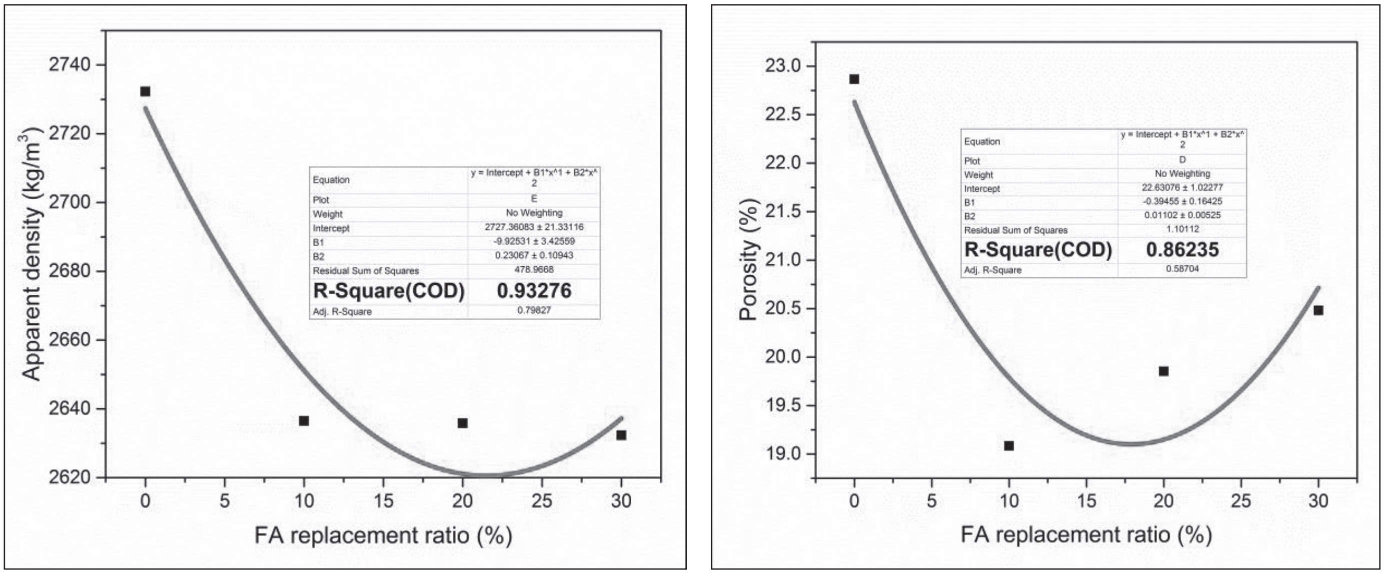

Figure 9. Variation of apparent density and porosity with respect to FA replacement at the age of 28 d.

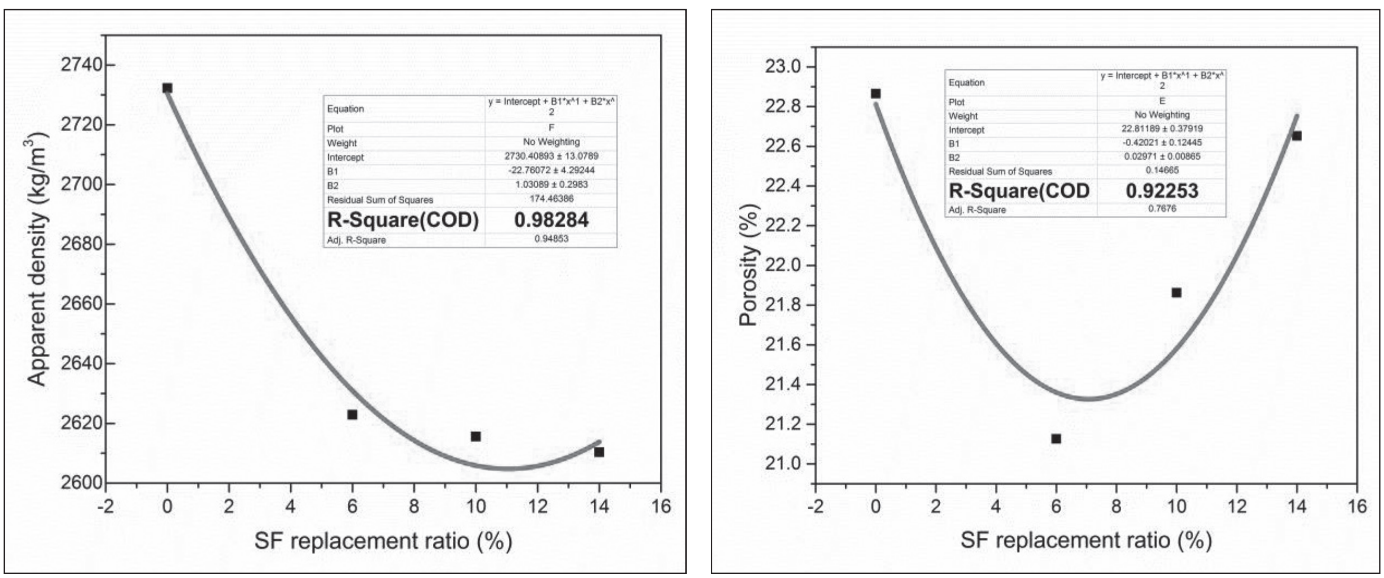

Figure 10. Variation of apparent density and porosity with respect to SF replacement at the age of 28 d.

- The increase in content of SF caused the increase in compressive strength; the increase in FA content affected compressive strength in the reverse direction.
- The highest flexural tensile strength values were obtained from binary mixes of SF at the age of 28-day.
- The porosity of binary mixes of SCMs containing FA increases as the content of FA increases.

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