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Influence of Fly Ash on the Properties of Self-Compacting Fiber Reinforced Concrete

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Keywords: compressive strength, fly ash, fresh concrete, polypropylene fibers, self-compacting concrete.

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Influence of Fly Ash on the Properties of Self-Compacting Fiber Reinforced Concrete

Abdullah Mohsen Ahmed Zeyad [α] & Abdullah Mustafa Saba [σ]

Abstract- Self-compacting concrete (SCC) has high flowability and high resistance to segregation and bleeding. These characteristics facilitate the mixing, casting and finishing of SCC without using compacting or vibrating machines. Adding mineral admixtures, such as fly ash (FA), and superplasticizers improves SCC properties by preventing segregation and bleeding and by increasing rheological parameters. SCC requires high flowability under the influence of self-weight to completely fill all mold parts for full compaction. This investigation discusses the results of experimental tests on the properties of SCC and self-compacting fiber reinforced concrete (SCFRC) mixtures with the inclusion of polypropylene fibers (PFs) and containing FA at replacement rates of 0%, 20%, 40%, and 60 % cement mass. The compressive, flexural, and split tensile strengths of the prepared concrete samples were investigated at ages of 7, 14, 28, and 90 days. The workability of fresh concrete mixtures was also studied through segregation, bleeding, slump flow, slump flow T50, L-box V-funnel T5, and V-funnel tests. Results showed that the best properties of fresh SCCs were obtained when FA was added at replacement rates of 20% and 40% cement mass. In addition, the inclusion of PFs at a volumetric ratio of 0.22% decreased segregation and bleeding and improved the flexural and tensile strengths of SCFRCs.

Keywords: compressive strength, fly ash, fresh concrete, polypropylene fibers, self-compacting concrete.

I. Introduction

Self-compacting concrete (SCC) and self-compacting fiber reinforced concrete (SCFRC) are special types of concrete mixture that is characterized by resistance to bleeding and segregation. SCC can be cast without need to using vibration machine or compaction. Products made with SCC have high quality, excellent finish, and are virtually free of flaws, such as large voids, because of the excellent filling ability of SCC without honeycomb formation (Okamura and Ouchi, 2003; Brouwers and Radix, 2005; Nanthagopalan and Santhanam, 2011). SCC is produced with the addition of fine industrial wastes, including fly ash (FA), silica fume, and furnace slag (Siddique, 2011). FA and some types of pozzolanic materials have been successfully used as mineral admixtures in SCC (Gesoglu and Ozbay, 2007; Ramanathan et al., 2013). The addition of mineral admixtures results in the sufficient viscosity of SCC, consequently reducing bleeding, segregation, and plastic shrinkage. In addition to fine mineral admixtures, agricultural waste materials, including palm oil fuel ash or rice husk ash, can be used as admixtures in SCC (Safiuddin et al., 2011; Mohammadhosseini et al., 2015). FA is added to concrete mixtures to prevent segregation and bleeding, increase flowability, and control hardened concrete properties, including compressive, indirect tensile, and flexural strengths (Siddique, 2012; Ashtiani et al., 2013; Celik et al., 2014;). The use of FA in SCC production requires the addition of a superplasticizer (SP) to the concrete mix to achieve high workability and appropriate mix proportions. A high SP dosage, however, increases bleeding and segregation in fresh concretes. These problems can be avoided by adding a viscosity-modifying admixture (VMA) to increase the viscosity of fresh concretes. Furthermore, the use of fine mineral admixtures can reduce the amount of SPs required to achieve the desired rheology. Moreover, the use of FA as an alternative material reduces the need for VMAs (Ouchi et al., 1997; Cyr and Mouret, 2003; Felekoğlu et al., 2007). Nevertheless, replacing the fine mineral admixtures of cement mass, especially at high mass replacement, affects the characteristics of SCCs because of the variations in cement mass and in water/cement ratio. The addition of fibers improves the flexural strength, toughness, and tensile strength of concrete. Numerous researchers have reported that adding fibers at volumetric ratios of 0.1% to 1.0% improves the strength and engineering properties of ordinary concrete (Mohamed, 2006; Banthia and Gupta, 2006; Al Qadi et al., 2011; Islam and Gupta, 2016). The addition of fibers to concrete, however, has negligible effects on compressive strength and the modulus of elasticity. Moreover, the workability and flowability of SCRFCs decrease upon the addition of polypropylene fibers (PFs). The reduction of SCRFC workability due to the addition of fibers depends on many parameters, such as fiber type, dosage, and shape (Corinaldesi and Moriconi, 2011; El-Dieb and Taha, 2012). FA has been successfully added to SCC at replacement rates of up to 60% cement mass, and at a replacement rate of 35% cement mass to cement mixtures without the inclusion of PFs. Previous studies on the properties of SCCs have reported that replacing 30% of cement mass with FA produced concretes with excellent flowability and workability without the addition of fibers. The goal of the present investigation is to study the properties of fresh

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and hardened SCC and SCRFC. In this study, FA was added at replacement rates of 0%, 20%, 40%, and 60% cement mass. Then, PFs were added to the cement mixtures at a volumetric ratio of 0.22% to produce SCFRC. Segregation, bleeding, slump flow, slump flow T50, L-box V-funnel T5, and V-funnel tests were conducted on fresh concrete. In addition, the compressive, flexural, and tensile strengths of hardened concrete at ages 7, 14, 28, and 90 days were investigated.

II. Materials and Methods

a) Materials

The tests carried out in order to study behavior the SCC during states the fresh and hardened concrete with (SCCF) and without polypropylene. The Slump flow, slump flow T50, L-box V-funnel T5, V-funnel, segregation and bleeding tests are conducted during the fresh state. After casting then curing concrete samples in the water basin until the ages of testing, compressive, tensile and flexural strength tests have been carried out. Production of the SCC and SCCF requires application stringent on materials selecting and its quality, also determine the proportions all of the ingredients according to the mix design method, taking into consideration.

b) Cement

Ordinary Portland cement (OPC) was used in the present investigation. Cement characterization tests were conducted in accordance with ASTM C150 (ASTM, 2004). Tables 1 and 2 shown the chemical composition and physical characteristics of cement respectively.

Table 1: Percentage of Oxide Composition and Main Compounds

Oxide composition	Abbreviation	Content (percent)	Limit of ASTM specification
Lime	CaO	63.68	60-67
Silica	SiO_2	20.68	14-25
Alumina	AL_2O_3	6.12	3-8
Iron Oxide	Fe_2O_3	3.8	0.5-6
Sulphate	SO_3	2.68	1-3
Soda	Na_2O	0.29	0.2-1.3
Potassa	K_2O	0.42	
Magnesia	MgO	1.21	0.1_4
Loss on Ignition	L. O. I	1.55	≤ 4
Tricalcium Silicate	C_3S	41.51	45-55
Di Calcium Silicate	C_2S	28.16	20-30
Tri Calcium Aluminate	C_3A	9.87	8-12
Tetra Calcium Alumina Ferrite	C_4AF	11.57	6-10

Table 2: Cement Physical Properties

Physical properties	Test Results	Limit of ASTM specification
Specific Surface area (Blaine method , cm^2/gm)	3220	≥ 2300.0
Initial Setting time, min	120	Min 30
Final Setting time, min	480	Mix 365
Compressive strength of mortar: 14- days, MPa	27	Min 19

c) Fly ash

FA meets the general requirements of ASTM C618 Class F (ASTM, 2004). Table 3 presents the chemical composition and physical characteristics of fly ash.

Table 3: Chemical and Physical Properties of FA

Oxides	Content %	ASTM C 618 Class F
SiO_2	51.45	>70%
Fe_2O_3	5.19	
Al_2O_3	27.26	
CaO	7.73	-
MgO	5.16	-
SO_3	0.5	5.0 max
K_2O	2.5	-
L.O.I	0.19	6.0 max
Physical Properties		
Fineness (Blain)	4020 cm^2/g	-
specific gravity	2.32	-

d) Aggregate

A crushed basalt rock with a maximum size of 12.7 mm was used as a coarse aggregate (CA), and natural sand was used in the concrete mixtures as a fine aggregate (FA). The CA and FA had a specific gravity of 2.63 and 2.71, and water absorptions of 0.6 and 0.9 % respectively.

e) Fine Aggregate

The particle shapes and grade of FAs are important factors in SCC production. In this investigation, natural sand, which conforms to ASTM C33 specification, (ASTM, 2004) was used. Table 4 shows the grading analysis of FA.

f) Coarse Aggregate

Table 4 shows that the grade of the CA, which conforms to the ASTM C33 specifications (ASTM, 2004).

Table 4: Grading of Coarse and Fine Aggregate

Sieve size (mm)	% Passing by weight	
	FA	CA
19	100	100
12.5	100	95
9.5	100	66.3
4.75	96.4	4.3
2.36	92.5	1.4
1.18	78.4	0
0.60	40.8	0
0.30	11.6	0
0.15	3.1	0
Fineness Modulus	2.8	-

g) Polypropylene fibers

In this paper, 12 mm PFs were used, some of their physical properties are provided in Table 5.

Table 5: Physical properties FPs

Properties	FPs
Form	White color fibers
Density	0.91 kg/l
Fiber Length	12 mm
Fiber Diameter	18 micron
Softening point	160 °C
Specific surface area	200 m^2 / kg
Tensile strength (MPa)	350 MPa

h) Superplasticizer

High-reduce water range (HRWR) superplasticizer, a new generation of copolymer-based superplasticizer, designed for the production of self-compacting concrete (Viscocret 5030), was used in this study.

i) Mix design methods

Mix design methods for SCC differ considerably from the regular conventional concrete design. There are many mix design methods. Estimating the required batch weights involves sequence of steps. These steps fit a proportioning procedure that covers a combination of: selection of aggregate to provide the desired passing ability; a cementitious (powder)/water ratio and mortar-paste fraction ratio that have been historically proven to produce SCC with the required slump flow; and stability. These steps, in combination with the addition of the appropriate admixture technology, should yield a trial batch with the desired fresh SCC properties. The following is a summary of steps for determining performance requirements and proportioning of SCC mixes.

Step 1: Determine slump flow performance requirements;

Step 2: Select coarse aggregate and proportion;

Step 3: Estimate the required cementitious content and water;

Step 4: Calculate paste and mortar volume;

Step 5: Select admixture;

Step 6: Make trial batch mixtures;

Step 7: Test. When assessing the workability attributes of SCC (stability, filling ability, and passing ability), the slump flow test as well as a test to evaluate stability and passing ability (such as column segregation, or L-box) should be run; and

Step 8: Adjust mixture proportions based on the test results and then re-batch with further testing until the required properties are achieved.

The proportions of the concrete mixtures are summarized in Table 6.

Table 6: Proportions of the concrete mixtures

Mixture	Cement	FA	CA	FA	FPs	Water	SP
	(kg/m^3)						
SCC0	500	0	794	809	0	200	7.5
SCCF	500	0	794	809	0	200	7.5
SCC20	400	100	794	809	0	200	7.5
SCCF20	400	100	794	809	2	200	7.5
SCC40	300	200	794	809	0	200	7.5
SCCF40	300	200	794	809	2	200	7.5
SCC60	200	300	794	809	0	200	7.5
SCCF60	200	300	794	809	2	200	7.5

j) Mixture proportions

The preliminary investigations of this study include evaluation of the equipment and test procedures, evaluation of the mixture proportioning method chosen, mixing procedure and replacement of the FA, PF and dosage of superplasticizer. Testing for these initial investigations is limited on fresh concrete properties.

k) Mixing and casting of specimens

In this investigation, the required quantities of materials were weighed for the correct mixing proportions. Then, cement was mixed with fly ash. The mixture was added to the coarse and fine aggregates. Then, all of the materials were mixed while dry for two minutes. Water was added to the mixtures in two stages: Half of the amount of water was initially added at the start of concrete mixing. The remaining water was then added after 30 s of concrete mixing. To obtain a homogeneous mixture, the concrete was continuously mixed for three min after the addition of water. After carrying out tests for fresh properties, mixing was immediately followed by casting. The specimens were removed from molds after 24 h of storage under laboratory conditions. Storage conditions were in accordance with ASTM C192.

III. Testing of the Samples

a) Fresh concrete tests

For determining SCC properties at fresh concrete state, the slump flow, slump flow T50, V-funnel, V-funnel T5, L-box, segregation and bleeding tests were applied. In order to reduce the influence of workability loss on tests' results of concrete samples, properties of fresh concrete were determined within 20 minutes of adding water.

- The Flow test was performed in according with the European Guidelines for Self-Compacting Concrete (EFNARC) standards (Concrete, 2005). Flow test using the cone, which allows the flow and movement of the SCC of unimpeded to can be characterized. It includes measuring slump flow diameter (D) after lifting the concrete cone, and in the same time measuring the time taken the concrete to spread in diameter 50 cm (T50).
- V-funnel test was performed in according with EFNARC standards .V-funnel is used to evaluate the fluidity, pass ability and segregation of self-compacting concrete. The test time of V-Funnel is the time in seconds from the opened the outlet at the in the bottom the device until seen the light from above. In order get good properties in a fresh concrete of SCC, it requires to have test time between 6 to 12 second.
- L-box test was performed in according with EFNARC standards. L-box is used to assess the possibility of obstruction the filling capacity of the concrete in a confined construction elements. The filling capacity, determined as the ratio of the height the concrete in H2 at end of L-box with H1 at exit outlet (H1/H2), the ratio must be higher than 0.8. Figures 1 a, b, c and d show fresh concrete tests.
- The segregation test is carry out by filling the concrete into a cylinder a 66 cm high and diameter of 20 cm, which has split into three parts. The first part from the bottom is 16.5 cm in height, the middle section is 33 cm in height and the top part is 16.5 cm in height. After filling the apparatus left the concrete undisturbed or movement for 15 ± 1 minutes, then collecting the concrete in the top and bottom parts and washed over a sieve a 4.75 mm to maintain the CA. The relative weight of CA in the top and bottom of the apparatus is used as an indication of resistance the segregation.
- Bleeding test was carried out on ASTM C 232. with maintaining the surrounding temperature of 18 to 24°C. Immediately record the mass of the container and its contents. Then place the container on a level platform free of vibration and cover the container to inhibit evaporation the water of the concrete sample. Must keep the cover of the container during time of the test. Water suction by pipet or similar instrument the, the accumulated water on the surface, at every 10-min through the first 40 min then at every 30 min thereafter until cessation of bleeding.

Global Journal of Researches in Engineering (E) Volume XVII Issue I Version I Year 2017

Fig. 1(a): Slump flow T50 test

Fig. 1(b): Slump flow test

Fig. (1) c: Bleeding test

Fig. (1) d: V-Funnal test

Fig. (1) e: Segregatin test

Fig. 1(f): L-Box test

Fig. 1: Fresh concrete test

b) Hardened concrete tests

In the state of hardened concrete, the tests that were carried out are compressive, indirect tensile and flexural strength. Compressive strength test according to ASTM C39 standard cubes measuring 150 x150 x 150 mm were used. Indirect tensile tests were carried out according to ASTM C496. The dimensions of the standard cylinder are 150 D x 300 H mm. Flexural tests were carried out according to ASTM C78. The dimensions of the standard prisms are 100 x100 x 400 mm. All tests were conducted at 7, 14, 28 and 90 days. The average value of the three specimens for each test age is determined and recorded.

IV. Results and Discussion

a) Properties of fresh concretes

The results of the slump flow test are presented in Table 7. The results represent the maximum spread (the final diameter of slump flow) and T50, the time required for the concrete flow to fill a 50-cm-diameter circle. EFNARC recommends that concrete mixtures should have slump flow diameters of 55 cm to 75 cm to be considered as self-compacting mixture (EFNARC, 2002). Slump flow that exceeds a 75-cm diameter may cause concrete to segregate, whereas that with less than a 55-cm diameter may indicate concrete with flow rates that are insufficient for passing through an overcrowded reinforcement. The results showed that concrete mixtures with PF (SCFRC) and without PF (SCC) and with the addition of FA at replacement rates of 20% and 40% cement mass met the slump flow requirements for SCCs. Concrete mixtures with the addition of FA at replacement rates of 0% and 60% cement mass exhibited low slump flow. Moreover, the results showed a wide range of variations, illustrating the effects of FA replacement rates and PF addition on SCC and SCRFC flowability. The decrease in the workability and flowability of SCC may be attributed to the addition of a high volume of FA as an alternative material. Slump flow rates increased by 40% and 34% when FA was added at replacement rates of 20% and 40% cement mass, respectively. The workability and flowability of all SCRFC mixtures were lower than those of all SCC mixtures. Moreover, the flowability SCC and SCFRC mixtures that contained FA at replacement rates of 0% and 60% cement mass did not meet the minimum requirements of the T50 test. Results also showed that the slump flow rates of SCFRCs decreased by 21%, 12%, and 17% when FA was added at replacement rates of 0%, 20%, and 40% cement mass, respectively. In general, increasing the replacement rates of FA from 20% to 40% cement mass did not significantly decrease the workability of concrete. Adding FA to cement at a replacement rate of 06% has a negative effect on properties of SCC.

Table 7: Results of Slump flow Tests

Mixture	Slump flow (cm)	T50 (sec)
SCC0	52	8
SCCF	41	-
SCC20	73	2.3
SCCF20	64	5
SCC40	70	2.5
SCCF40	58	4
SCC60	47	-
SCCF60	46	-

In addition to the slump flow test and slump flow T50, the V-funnel test was conducted to estimate the flowability of SCC and SCFRC mixtures. The V-funnel flow time was calculated in seconds between the time of the beginning of opening the bottom outlet until the light became noticeable from the bottom outlet. EFNARC recommends that concretes should have V-funnel flow times of 6 s to 12 s and a L-box ratio H2/H1 greater than 0.80 to be considered as SCCs (EFNARC, 2002).

Table 8 shows the results of V-funnel test and L-box. The results indicated that SCC and SCFRC mixtures that contained FA at replacement rates of 20% and 40% cement mass met the requirements for SCC. By contrast, SCC and SCFRC mixtures that contained FA at replacement rates of 0% and 60% cement mass did not meet the requirements for SCC. The decrease in the passing and filling abilities SCCs likely resulted from the high volume of added FA. Moreover, all SCRFC mixtures had lower passing and filling abilities than SCC mixtures. SCC and SCFRC mixtures containing FA at a replacement rate of 60% cement mass did not pass the V-funnel and L-box V-funnel T5 tests. The results suggested that increasing the replacement rate of FA to 60% cement mass exerted the greatest negative effect on the passing and filling abilities of the cement mixtures.

Table 8: Results of L-box and v-funnel tests

Mixture	V-funnel (sec)	V-funnel (T_5) (sec)	L- Box ratio (H_2/H_1)
SCC0	10	17	0.76
SCCF	-	-	0.55
SCC20	5.2	7	0.86
SCCF20	6.3	9	0.81
SCC40	5.3	8	0.88
SCCF40	7.6	10	0.89
SCC60	14	16	0.71
SCCF60	17	26	0.59

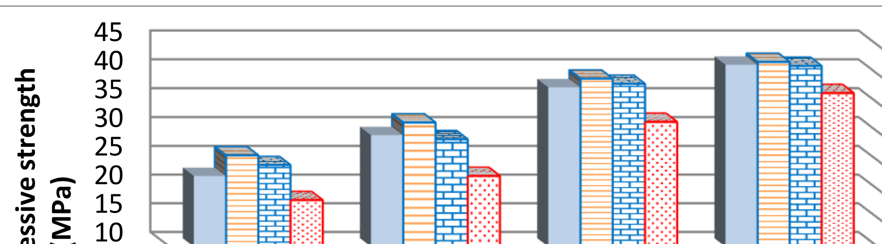
Table 9 shows the results of the bleeding and segregation tests. SCC and SCFRC mixtures that contained FA at replacement rates of 20% or 40% cement mass had high rates of bleeding and segregation. By contrast, SCC and SCFRC mixtures that contained FA at replacement rates of 0% or 60% cement mass had the lowest rates of bleeding and segregation. The addition of a high volume of FA likely decreased the bleeding and segregation of SCCs. Furthermore, the bleeding and segregation rates of SCFRC mixtures were lower than those of SCC mixtures.

Table 9: Results of bleeding and segregation tests

Mixture	Segregation index, %	Total bleeding water(ml/cm^2)
SCC0	3.2	0.08
SCCF	2.3	0.0
SCC20	5.6	0.12
SCCF20	3.5	0.09
SCC40	7	0.18
SCCF40	4.1	0.09
SCC60	2.5	0.02
SCCF60	1.8	0.0

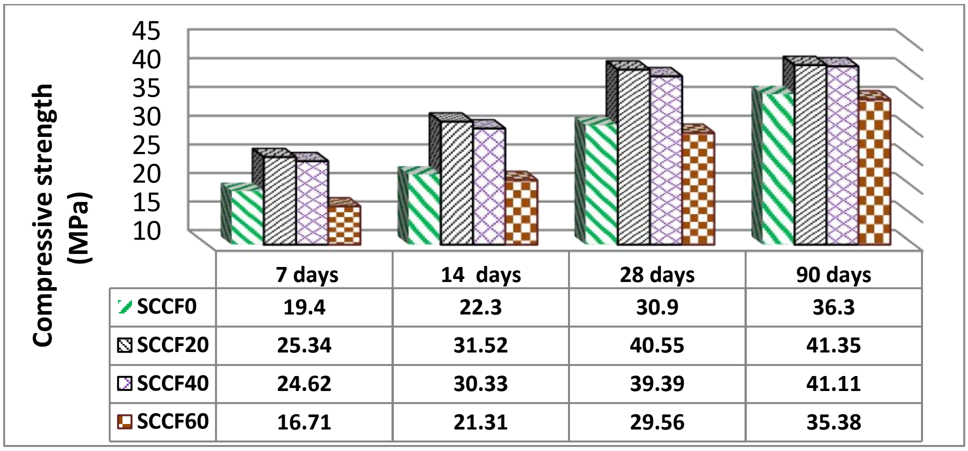
b) Compressive strength

Figures 2, 3, and 4 show the compressive strength test results for SCC and SCRFC at ages 7, 14, 28, and 90 days. Results showed that the evolution of compressive strength varied in SCC and SCRFC. The decline in compressive strength became apparent when FA replacement ratio increased to 60% cement mass. The decline in the compressive strength of SCC and SCRFC may be attributed to the addition of FA at the high replacement rate of 60% cement mass, which introduced air bubbles in hardened concrete and decreased compressive strength. The best compressive strength of SCCs at ages 7, 14, 28, and 90 days was obtained when FA was added at the replacement rate of 20%. The compressive strength of SCCs increased by 16.1%, 7.4%, 3.9%, and 1.2% at ages 7, 14, 28, and 90 days, respectively, when FA was added at the replacement rate of 20% cement mass. In addition, the compressive strength of SCCs increased by 8.5% and 1.5% at ages 7 and 82 days, respectively, when FA was added at the replacement rate of 40% cement mass. Compressive strength decreased by 18.8%, 24.1%, 15.9%, and 11.8% at ages 7, 14, 28, and 90 days, respectively, when FA was added at the replacement rate of 60% cement mass. The compressive strength of SCRFCs s decreased compared with that of SCCs. Adding FA at the replacement rate of 60% cement mass greatly decreased the compressive strength of SCRFCs s. The percentages of decrease in compressive strength were higher in SCRFC mixtures. Thus, this finding may be attributed to the negative effect of fibers on concrete rheology, which affected the degree of concrete compaction and consequently decreased the compressive strength of concrete(Akinpelu et al., 2017).



	7 days	14 days	28 days	90 days
SCC0	22.3	29.4	37.7	41.6
SCC20	25.9	31.6	39.2	42.1
SCC40	24.2	28.7	38.3	41.4
SCC60	18.1	22.3	31.7	36.7

Fig. 2: Results of Compressive Strength Test of SCC



	7 days	14 days	28 days	90 days
SCCF0	19.4	22.3	30.9	36.3
SCCF20	25.34	31.52	40.55	41.35
SCCF40	24.62	30.33	39.39	41.11
SCCF60	16.71	21.31	29.56	35.38

Fig. 3: Results of Compressive Strength Test of SCCF

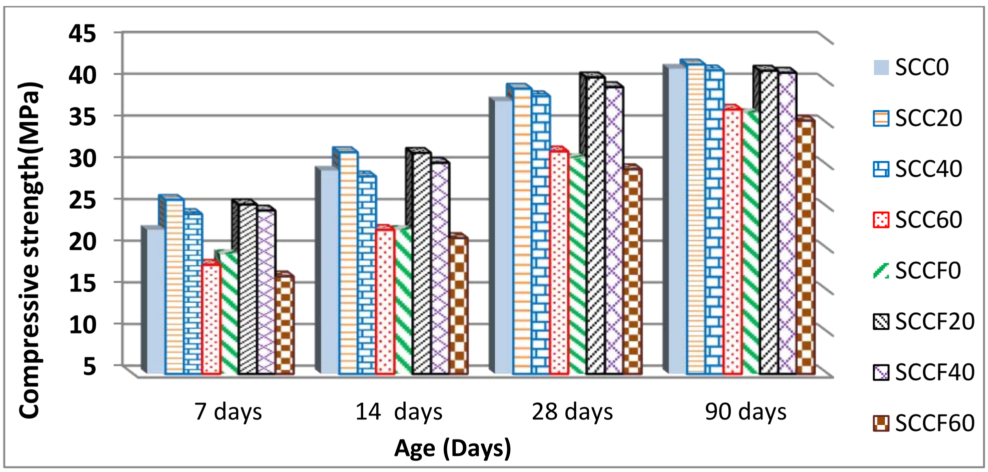
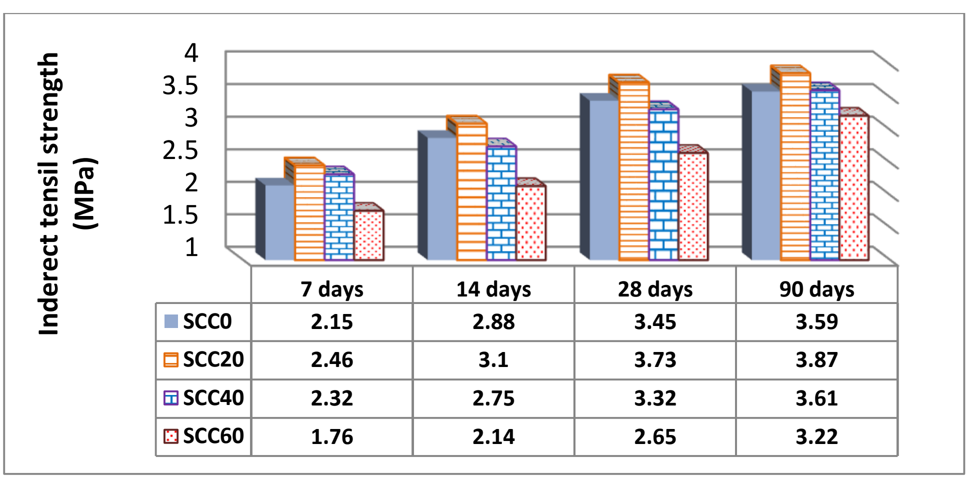


Fig. 4: Results of Compressive Strength Test of SCC and CCF

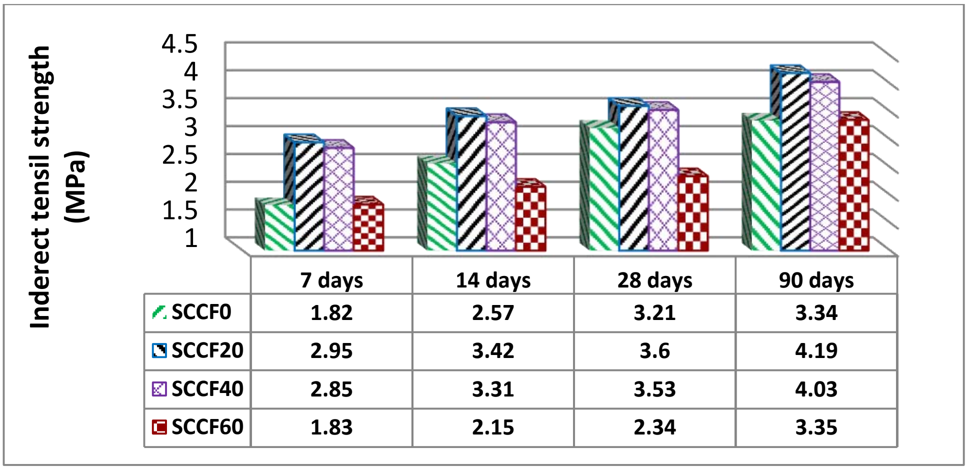
c) *Indirect tensile strength*

Figures 5, 6, and 7 show the results of the indirect tensile strength for SCC and SCRFC mixtures at ages 7, 14, 28, and 90 days. The indirect tensile strength of SCRFC concrete slightly improved compared with that of SCC, thus suggesting that the addition of PFs improved the tensile strength of hardened concretes.



	7 days	14 days	28 days	90 days
SCC0	2.15	2.88	3.45	3.59
SCC20	2.46	3.1	3.73	3.87
SCC40	2.32	2.75	3.32	3.61
SCC60	1.76	2.14	2.65	3.22

Fig. 5: Results of Indirect Tensile Strength Test of SCC



	7 days	14 days	28 days	90 days
SCCF0	1.82	2.57	3.21	3.34
SCCF20	2.95	3.42	3.6	4.19
SCCF40	2.85	3.31	3.53	4.03
SCCF60	1.83	2.15	2.34	3.35

Fig. 6: Results of Indirect Tensile Strength Test of SCCF

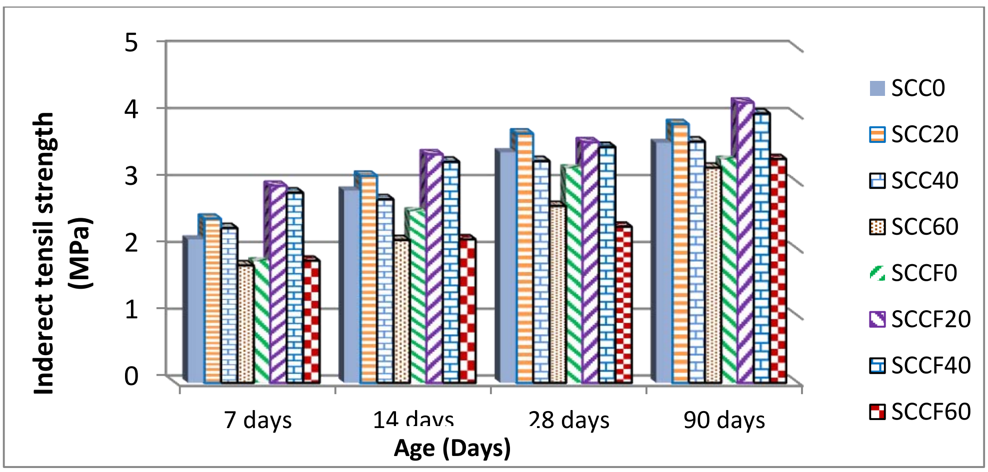
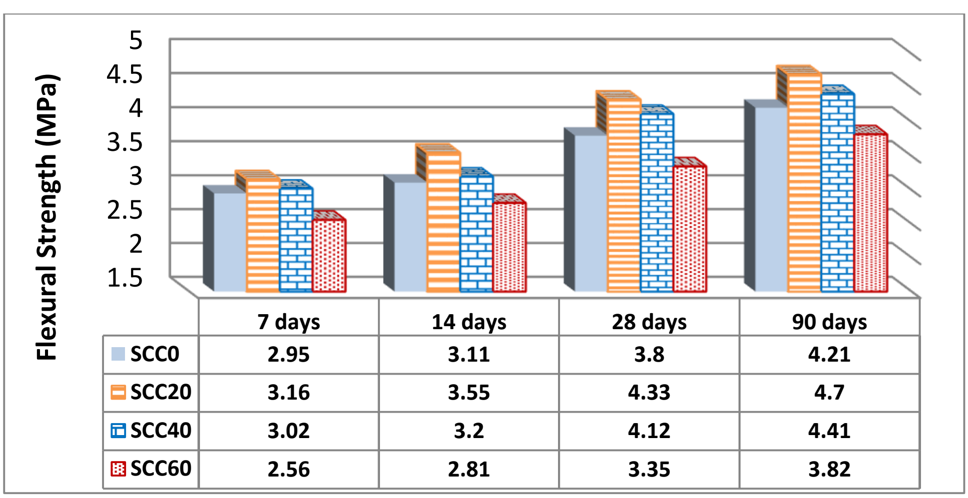


Fig. 7: Results of Indirect Tensile Strength Test of SCC and SCCF

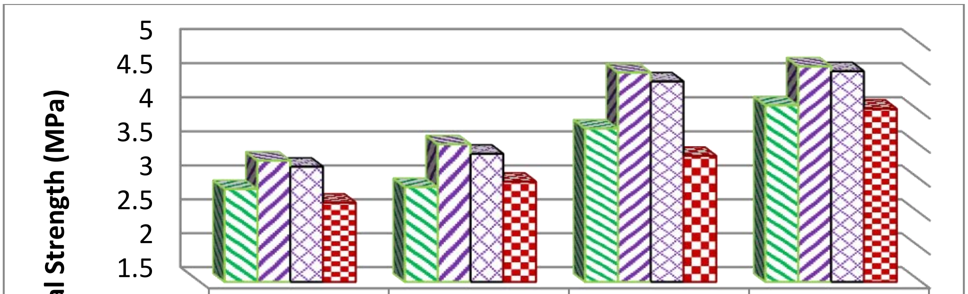
d) Flexural strength

Figures 8, 9, and 10 show the results of flexural strength for SCC and SCRFC mixtures at ages 7, 14, 28, and 90 days respectively. The results showed that indirect tensile strength of SCRFC slightly improved compared with that of SCC, indicating that the addition of PFs improves the flexural strength of hardened concretes.



	7 days	14 days	28 days	90 days
SCC0	2.95	3.11	3.8	4.21
SCC20	3.16	3.55	4.33	4.7
SCC40	3.02	3.2	4.12	4.41
SCC60	2.56	2.81	3.35	3.82

Fig. 8: Results of Flexural Strength Test of SCC



	7 days	14 days	28 days	90 days
SCCF0	2.87	2.9	3.76	4.1
SCCF20	3.29	3.53	4.58	4.67
SCCF40	3.2	3.39	4.45	4.6
SCCF60	2.67	2.98	3.36	4.05

Fig. 9: Results of Flexural Strength Test of SCCF

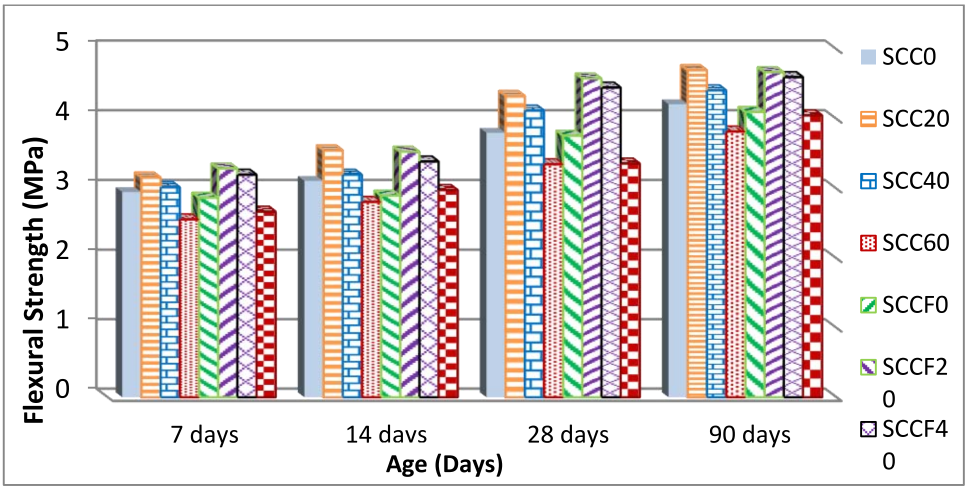


Fig. 10: Results of Flexural Strength Test

V. Conclusions

The following conclusions were drawn from the results of this study:

1. The addition of FA positively affected the properties of fresh concrete and the compressive strength of mixtures at all ages.
2. SCCs with and without PFs were obtained by adding FA at the replacement rates up to 40% cement mass.
3. The best SCC workability was obtained when FA was added at replacement rates of 20% and 40% cement mass without PFs. Fresh SCC samples with this formulation exhibited slump flow diameters of 73 cm and 70 cm; blocking ratios of 0.86 and 0.88; and flow times of 5.2 to 5.3 s.
4. Based on the test results, FA should be utilized to produce SCC with high strength at 90 days. Compressive strength reached 41 MPa when FA was added at replacement rates of 20% and 40% cement mass to SCC and SCRFC.
5. The addition of FA at different replacement ratios to SCC and SCRFC mixtures exerted different effects. Thus, for reasons of economy, FA should be added to SCCs and SCRFCs s at replacement rates of 20% to 40% cement mass.
6. The addition of PFs decreased the properties of fresh concrete but improved flexural and indirect tensile strengths.

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