

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

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Abstract

Self-compacting concrete (SCC) has high flow ability 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 flow ability under the influence of self-weight to completely fill all mold parts for full compaction. This paper discusses the results of an experimental investigation 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

Introduction

Self-compacting concrete (SCC) and self-compacting fiber reinforced concrete (SCFRC) are special types of concrete mixture that is characterized by high resistance to segregation and bleeding. SCC can be cast without compaction or vibration. 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 [1-5].

SCC is produced with the addition of fine industrial wastes, including fly ash (FA), silica fume, and furnace slag [6]. FA and some types of pozzolanic materials have been successfully used as mineral admixtures in SCC [4-7]. 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 [8,9].

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 [10-12]. 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 [13-15]. 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 [16-19]. The addition of fibers to concrete, however, has negligible effects on compressive strength and the modulus of elasticity. Moreover, the workability and flowability of SCFRCs decrease upon the addition of polypropylene fibers (PFs). The reduction of SCFRC workability due to the addition of fibers depends on many parameters, such as fiber type, dosage, and shape [20,21]. 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 and hardened SCC and SCFRC. 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.

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Methods and Materials

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.

Cement: Ordinary Portland Cement (OPC) was used in the present investigation. Cement characterization tests were conducted in accordance with ASTM C150 [22]. Tables 1 and 2 have shown the chemical composition and physical characteristics of cement, respectively.

Fly ash: Fly ash meets the general requirements of ASTM C618 Class F [22]. Table 3 presents the chemical composition and physical characteristics of fly ash.

Aggregate: A crushed basalt rock with a maximum nominal size of 12.5 mm was used as a coarse aggregate (CA), and natural sand was used in the concrete mixtures as a fine aggregate (FA). The coarse and fine aggregate had a specific gravity (GS) of 2.63 and 2.71, and water absorptions (Wa) of 0.6 and 0.9 % respectively.

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.

Coarse aggregate: Table 4 shows that the grade of the coarse

Oxide composition	Abbreviation	Content (percent)	Limit of ASTM specification
Lime	CaO	63.68	60-67
Silica	SiO ₂	20.68	14-25
Alumina	Al ₂ O ₃	6.12	03-Aug
Iron Oxide	Fe ₂ O ₃	3.8	0.5-6
Sulphate	SO ₃	2.68	01-Mar
Soda	Na ₂ O	0.29	0.2-1.3
Potassa	K ₂ O	0.42	0.2-1.3
Magnesia	MgO	1.21	0.1_4
Loss on Ignition	L. O. I	1.55	£ 4
Insoluble residue	I. R	0.63	£1.5
Lime saturation factor	L. S. F	0.91	0.66-1.02
Tricalcium Silicate	C ₃ S	41.51	45-55
Di Calcium Silicate	C ₂ S	28.16	20-30
Tri Calcium Aluminate	C ₃ A	9.87	08-Dec
Tetra Calcium Alumina Ferrite	C ₄ AF	11.57	43014

Table 1: Percentage of Oxide Composition and Main Compounds.

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

Table 2: Cement Physical Properties.

Oxides	Content %	ASTM C 618 Class F
SiO ₂	51.45	>70%
Fe ₂ O ₃	5.19	
Al ₂ O ₃	27.26	
CaO	7.73	-
MgO	5.16	-
SO ₃	0.5	5.0 max
K ₂ O	2.5	-
L.O.I	0.19	6.0 max
Physical Properties		
Fineness (Blain)	4020 cm ² /g	-
specific gravity	2.32	-

Table 3: Chemical Composition and Physical Properties of fly ash.

Sieve size (mm)	% Passing by weight	
	Fine Aggregate	Coarse Aggregate
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
0.6	40.8	0
0.3	11.6	0
0.15	3.1	0
Fineness Modulus	2.8	-

Table 4: Grading of Coarse and Fine Aggregate.

Properties	fiber
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

Table 5: Physical properties of polypropylene fibers.

aggregate, which conforms to the ASTM C33 specifications (ASTM, 2004).

Polypropylene fibers: In this investigation, 12 mm PFs were used, some of their physical characteristics are provided in Table 5.

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

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.

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.

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 top surface of the specimens was scraped to remove excess material and to achieve a smooth finish. The specimens were removed from molds after 24 h of storage under laboratory conditions. Storage conditions were in accordance with ASTM C192.

Testing of the sample

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 [23]. 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 and 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. Figure 1a-1d show fresh concrete tests.

Segregation test was conducted on ASTM C 1610. The segregation test is conducted by filling concrete into a 66 cm tall, 20 cm diameter column, which is split into 3 sections. The top and bottom sections are 16.5 cm inches in height and the middle section is 33 cm in height. The test apparatus is split into four sections based on an earlier version of the test. In this case, the middle two sections can be used as a single section. The concrete is left undisturbed for 15 ± 1 minutes, after which the concrete in the top and bottom sections is collected and washed over a No. 4 sieve to retain all coarse aggregate. The relative amounts of coarse aggregate in the top and bottom of the column is used as an indication of segregation resistance.

Bleeding test was conducted on ASTM C 232. During the test; maintain the ambient temperature between 18 and 24°C. Immediately after troweling the surface of the specimen, record the time and determine the mass of the container and its contents. Place the specimen and container on a level platform or floor free of noticeable vibration and cover the container to prevent evaporation of the bleed water. Keep the cover in place throughout the test, except when drawing off the water. Draw off (with pipet or similar instrument) the water that has accumulated on the surface, at 10 min intervals during the first 40 min and at 30 min intervals thereafter until cessation of bleeding. To facilitate the collection of bleeding water, tilt the specimen carefully by placing a block approximately 50 mm thick under one side of the container 2 min prior to each time the water is withdrawn. After

Mixture	Cement	Fly Ash	Coarse Aggregate	Fine Aggregate	Poly-propylene Fibers	Water	Super-plasticizer
	(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

Table 6: Proportions of the concrete mixtures.



Figure 1a: Slump flow T50 test.



Figure 1d: V-Funnel test.



Figure 1b: Slump flow test.



Figure 1e: Segregatin test.



Figure 1c: Bleeding test.

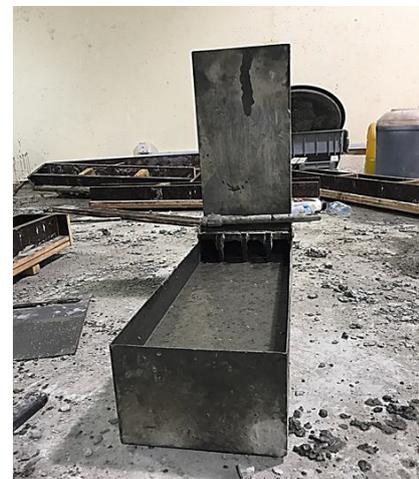


Figure 1f: L-Box test.

the water is removed, return the container to a level position without jarring. After each withdrawal, transfer the water to a 100 mL graduate. Record the accumulated quantity of water after each transfer. When only the total volume of bleeding is desired to be determined, the periodic removal procedure shall be omitted and the entire amount removed in a single operation. If it is desired to determine the mass of the bleeding water and to exclude the material present other than the water, carefully decant the contents of the cylinder into a metal beaker.

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 × 150 × 150 mm were used. Indirect tensile tests were carried out according to ASTM C496. The dimensions of the standard cylinder are 150 D × 300 H mm. Flexural tests were carried out according to ASTM C78. The dimensions of the standard prisms are 100 × 100 × 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.

Results and Discussion

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 [24]. 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 SCFRC 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 SCFRC 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 0% has a negative effect on properties of SCC.

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

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	-

Table 7: Results of Slump flow Tests.

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 SCFRC 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 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.

Compressive strength

Figures 2-4 show the compressive strength test results for SCC and SCFRC at ages 7, 14, 28, and 90 days. Results showed that the evolution of compressive strength varied in SCC and SCFRC. 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 SCFRC 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%,

Mixture	V-funnel (sec)	V-funnel (T5min.) (sec)	L-Box ratio (H2/H1)
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 8: Results of L-box and v-funnel tests.

Segregation index, %	Total bleeding water, ml/cm ²	Mixture
3.2	0.08	SCC0
2.3	0	SCCF
5.6	0.12	SCC20
3.5	0.09	SCCF20
7	0.18	SCC40
4.1	0.09	SCCF40
2.5	0.02	SCC60
1.8	0	SCCF60

Table 9: Results of bleeding and segregation tests.



Figure 2a: compressive strength test.



Figure 2d: Curing method.



Figure 2b: flexural strength test.



Figure 2c: Tensile strength test.

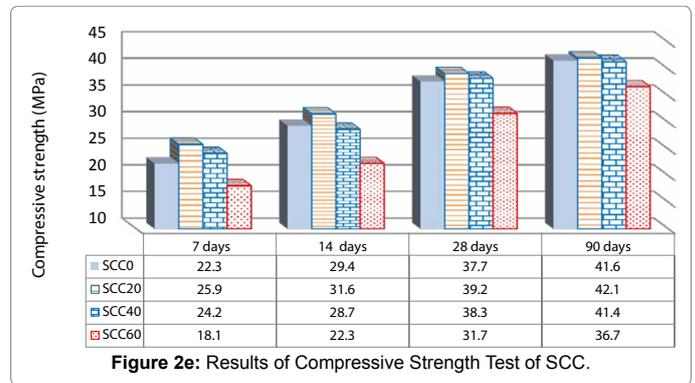


Figure 2e: Results of Compressive Strength Test of SCC.

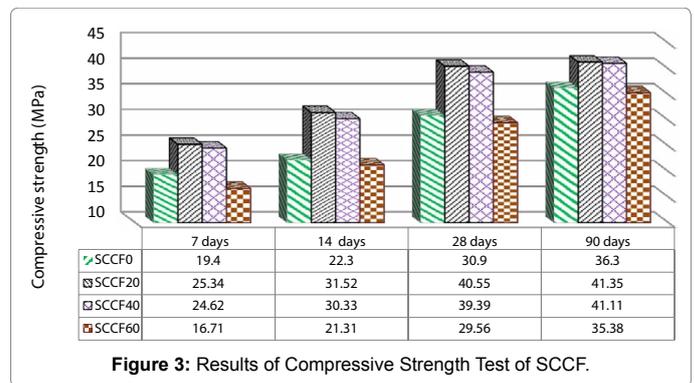


Figure 3: Results of Compressive Strength Test of SCCF.

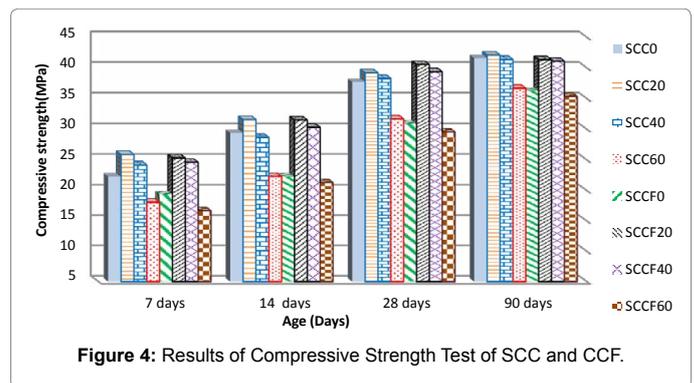


Figure 4: Results of Compressive Strength Test of SCC and CCF.

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 [25].

Indirect tensile strength

Figures 5-7 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.

Flexural strength

Figures 8-10 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

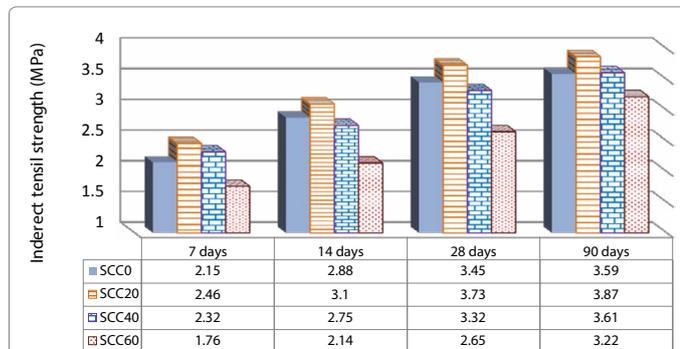


Figure 5: Results of Indirect Tensile Strength Test of SCC.

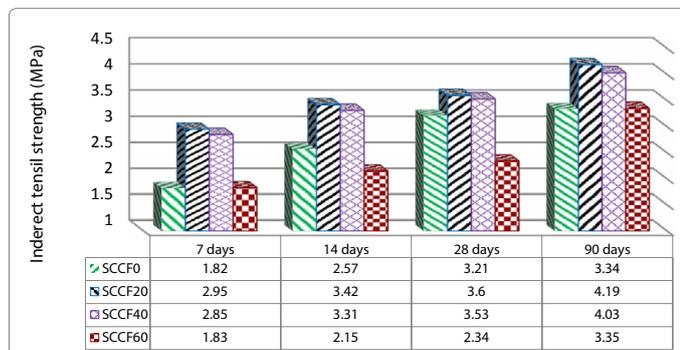


Figure 6: Results of Indirect Tensile Strength Test of SCCF.

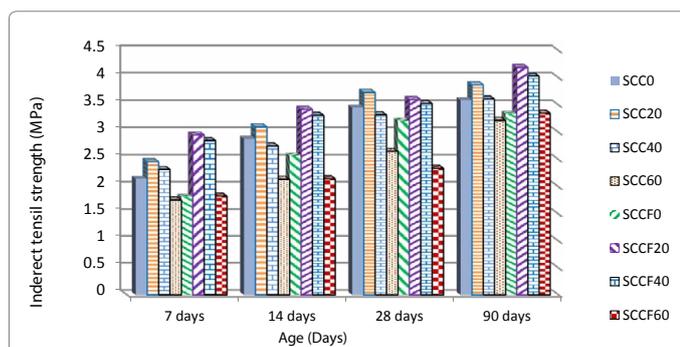


Figure 7: Results of Indirect Tensile Strength Test of SCC and SCCF.

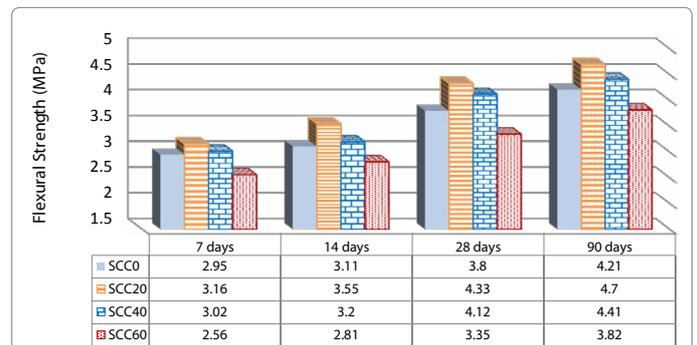


Figure 8: Results of Flexural Strength Test of SCC.

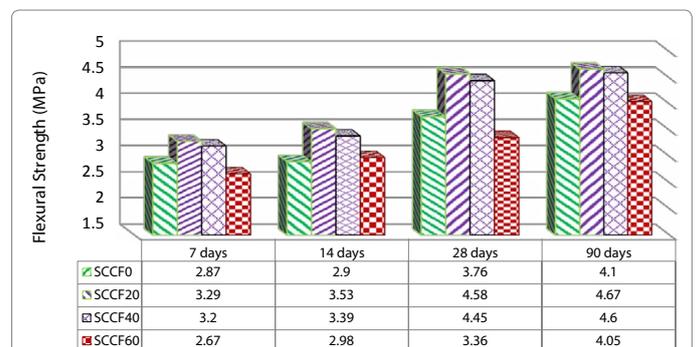


Figure 9: Results of Flexural Strength Test of SCCF.

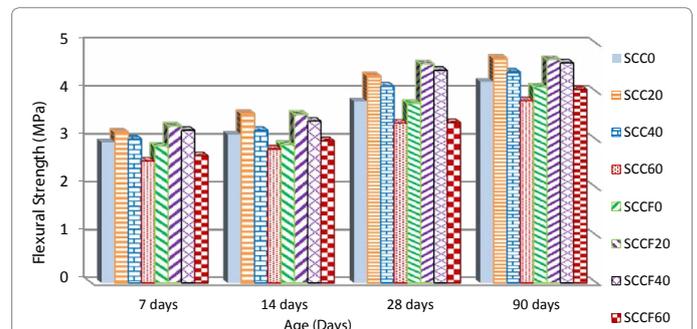


Figure 10: Results of Flexural Strength Test.

compared with that of SCC, indicating that the addition of PFs improves the flexural strength of hardened concretes.

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 at replacement rates of 20% to 40% cement mass.

- The addition of PFs decreased the properties of fresh concrete but improved flexural and indirect tensile strengths.

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