

# Evaluating the Effect of Fly Ash on the Rheological and Mechanical Performance Self-Compacted Concrete

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## Abstract

Self-Consolidating Concrete (SCC) is a special concrete which is highly flowable, non-segregating and by its own weight spread into place, completely fill the formwork even in the presence of dense reinforcement without any compaction. This research was implemented to develop and to determine the effect of FA on fresh and hardened properties of self-consolidating concrete. Laboratory test was carried out to investigate the properties of SCC. Five composition of design mix at 0%, 15%, 30%, 45% and 60% fly ash were prepared and tested. The performance of the fresh SCC mixes was determined by testing the filling ability and passing ability through slump flow and slump T50 test, L-box and v funnel test. Standard concrete cylinders were casted comprising of five mixes, cured and tested for analyzing the compressive and split tensile strength behavior of SCC. The results indicate that as the amount of FA increase, the flow and passing ability is decreased continuously. However up to 45% of FA by weight of cement will fall within the limits define by technical specification for SCC and have good passing and flowability. Early age strength (7 days) decreased as the percentage of FA increased while long term the strength (28 and 56) is increased first up to 45% substitution of FA and then decreased gradually.

**Keywords:** Sustainable concrete • Compressive strength • Split tensile strength • Self-consolidating concrete • Flowability • Passing and filling ability

## Introduction

Self-Consolidating Concrete (SCC) is a special concrete which is highly flow able, non-segregating and by its own weight spread into place, completely fill the formwork even in the presence of dense reinforcement [1]. Self-compacting concrete (SCC) concept was proposed in 1986 by Hajime Okamura [2], however the prototype was first developed in Japan in 1988 by Ozawa [3].”

“Concrete is the highly used construction substance in the construction field because of its high stability & structural strength [4]. Construction related to sustainability has turned into crucial in the engineering sector & different beliefs have grown to minimize the effect of the environment of recent construction industries [5]. The cement business is fronting threats like cost raises in energy delivery, also to lessen CO<sub>2</sub> ejections & the delivery of unrefined materials in adequate quality [6]. Worldwide production of cement is increasing constantly from 1990 to 2050. This was expected because it is 2nd most consumed product on the earth after water. The industry is rapidly rising especially in developing countries like China & India that have a high need of cement for housing & infrastructure [7]. Last year, Pakistan produced 41.14 million tons of cement; according to International Cement Review [8]. The country's cement industry has already built capacity to produce 59.5 million tons in anticipation of future demand for housing and infrastructure [9].”

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Keeping in view these concerns of environment, cost of materials for construction, shortage of raw materials and higher demand of energy, practice of utilizing alternate material is becoming a common concern of the globe [10]. In this research particularly focus to partially used fly ash instead of cement. FA is obtained from coal fired power plants by filtration processes. Chemical composition of FA the source from which it was collected [11]. It is suggested by researchers that consumption of supplementary cementitious materials in concrete helps to reduce the adverse environmental effects related to the manufacturing process of cement or concrete [12]. With utilization of these wastes as supplementary and replacement materials there is considerable energy conservation and reduction in the consumption of cement which aids in the reduction of release of carbon dioxide in the environment [13]. Moreover, there could be considerable improvement in the strength and durability properties with use of supplementary cementing materials in concrete [14]. It should be noted that the wide application of fly ashes from black coal and brown coal combustion in construction and building materials is mainly determined by the fineness, chemical and mineral composition, as well as pozzolanic activity—like cement. At the same time, fly ashes have a beneficial effect on the technical properties of concrete, improving its compressive and bending strengths, and frost resistance [15,16]. These factors make the production of ash concretes attractive to both producers and final consumers [17]. It has been reported that, the chemical properties and pozzolanic activity of fly ashes indicated the potential of this innovative additive [18].

The significant use of fly ash as a cement replacement for Concrete production opens the possibility for more sustainable concrete. The interests of developing more environment-friendly concretes where cement consumption is reduced using fly ash as cement replacement materials justifies the further exploration of the role this mineral material plays in concrete performance. The mechanical properties and durability with incorporation fly ash have been investigated by many researchers [19,20]. However, the use of fly ashes as a partial cement substitute increases water demand and reduces the workability and density of concrete mixes [21].

Fontes et al. [22] showed that cement mortars in which cement was replaced with FASS in an amount of 10% to 30% showed similar bending strength values to reference mortars. In addition, the partial replacement of cement with fly ash increased the porosity of concrete. It has been also demonstrated that the replacement of 20% of Portland cement by fly ash from sewage sludge may result in a reduction in compressive strength [23]. It is also observed that the compressive and bending strengths after 28 days of curing decreased in comparison to ordinary mortar [24].

In existing short literature review show that very limited research was carried on SCC with incorporation of FA. Furthermore, knowledge about the utilization of high-volume fly ash in self compacting concrete is still scarce. The successful utilization in prevailing environment will offer multiple benefits including cost effective solution to construction industry and reduced environmental and health issues and would have positive impact on the durability and mechanical performance of the system."

## Materials and Experimental Program

### Cement

Ordinary Portland cement (OPC) type-1 in accordance to ASTM C150 [25] is used in this study. Its chemical and physical properties are displayed in Table 1.

### Fine aggregate and coarse aggregate

Natural sand was used as a FA (fine aggregate) in all the mixes in SSD (saturated surface dry) condition, which was obtained from, Larencepur Wah Cantt Punjab Pakistan. Normal weight coarse aggregate (crush stone) in saturated dry condition (SSD) was obtained from Margallah Wah Cantt Punjab Pakistan. Nominal maximum size of coarse aggregate is 19.5 mm. Different tests were performed on aggregate to evaluate its physical property as shown in Table 2.

### Fly ash

Fly ash was obtained from ICI Pakistan- Soda Ash Plant, Khewra. Class-F fly ash having specific gravity 2.10 and dark brown color is used. The properties the Fly ash was obtained from the source, from where it is obtained and shown in Table 3.

### Super plasticizer

Chemrite-530 used as super plasticizer because it is high range water reducing admixture and non-toxic and non-hazardous under relevant health and safety issue. The super plasticizer meets the requirements of EN 934-2 T 3.1/3 [17]. and ASTM C-494 Type F [26]. Typical properties of the super plasticizer are given as under Table 4.

### Experimental program

To achieve the goal of project, a two stage experimental program was developed. In the first stage, trial mix was prepared in order to achieve the requirement of technical specification for SCC [1] as shown in Table 6. In the

**Table 1.** Physical and chemical property of OPC.

Chemical property	Percentage (%)	Physical property	Results
CaO	60.7	Size	≤ 75 μ
SiO <sub>2</sub>	21.9	Fineness	91%
Al <sub>2</sub> O <sub>3</sub>	7.4	Normal Consistency	26%
Fe <sub>2</sub> O <sub>3</sub>	5.7	Initial Stetting Time	33 min
MgO	4.5	Final Stetting Time	408 min
SO <sub>3</sub>	3.9	Specific surface	322 m <sup>2</sup> /kg
K <sub>2</sub> O	2.4	Soundness	1.30%
Na <sub>2</sub> O	0.2	28-days compressive Strength	42 Mpa

**Table 2.** Physical property of fine and coarse aggregate.

Physical property	Fine aggregate	Coarse aggregate
Particle size	4.75 mm to 0.075 mm	19.5 mm to 4.75
Fineness modulus	2.83	4.3
Absorption capacity	5.08%	3.13%
Moisture content	2.8%	1.25%
Bulk density (kg/m <sup>3</sup> )	1586	1565

**Table 3.** Physical and chemical property of fly ash.

Chemical property	Percentage (%)	Physical property	Results
CaO	56.55	Color	Brown
SiO <sub>2</sub>	6.13	Specific Gravity	2.10
Al <sub>2</sub> O <sub>3</sub>	26.20	Type	F
Fe <sub>2</sub> O <sub>3</sub>	9.23	Clay (%)	Nil
MgO	0.32	Bulk density (kg/m <sup>3</sup> )	1065
SO <sub>3</sub>	0.07		
K <sub>2</sub> O	0.9		
Na <sub>2</sub> O	0.6		

**Table 4.** Physical property of super-plasticizer.

Property	Result
Color	Dark Brown
Relative density	1.58 at 27°C
Chloride content	< 0.2%
Physical state	Liquid

**Table 5.** Typical acceptance criteria for self-compacting concrete.

Sr.NO	Tests Methods	Unit	Minimum	Maximum
1	Slump Test	Mm	650	800
2	T50-Slump Flow	Sec	2	5
3	L-Box Test	(H2/H1)	0.8	1
4	V-Funnel Tests	Sec	6	12

second stage, six mixes were prepared with varying percentages of FA (0%, 15%, 30%, 45% and 60% by weight of cement) to determine the effects FA on self-compacting concrete (SCC), which are based on the finding of the first stage. Typical acceptance criteria for Self-compacting Concrete define by technical specification for self-compacting concrete with a maximum aggregate size up to 20 mm are shown in Table 5.

### Tests and size of specimen

Fresh properties of SCC such as Slump flow, Slump T50 Spread time, L-Box, V-funnel will be performed according to technical specification for SCC [1]. Cylinder of standard size (6 × 12 in) will be used to measure the compressive strength at as per ASTM C39/C39M [27]. Similar cylinders of standard size (6 × 12 in) will be cast and tested to find their tensile strength as per ASTM C496-71 [28]. Three specimens are tested for each test at 7,14 & 28 days and the mean value of the specimens is considered as strength.

### Sample preparation method

ASTM C-31 [29] method was followed for the preparation of the specimens and compaction was done manually by Roding in three layers having 25 blows per layer. Six mixes are prepared with varying dosage of FA. Details of the mixes are provided in the following Table 6. Before the mixing process was started, the required quantity of material was weighed by method of weighing. Speed of mixer was kept 35 rev/min for mixing of materials. First, coarse aggregate was added to the mixer & then fine aggregate, both materials were dry mixed then necessary quantity of cement and water were added with time and mixing was done about 8 minutes for all mixes.

## Results and Discussion

### First stage results

In first stage, eight mixes with varying dosage of superplasticizer (0%, 0.5%, 1.0% and 1.5% by weight of cement) for binding ratio 0.50 and 0.60 as shown in Table 6 were prepared in order to achieve a best possible mix which would fulfil the requirement of Technical Specification for (SCC). The major difference between conventional and SCC is due fresh characteristics. SCC is flowable, non-segregating and by its own weight spread into place, completely fills the formwork even in the presence of dense reinforcement without any compaction. Such characteristics can be determined through Slump flow, Slump T50 Spreads, L- Box and V-funnel test. Based on work results, fresh properties of SCC for each trial mix with different test methods (Slump flow, Slump T50 Spreads, L- Box and V-funnel) were show in Table 7.

From Table 7, it can be noticed that Mix 1 to Mix 5 are stiff while bleeding was observed in Mix 7 and Mix 8 on basis of different tests results. It is clear that, Mix 6 will satisfied the range of different test (Slump flow, Slump T50 Spread time, L-Box and V-funnel) given by specified by technical specification for self-compacting concrete. While others mix do not satisfy the range of such tests. Therefore Mix 6 is consider best mix of self-compacting concrete and can be used as a reference concrete (control) with varying percentages of FA starting from 0% up to 60% by weight of cement in increment by 15%.

### Second stage (Mix proportion of SCC)

Based on work results of first stage, Mix 6 (SCC) was selected for further experimental work (control). Therefore, second stage of the experimental work was conducted on Mix 6 (SCC) with incorporation of FA. Five mix were prepared at second stage, after achieved the requirement of technical specification for SCC (Mix 6) which given in the first stage as shown in



Figure 1. (a), (b) Slump flow, (c) V- funnel, (d) L- box tests.

Table 6. Trials mixes for Self-Compacting Concrete (SCC).

Materials	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Cement (kg/m <sup>3</sup> )	425	425	425	425	425	425	425	425
Sand (kg/m <sup>3</sup> )	625	625	625	625	625	625	625	625
Crush (kg/m <sup>3</sup> )	1270	1270	1270	1270	1270	1270	1270	1270
W/C	0.50	0.50	0.50	0.50	0.60	0.60	0.60	0.60
Superplasticizer (kg)	-	2.12	4.25	6.37	-	2.12	4.25	6.37

Table 7. Results of trial mixes for Self-Compacting Concrete (SCC).

Tests Methods	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8
Slump (mm)	535	542	568	622	572	755	810	838
L-Box (H2/H1)	0.60	0.68	0.72	0.83	0.76	0.94	0.92	0.98
V-Funnel (Sec)	19	16	15	11	14	7	5	3
Slump T50	11	8	7	5.2	6	4.5	2.8	2.2
Remarks As per EFNARC	Too Stiff + Segregation	Too Stiff	Small Stiff	Small Bleeding	Small Stiff	Good SCC	Small Bleeding	Too Bleeding + Segregation

Table 7. Different percentages of FA were added to fresh self-compacting concrete (SCC). The percentages of FA used were 15%, 30%,45% and 60% by weight of cement. Table 8 shows concrete mix proportions of SCC (Mix 6) with varying percentages of FA.

**Fresh properties**

**Slump flow and slump T50:** Slump flow and Slump T50 test for SCC is carried out according to EN 12350-8 (2010) [30]. Slump and slump flow were obtained by a slump flow test. Results of Slump flow and Slump T50 test were shown in Figure 2 and Figure 3 respectively. The test results indicate that, Slump flow decreased while Slump T50 value increased as the percentage of FA increased. The reduction of concrete mix workability when fly ash is added is attributed to the physical properties of fly ash which is porous and tends to absorb water. The characteristic of fly ash being porous and causes difficulties during mixing process has been highlighted by researcher elsewhere [31]. Mixes FA-0%, FA-15%, FA-30%, FA-45% have a slump flow value in between 650mm to 800mm, while slump T50 spread time were in range between 3 to 5 seconds. which means, as these FA-0%, FA-15%, FA-30%, FA-45% satisfied the requirement given by technical specification for SCC and have good filling ability. However at higher dosage FA-60%, have slump value 612 mm which is out of range given by technical specification for SCC. Therefore, high dosage of superplasticizer is needed.

**L-Box test:** L-Box test was used to assess the passing ability of self-consolidating concrete. Mixes (FA-0%, FA-15%, FA-30%, FA-45%) have L-Box test ratio (H2/H1) value in between 0.80 to 1 except FA-60% as shown in Figure 4. which means, as these mixes (FA-0%, FA-15%, FA-30%, FA-45%) satisfied the requirement given by technical specification for SCC have good filling and passing ability. While mix FA-60%, have L- Box test ratio (H2/H1) 0.73, which is out of range given by technical specification for SCC as shown in Figure 4. However, it should be noted that Hamzah [32] determined that 0.60 blocking ratio has been accepted for SCC to achieved good filling ability. According to this standard, once the value of H2/H1 in L box test is greater than 0.8, the SCC has good passing ability [33].

**V- Funnel test:** The V-Funnel test that was used to check the Flow ability

Table 8. Mix proportion of SCC.

Materials	Mix 6/ Control	FA-15%	FA-30%	FA-45%	FA-60%
Cement (kg/m <sup>3</sup> )	425	388.2	324.5	260.7	197
Sand/F. A (kg/m <sup>3</sup> )	625	625	625	625	625
Crush/C.A (kg/m <sup>3</sup> )	1270	1270	1270	1270	1270
W/C	0.5	0.5	0.5	0.5	0.5
Superplasticizer (kg)	2.12	2.12	2.12	2.12	2.12
Fly Ash (kg)	-	63.75	127.5	191.25	255

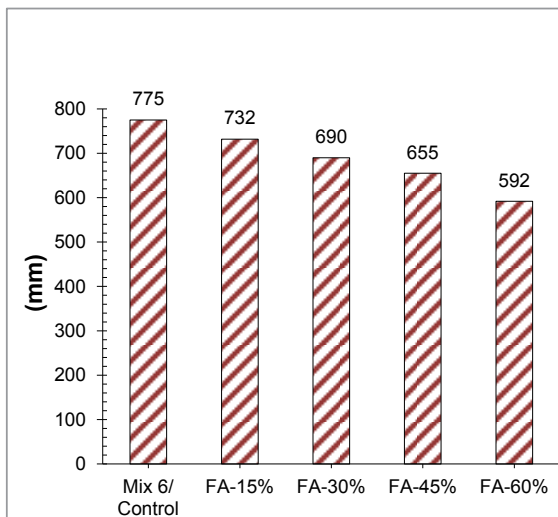


Figure 2. Slump test.

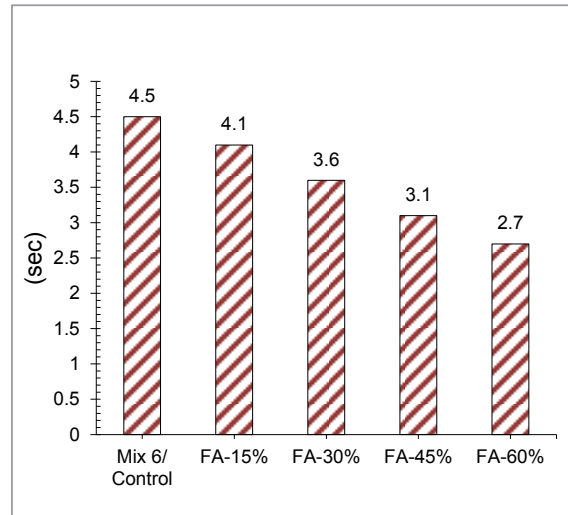


Figure 3. Slump T50 test.

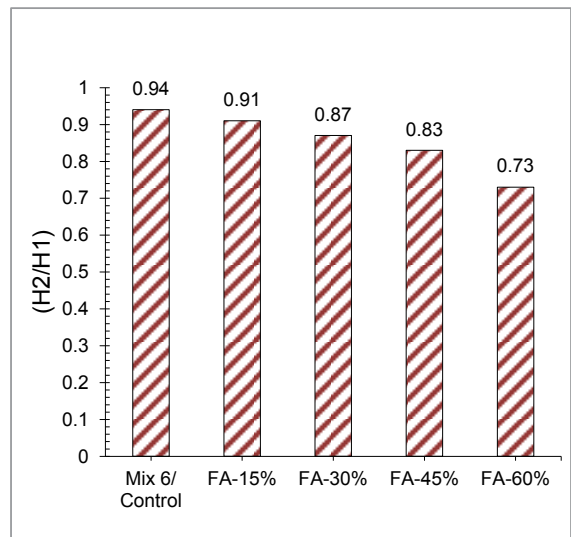


Figure 4. L-Box test.

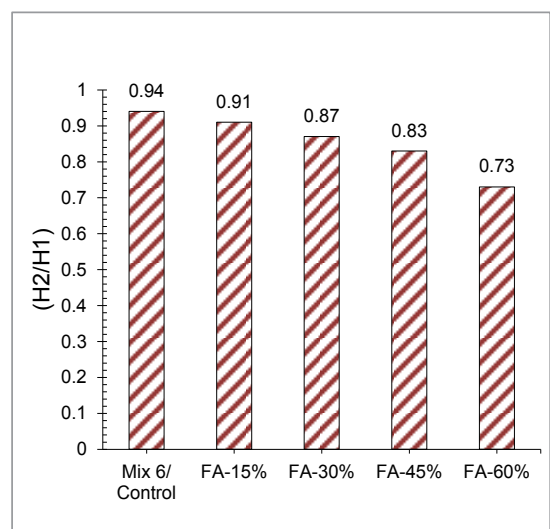


Figure 5. V-Funnel test.

of self-compacting concrete. The flow time of V- Funnel tests are used to find the filling ability of SCC. It measures the ease flow of concrete. Shorter the flow time indicate greater flow ability. Test results indicate, flow time are between 6 sec to 12 sec for mix (FA-0%, FA-15%, FA-30%, FA-45%) have acceptable

range given by technical specification for SCC as shown in Figure 5. According to specification for SCC, these mixes have good filling ability. However, at higher dosage of FA (FA-60%) have flow time 13 sec which is out of range given by technical specification for SCC.

### Mechanical properties

**Compressive strength:** Compressive strength is the property of material to resist stresses when it is compressed. The compressive strength test was done with compliance to the standard procedure of ASTM as ASTM C39/C39M [27] for cylindrical specimens having standard dimensions as 6 inches diameter and 12 inches length. In this test concrete specimens (cylinders) were exposed to compressive axial force at a rate within recommended limit till the concrete failure. Compressive strength was then determined from greatest failure load divided by X-sectional area of the specimen as shown in Figure 6.

Figure 7 shows Compressive strength of different FA mixes of SCC. As

the level of replacement increases the early-age strength (7 days) decreases. However, long-term strength (28 and 56 days) increased as the percentage of FA increased up to 45% substitute and then gradually decrease as shown in. It is reported that the strengths of SCC with high-volume fly ash were lower than that of concrete with pure Portland cement, especially at early age [34]. This could be because of the dilution effect and low pozzolanic reaction [35]. All mixes of FA SCC show greater strength than reference mix at the age 28- and 56-days curing. The maximum strength was obtained at 45% substitution of FA while minimum strength was obtained at 0% substitution of FA at 28- and 56-days curing. It is due to the pozzolanic reaction of SiO<sub>2</sub> in FA with Ch of cement producing additional cementitious compounds. The additional binder produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. It is well known that Pozzolanic reaction does not contribute at early ages, however that appears to offset this trend at a later age of hardening and as such provides to enhancement in the



Figure 6. Compressive strength test setup.

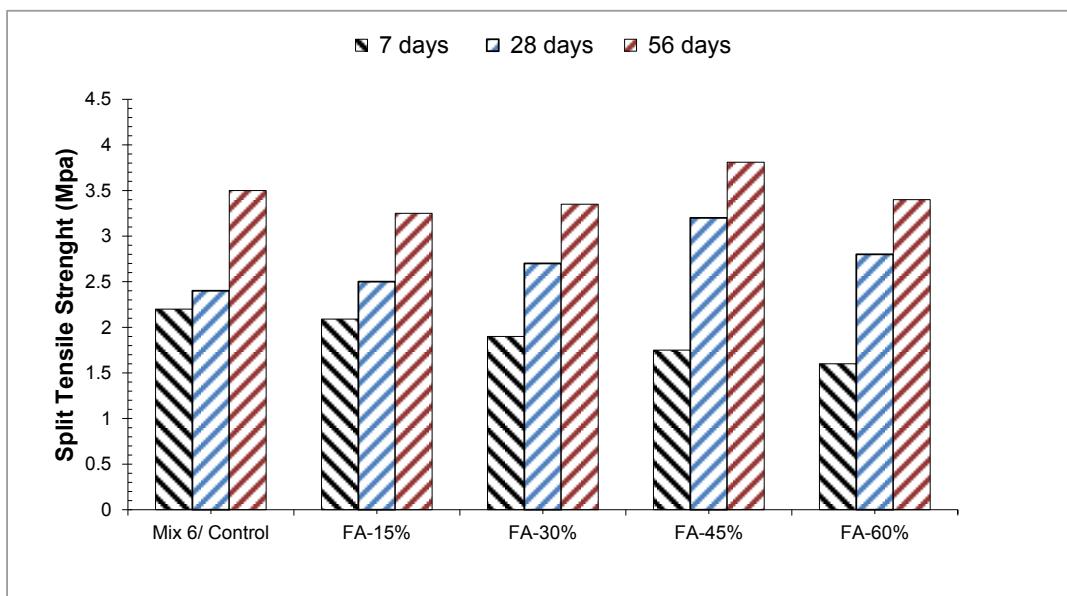


Figure 7. Compressive strength test results.



Figure 8. Split tensile strength test setup.

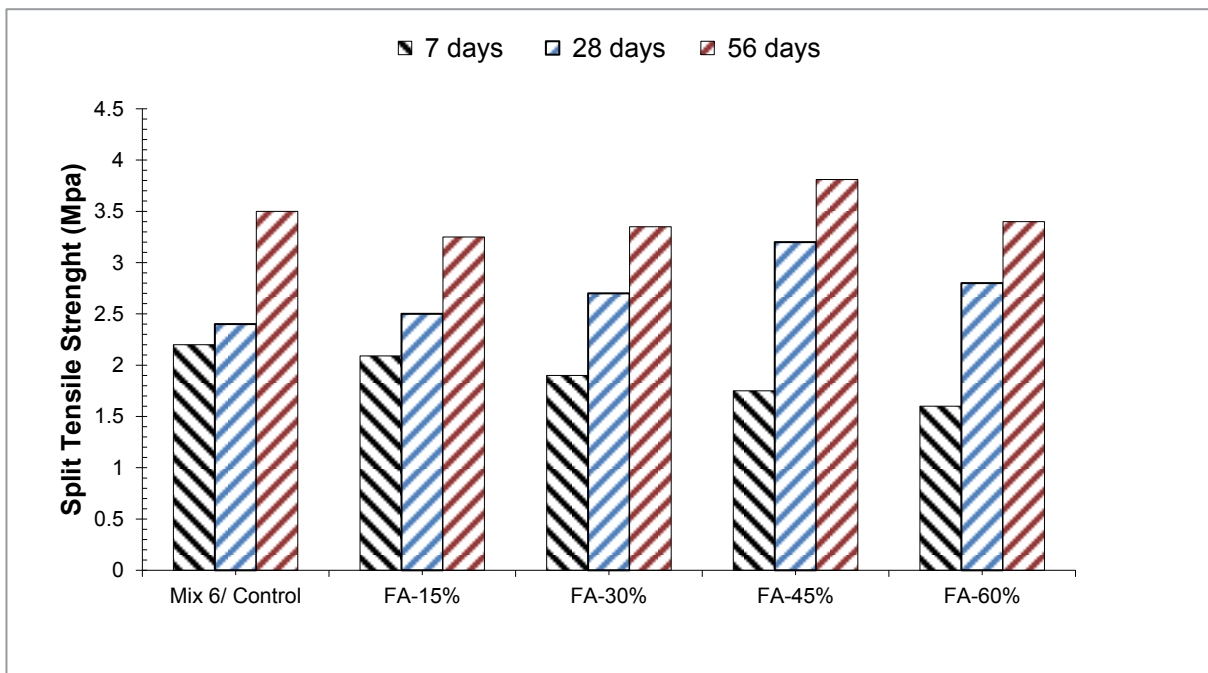


Figure 9. Split tensile strength test results.

compressive strength at 28 and 56 days. However, at higher dosage (FA-60), the compaction process become more difficult due lack of workability which results porous concrete, leading to lower strength. Therefore, 45% substitution of FA is optimum dosage, giving maximum strength.

### Split tensile strength

Tensile strength for concrete samples is called the tensile stresses generated due to applying of the compressive load at which the concrete sample may fail. According to ASTM C496-71 [20], split cylinder test was carried out on cylindrical specimens of 150 mm diameter and 300 mm height at the ages of 7, 28- and 56-days curing as shown in Figure 8.

Figure 9 shows split tensile strength of varying dosage of FA (0%, 15%, 30%, 45% and 60% by weight of cement). Like Compressive strength, as the

level of replacement increases the early age split tensile strength (7 days) decreases. However, long-term strength (28 and 56 days) increased as the percentage of FA increased up to 45% substitute and then gradually decrease as shown in This could be because of the dilution effect and low pozzolanic reaction [34,35]. All mixes of FA SCC show greater split tensile strength than reference mix at the age 28- and 56-days curing. The maximum Split tensile strength was obtained at 45% of FA while minimum strength was obtained at 0% substitution of FA.

### Conclusions

In this research fly ash was used as a binding material in proportion of

0%, 15%, 30%, 45%, 60% by weight cement. Based on experimental work following conclusion has been drawn.

- Fresh properties of SCC such as flowability, passing and filling ability decreased as the percentages of fly ash (FA) increased. It is due to the physical properties of fly ash which is porous and tends to absorb more water. However up to 45% of fly ash (FA) by weight of cement will fall within the limits defined by technical specification for SCC and have good flowability, passing filling ability.
- At 7 days curing, strength (compressive and split tensile strength) decrease as the percentages of fly ash (FA) increased as compare to blank mix. However, at 28- and 56-days curing, strength (compressive and split tensile strength) increase as the percentages of fly ash (FA) increased up to 45% by weight of cement and then decreased as compare to blank mix. It is due to pozzolanic reaction, which forms secondary C-S-H gel allowing concrete to gain more strength over the time. However, at higher dosage (FA- 60%) compaction process become more difficult due lack of flowability, leading to porous concrete which results to decreased ultimate strength of SCC.
- Therefore, it is advisable to use fly ash (FA) up to 45% by weight of cement to obtain maximum benefits by considering workability and mechanical performance of SCC.

## Conflict of Interest

All authors declare no conflicts of interest in this paper.

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29. Specimen CT ASTM C 31; one set of four standard cylinders for each compressive-strength test, unless otherwise directed. Mold store Cylind Lab test specimens except when field-cured test specimens are required.
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