A Study on the Fresh and Hardened Properties and Cost-Analysis of High-Volume Fly Ash Self-Compacting Concrete

Athira Surendran[1*], Riyana M.S.[2]

[1]PG Student, Dept. of Civil Engg., Sree Narayana Institute of Technology, Adoor, Pathanamthitta, Kerala,
[2]Assistant Professor, Dept. of Civil Engg, Sree Narayana Institute of Technology, Adoor, Pathanamthitta, Kerala,
*Corresponding author's e-mail: athirasnit1191@gmail.com
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ABSTRACT

Concrete was prevailed in construction since ancient times. Over the years, numerous developments have been carried out to upgrade the concrete. One such developmentis Concrete that self-compacts and binds to itself is known as Self Compacting Concrete (SCC) and is used in areas where reinforcements are crowded and conventional compaction is difficult. However, the increased use of cement has led to a significant amount of CO_2 emissions into the atmosphere. The cement manufacturing industry alone accounts for 5%-7% of global CO_2 emissions. To reduce these emissions, pozzolanic materials can replace cement in concrete. By employing fly ash (FA) in SCC is common because it enhances the ability to flow. To further reduce the carbon footprint from cement production, High-Volume Fly Ash Self Compacting Concrete (HVFA SCC) uses more than 30% FA in place of cement. This increases the durability of concrete by reducing chloride penetration but reduces compressive strength. The addition of FA increases the rheology too. The work aims in understanding the rheological and hardened state behaviour of HVFA SCC and comparing the cost of construction of HVFA SCC with Normal concrete.

Keywords: Self Compacting Concrete, Crimped Steel Fiber, High Volume Fly Ash

1 Introduction

The primary component of any construction project is concrete which will continue to be in need for a long time in the future because it is the highest utilized artificially created material in the world. Due to its exceptional qualities,such as strength and durability, placement flexibility, and lowcost, concrete is the most well-known and significant material in the world. Cement, fine aggregate, coarse aggregate, and water make up concrete. It has been utilized for construction since the beginning of time. Over the years, concrete has seennumerous advancements as a result of the need to buildstronger, longer-lasting structures with less time and effort. One such development in concrete is SCC. SCC is a form of concrete that consolidates under its own weight even when external compaction or vibration is not provided. The excellent flowability of the material allows for self- compaction. SCC is poured between the reinforcement, as shown in Fig. 1.

Figure 1: *Pouring SCC between the reinforcement(Source: Rich et al., 2012)*

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It is utilized in locations where it is challenging to compact normally and where reinforcements are congested. SCC has benefits in both production and installation, such as the removal of vibration, improved workability and flowability, and greater binding between congested reinforcement. The concrete building has taken place in a lot less time because of SCC. Additionally, it has a higher viscosity and keeps concrete from bleeding and segregation. Some advantages of employing SCC include shorter construction times, less noise on the job site, ease of creating complex shapes, thinner sections, and innovative designs.

In order to use industrial by-products like FA, Bagasse Ash, and Rice Husk Ash successfully in concrete, researchis being done in this area. In particular, FA is more frequently utilized in SCC than other types of concrete. Concrete becomes more workable when FA is added. SCC demands being extremely workable. This made it possible forFA to be applied in SCC. FA is typically used in place of cement. FA is replacing 15% of the cement in construction projects. HVFA SCC is a term used to describe concrete in which FA is replaced by a volume that is greater than 15%. This HVFA SCC enhances SCC's performance in its fresh state. The concrete is more workable and has a lower viscosity.

2 Literature Review

Alterary and Marei, 2021, released a review study that examines the characteristics, uses, and qualities of fly ash. The fly ash is made up of unburned carbon, metal oxides, etc.Class F and C are the two types of FA. The classification is based on the maximum and lowest contents of its composites. For Class F, the loss of ignition is greater. Concrete that has FA added to it is more durable, has smaller pores, and costs less to produce. Cement can be replaced by FA in Autoclaved Aerated Concrete (AAC) by a value of up to 70%.

Researchers examined the progression of the HVFA SCC's hydration and compressive strength with the addition of hydrated lime and without it. A replacement of 60–70%of the cement is possible. Metakaolin and FA are added, which lowers the quantity of superplasticizers used in the concrete. When added at 5%, hydrated lime has a compressive strength of greater than 38%. Hydrated lime was added, and the 60% FA concrete composition was re- alkaline.

A few researchers also examined the mechanical, fresh, and ecological performance of HVFA SCC. In this study, they used FA with three different finenesses to analyze the characteristics of HVFA SCC. Both viscosity and the amountof superplasticizer were decreased as a result of the addition of FA. The stability of the various finenesses of FA was increased by the finest fly ash. The finest fly ash- containing concrete also shows higher compressive strength than other types. The compressive strength can be significantly increased by substituting fly ash for 40–60% of the cement. Fly ash has a smooth, spherical shape that improves flowability, creates a ball-bearing effect, and decreases resistance to flow between the particles. Million tonnes of FA are produced annually in the world and are primarily disposed of in landfills. Therefore, a trustworthy solution is necessary for this and must be applied in concrete. When coal burns, the mineral impurities fuse and harden into spherical-shaped fly ash, which frequently takes the form of a cenosphere. Compared to cement, fly ash produces less heat during hydration. This aids in preventing the development of cracksas concrete ages. Early age causes a reduction in HVFA SCC's compressive strength, which increases as concretematures. Water absorption rates of HVFA SCC vary more forlevels of fly ash than 40%. but can be enhanced by lengthening the curing time.

Zhou *et al.*, 2020, examined the properties of HVFA SCC in their work. The investigation led to the discovery that fibres can enhance crack resistance. Additionally, the workability criteria were met when PP fibers were added at a level of 0.15 percent of the volume of concrete. PP fibers were added, andthis resulted in increased tensile strength. The initial-age strength of concrete is improved after adding seawater. Increasing the amount of FA can aid in the development of sustainable building practices. Due to its strong cohesion and segregation resistance, HVFA SCC is favourable.

3 Materials and Methodology

3.1 Materials Used

3.1.1 Cement

Ordinary Portland Cement (OPC) of 53 Grade- Chettinad cement with a specific gravity (SG) of 3.16, fineness of 5%, and standard consistency of 32.8% was used.

3.1.2 Fine Aggregate

Manufacturing Sand (M-Sand) with a SG of 2.62 and fineness modulus of 2.7 was used as fine aggregate. The particle size distribution of M-Sand is in Fig. 2.

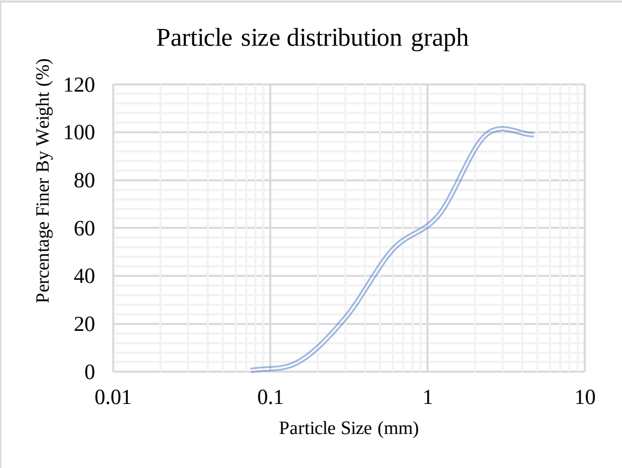

Figure 2: *Particle size distribution graph*

3.1.3 Coarse Aggregate

The size of coarse aggregate used for SCC ranges from 10mm to 20mm. A coarse aggregate of size 12.5mm was made use for the project with an SG of 2.7 and with water absorption of 0.5%.

3.1.4 Fly Ash

Admixture is a material other than basic ingredients of concrete. It is added to concrete during mixing. The admixture used in the concrete is FA of Class C. FA is fine residue obtained from the combustion of coal. The fineness obtained for FA was 10%, consistency was 34.3% and specific gravity was 2.6. All the test results showed a comparable range of value with that of cement.

3.1.5 Water

When water is added to the concrete, it forms a paste, and this bonds the aggregate together. The water causes the hardening of concrete through the process of hydration. Ordinary tap water, available in the laboratory is adopted for the experiment.

3.1.6 Superplasticizer

High Range Water Reducer (HRWRA), polycarboxylate ether-based water-reducing admixture was used as superplasticizer (SP) at a rate of 0.4% by weight of cement.

3.2 Mix Design

The constituents of concrete selected in suitable proportions to obtain the required strength and durability characteristics are called Mix designs. The properties of each material in concrete vary widely and it is necessary to understand all these properties to design a mix to obtain the required strength and durability.

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The design mix must be economical while it satisfies the strength and durability requirements. In this design, American Concrete Institute (ACI) 211.1 is adopted. It is a simple design procedure.

There are three different FA-Cement proportions with a replacement of 20%, 30% & 40%, coded as FA20SCC, FA30SCC, and FA40SCC, respectively, and one control SCC mix with a replacement 15% of cement by FA, coded as Control Mix.

The proportions of SCC samples are; Cement- 535 kg/m³, Fine aggregate- 833 kg/m³, Coarse aggregate- 778 kg/m³, and Water- 211 kg/m³. And FA was added as cement replacement at different percentages.

3.3 Test Methods

Following the ASTM standards, the flowability, passing capacity, and viscosity of fresh SCC were each examined using the slump flow, V-funnel, and L-box tests. In Fig. 3, these tests are displayed. Tests were done on the hardened qualities, including compressive strength, split tensile strength, and flexural strength.

a) L-box test b) Slump flow test c) V-funnel test

Figure 3: *Test for fresh taste properties of SCC*

Flexural strength test was conducted in accordance with IS 456: 2000, and the compressive strength and split tensile tests were conducted in accordance with IS 516 (1959). Fig. 4 depicts the tests for toughened characteristics.

a) Compression strength b) Flexural strength c) Flexural strength- crack on the beam

Figure 4: *Test for hardened state properties of SCC*

A cost comparison was done to analyze the cost for 1 m³ of concrete with; a) 0% cement replacement and no SP used, b) SCC with 15% cement replacement by FA and with SP, c) SCC with 30% (optimum percentage of replacement by FA) cement replacement and with SP.

FA, being an industrial waste, is available at zero price. SP is a main component in preparing SCC to enhance water demand and improve workability. The variation in the cost of concrete is entirely dependent on these two components.

4 Discussion of the Results

4.1 Fresh State Properties

Table 1 displays the test findings for various fresh stage attributes. The criteria for the workability or flowability were satisfied by the Control mix, FA20SCC, FA30SCC, and FA40SCC. Any of the mixes did not show serious segregation but showed increased workability and flowability.

Table 1: *Fresh State Properties of SCC*

Mix	Slump Flow	V-Funnel	L-Box
Control Mix	690	10	0.87
FA20SCC	690	10	0.89
FA30SCC	710	9	0.91
FA40SCC	720	9	0.93

4.2 Hardened State Properties

Fig. 5 shows the variation in compressive strength of SCC with Fly Ash at different proportions at 7, 28, and 56 days. It is observed that the compressive strength obtained at early ages of concrete, of all mixes, was less. This might be because of the reduced production of Ca $(OH)_2$ during the hydration process. A slight increase in the compressive strength was observed from 15% replacement to 30% replacement of cement.

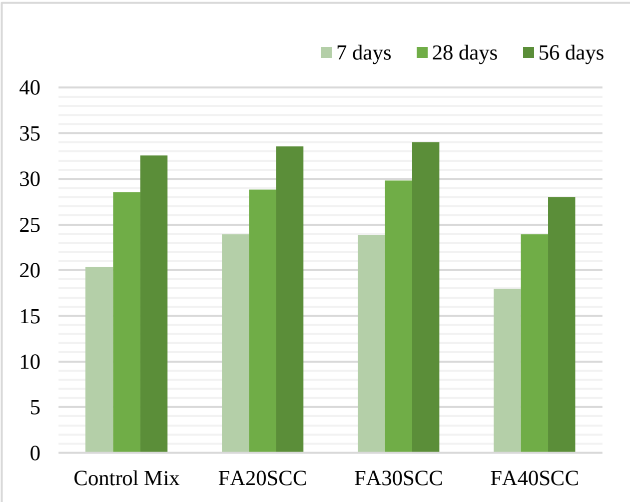

Figure 5: *Compressive strength of SCC at 7, 28, and 56 days*

But after this, a significant decrease in strength is observed. The split tensile strength and flexural strength results also showed a similarity in variation of strength and are depicted in Fig. 6 and Fig. 7, respectively. A betterperformance was observed when cement was replaced by FAby 30%. There the replacement of cement by about 30% of FA is recommendable and not beyond that. The replacement of 20% also gives an appreciable range of strength characteristics.

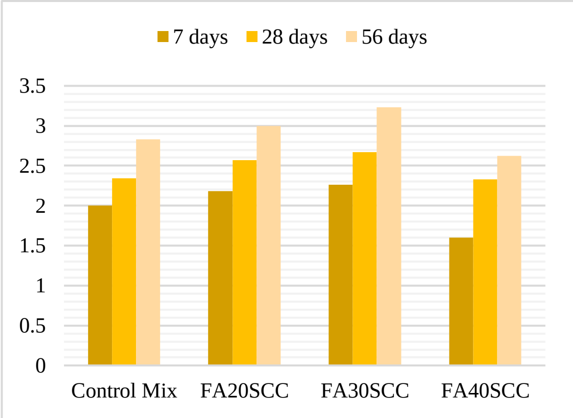

Figure 6: *Split tensile strength of SCC at 7, 28, and 56 days*

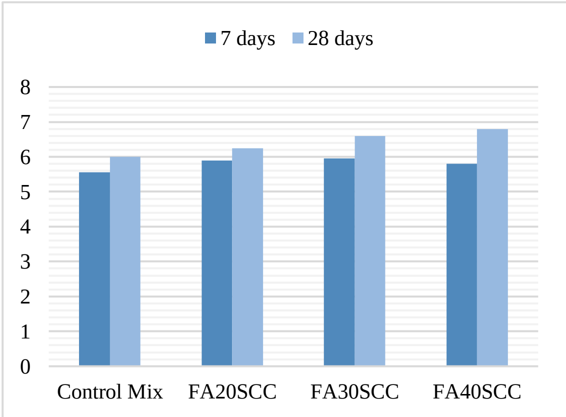

Figure 7: *Flexural strength of SCC at 7 and 28 days*

4.3 Cost Analysis

Table 2 show cost for various components of SCC. The cost analysis was carried out based on this rate. And the cost for 1m³ of concrete is shown in Table 3, Table 4, and Table 5, for different concrete mixes.

Table 2: *Cost of Components of SCC (Per Unit)*

Material	Cost (Rs.) per Kg
Cement	8.4
FA	-
Fine Aggregate	2.6
Coarse Aggregate	1.84
SP	480
Water	-

Table 3: *Cost of Normal Concrete*

Mix 1: Normal concrete (concrete with 0% FA and with no SP)			
Component per m³ of concrete	**Quantity (kg)**	**Cost (Rs.)**	**Total Cost (Rs.)**
Cement	535	4495	8092.32
Fly Ash	0	0	
Fine Aggregate	833	2165.8	
Coarse Aggregate	778	1431.52	
Superplasticizer	0	0	
Water	210.86	0	

Table 4: *Cost of SCC with 15% Replacement by FA*

Mix 2: Control Mix (concrete with 15% FA and with SP)			
Component per m³ of concrete	**Quantity (kg)**	**Cost (Rs.)**	**Total Cost (Rs.)**
Cement	454.75	4495	8444.42
FA	80.25	0	
Fine Aggregate	833	2165.8	
Coarse Aggregate	778	1431.52	
SP	2.14	1027.2	
Water	210.86	0	

Table 5: *Cost of SCC With 30% Replacement by FA*

Mix 3: Optimum Mix (concrete with 30% FA and with SP)			
Component per m³ of concrete	**Quantity (kg)**	**Cost (Rs.)**	**Total Cost (Rs.)**
Cement	374.5	3145.8	7770.0
FA	160.5	0	
Fine Aggregate	833	2165.8	
Coarse Aggregate	778	1431.52	
SP	2.14	1027.2	
Water	210.86	0	

When the cost of the mixes was compared, it was inferred that the cost for SCC, in terms of FA addition, is reduced. Since FA is free of cost, the cost of the binder is reduced. So, the concrete with cement replaced by FA is more economical than normal concrete. But, since SCC uses HRWRA, the costis increased for SCC. The cost of these superplasticizers is much higher. When the normal concrete mix is compared with the optimum value, found that cost is much less for SCC. Therefore, from this result, it is inferred that SCC with 30% replacement of cement by FA is economical.

5 Conclusions

In this work, the fresh and hardened state characteristics of HVFA SCC and a cost-analysis between concrete with FA at 0%, 15%, and 30% replacements were carried out and the following conclusions were drawn:

- Being a pozzolanic and cementitious material, Class C- Fly Ash is highly recommendable as Supplementary Cementitious Material. Though the early-age strength of SCC reduces with the addition of FA, it has higher later-age strength. The reduction in early age strength isdue to the reduced production of $Ca(OH)_2$ during the hydration process.

- FA has a spherical shape and smooth surface with a sizeranging from 0.5μm to 200μm. This greatly influences enhancing the flowability and workability of SCC. As the fraction of FA increases, the workability and flowability also increase. This helps the concrete to easily flow and fill even the congested reinforcement.
- Cement replaced with FA by 30% has comparatively higher strength than the others. An acceptable value of strength was also observed in SCC with 20%FA. But when the percentage of replacement became 40%, the strength reduced significantly.
- The replacement of cement greatly reduces carbon footprint of SCC. Cement usage can be considerably decreased.
- The reduction in cement usage, by the addition of FA not only makes the concrete eco-friendlier, but economical too.
- The use of FA in SCC also helps effectively manage theFA, an industrial waste product.

6 Publisher's Note

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