PERFORMANCE EVALUATION OF SELF-COMPACTING CONCRETE INCORPORATING FLY ASH AND SILICA FUME

John Prakash, Y. Himath Kumar, N. Lingeshwaran and Nadigatla Naveen Kumar
Department of Civil Engineering, Koneru Lakshmaiah Education Foundation (KL Deemed to be University), Guntur, Vaddeswaram, India
E-Mail: jp4189534@gmail.com

ABSTRACT

The study aimed to produce SCC by mixing fly ash and silica fume, two typical mineral wastes. Two binary blended mixes were created: the first replaced cement with fly ash in varying percentages (10%, 20%, 30%, and 40%), while the second took the best fly ash mix and replaced cement with silica fume at 5%, 7.5%, and 10%. Important studies that were carried out included tests for workability, compressive strength, split tensile strength, water sorptivity, and rapid chloride penetration. Compared to regular concrete, the performance attributes improved as these components were added to SCC.

Keywords: self-compacting concrete (SCC), supplementary cementitious materials (SCMs), fly ash, silica fume, compressive strength.

Manuscript Received 24 October 2024; Revised 27 January 2025; Published 21 March 2025

INTRODUCTION

The construction industry is constantly searching for innovative materials and techniques to improve the durability, sustainability, and efficacy of concrete structures. Self-Compacting Concrete (SCC) is a ground-breaking material that eliminates the need for mechanical consolidation during placement while simultaneously enhancing workability, durability, and aesthetic quality. This study looks at the mechanical properties, durability, and sustainability implications of SCC when some of the cement is replaced with fly ash and silica fume.

Self-Compacting Concrete

Because SCC can fill intricate forms and flow underweight without incurring mechanical disruption, it represents a significant advancement in concrete technology. By utilizing viscosity-modifying agents (VMA), high-range water-reducing admixtures (HRWRA), and appropriate aggregates, its mix design guarantees enhanced flowability and stability.

Important characteristics of SCC include

- **Flowability:** Under gravity, SCC fills and spreads formwork without bleeding or segregating.
- **Cohesiveness:** It ensures consistency by maintaining a uniform distribution of elements and aggregates.
- **Durability:** Its durability is improved by less segregation and compaction-related flaws.
- **Finishability:** SCC minimizes the need for extra surface treatments by achieving smooth surface finishes.

Cement, the binder used in concrete, gives it durability and strength. Calcium silicate hydrates (C-S-H) gel, which is produced when Portland cement, which is mostly composed of calcium silicates, aluminates, and ferrites, is hydrated, gives concrete its strength and durability.

Fly Ash

A popular supplemental cementitious material (SCM) in concrete is fly ash, which is a byproduct of burning coal in thermal power plants. Its application has technological, financial, and environmental advantages.
Important traits of fly ash include:

- **Pozzolanic activity:** It increases the strength and durability of concrete by reacting with calcium hydroxide to generate more C-S-H gel.
- **Increased strength and durability:** Fly ash increases defenses against alkali-silica reactions (ASR), sulfate attacks, and chemical attacks.
- **Decreased heat of hydration:** By lowering the heat of hydration, it lowers the possibility of thermal cracking and improves durability over the long run.
- **Environmental benefits:** By reducing the need for Portland cement and keeping trash out of landfills, the use of fly ash promotes sustainability.

To determine their usefulness in construction, this study investigates SCC by partially substituting fly ash and silica fume for cement. It does this by analyzing the impact of these materials on new qualities such as workability, flowability, and stability.

Silica Fume

A by-product of the manufacturing of silicon metal is silica fume, sometimes referred to as micro silica. Its excellent pozzolanic qualities and small, amorphous particles improve the durability and mechanical qualities of concrete.

Advantages of silica fume

- **Enhanced strength:** It forms more C-S-H gel when it combines with calcium hydroxide, strengthening concrete and lowering permeability.
- **Less permeability:** The concrete's microstructure becomes denser, making it more resistant to harsh chemicals and freeze-thaw cycles.
- **Better workability:** Silica fume improves the concrete mix's lubricating and cohesive qualities.

To provide insights into their useful applications and contributions to sustainable construction, this study intends to evaluate the synergistic impacts of silica fume, fly ash, and SCC on concrete characteristics.

Objective of the Project

a) Use fly ash (FA) and silica fume (SF) in concrete to introduce novel building materials.

b) Examine the mechanical characteristics of concrete that has been improved with fly ash and silica fume.

c) Determine the ideal amount of fly ash and silica fume to add to concrete to maximize its compressive strength.

d) Find the best amount of fly ash and silica fume to add to concrete to increase its tensile strength.

e) Use sorptivity and quick chloride permeability tests to assess the amended concrete's durability.

LITERATURE REVIEW

Self-compacting concrete (SCC) has gained significant attention in recent decades due to its enhanced workability, mechanical properties, and sustainability potential. SCC, developed in the late 20th century, is known for its ability to flow under its weight, filling formwork and encapsulating reinforcement without the need for mechanical vibration [1].

The early developments of SCC, as discussed by Okamura *et al*. (2000), established the foundational properties and applications of this material, focusing on its fluidity, stability, and segregation resistance [1]. The importance of self-compaction for ensuring uniformity and durability has been consistently highlighted in subsequent studies. Goodier (2003) expanded upon this, outlining the evolution of SCC technology and its adoption across various sectors due to its improved durability and reduced labor costs [5]. Similarly, Domone (2006) provided an extensive analysis of SCC applications across multiple projects, emphasizing the long-term performance and versatility of SCC in diverse construction environments [2].

Further research has also focused on optimizing the mix design of SCC. Brouwers and Radix (2005) presented both theoretical and experimental studies to improve the material's properties, particularly its viscosity and mechanical strength [3]. This has led to the development of various guidelines, such as those from the European Federation of National Associations Representing for Concrete (EFNARC), which have standardized SCC production methods, ensuring consistency and quality across projects [4].

In addition to its workability, researchers have examined the mechanical properties of SCC. Khayat and De Schutter (2014) explored the mechanical behavior of SCC, particularly its strength characteristics under different loading conditions [7]. Their findings indicated that SCC could meet or exceed the performance of conventional concrete in structural applications. These results were corroborated by Aslani and Nejadi (2012), who conducted an analytical study comparing the mechanical properties of SCC with conventional concrete. Their results demonstrated SCC's superior performance in terms of compressive and tensile strength [10].

Sustainability has also become a critical focus in the development of SCC. Recent studies, such as those by Elsayed *et al*. (2022), have explored the incorporation of eco-friendly materials like ground granulated blast furnace slag (GGBS) and fly ash as cement replacements in SCC mixtures. These materials have been shown to enhance the environmental sustainability of SCC without compromising its mechanical properties [11]. Similarly, the study by Kavyateja *et al*. (2020) highlighted the effectiveness of using alccofine and fly ash in ternary blended SCC, further demonstrating the potential of sustainable materials in concrete technology [12].

In conclusion, the development of SCC represents a significant advancement in concrete technology, offering improved workability, mechanical properties, and sustainability. The ongoing research into optimizing mix designs and incorporating eco-friendly materials will likely continue to enhance the performance and application of SCC in the construction industry.

METHODOLOGY

Workability Tests

Workability is a fundamental property of fresh concrete, reflecting its ease of placement and ability to be compacted without segregation. It is critical for various construction applications as it directly impacts the strength and durability of hardened concrete. Different types of concrete require varying levels of workability, which can be evaluated using standardized tests.

Slump Flow Test

The slump flow test is conducted using a slump flow apparatus, which consists of a base plate and a coneshaped mold (bottom diameter: 20 cm, top diameter: 10 cm, height: 30 cm), following ASTM C1611 or EN 12350-8 standards. The procedure includes:

a) **Preparation:** Ensure the apparatus is clean and level. Fill the cone with freshly mixed self-compacting concrete (SCC) without compaction.
b) **Test execution:** Lift the cone vertically to allow the concrete to flow freely.
c) **Measurement:** Measure the horizontal spread of the concrete at several points and record the average diameter.
d) **Assessment:** The slump flow value provides insight into the concrete's ability to fill formwork without excessive vibration, which is crucial for minimizing defects like honeycombing.

L-Box Test

The L-Box exam uses strengthened portions to assess SCC's passing capacity. The device consists of a horizontal flow tank with obstructions and a vertical hopper. The steps are as follows:

a) Setup: Position the L-Box on a sturdy surface and coat the inside surfaces with a release agent.

b) Filling: Pour around 14 liters of SCC into the vertical hopper and let it sit for a minute.

c) Flow measurement: Set a stopwatch and open the sliding gate. When the concrete reaches the 200 and 400 mm markings, note how long it takes.

d) Calculations: Determine the blocking ratio (H2/H1) by measuring the concrete's heights (H1 and H2) in both sections. A score of 0.8 to 1 denotes a solid passing grade.

U-Box Test

The U-Box test evaluates SCC's filling and passing skills. A U-shaped box with movable barriers makes up the equipment. The actions consist of:

a) Get the U-Box ready by cleaning it and moistening the inside surfaces.

b) Filling: Without compacting, fill the left compartment with SCC, then let it rest for a minute.

c) Measurement of flow: Let the concrete enter the appropriate compartment by opening the gate. Following the completion of the flow, measure the heights (H1 and H2).

d) Filling height calculation: Find the difference between H1 and H2. Good workability is indicated by a slight difference.

V-Funnel Test

The filling capacity of SCC with a maximum aggregate size of 20 mm is evaluated using the V-Funnel test. The process consists of:

a) Setup: Place the funnel on a level surface after moistening it. About 12 liters of uncompacted concrete should be added to it.

b) Flow measurement: Time how long it takes for the concrete to pass through the funnel after opening the trap door in ten seconds

c) Evaluation: A much longer flow time indicates a decreased filling ability if the concrete shows segregation.

Compressive Strength Testing

Concrete's ability to support weight is evaluated through compressive strength testing. The procedures are as follows:

a) Specimen preparation: 150 x 150 x 150 mm cubes of cast concrete with different proportions of fly ash (10%, 20%, 30%, 40%) and silica fume (5%, 7.5%, 10%), while keeping the fly ash content at 30%.

b) Curing: After 24 hours, demold the specimens and cure them for 7 and 28 days in potable water.

c) Testing: Apply load until the specimen fails and note the maximum load using a 2000 kN compression testing equipment by IS: 516-1959.

d) Calculating strength: The following formula is used to determine the compressive strength:

Maximum Load (N) = Cross-sectional Area (mm2) = Compressive Strength (MPa)

Split Tensile Strength Testing

The split tensile strength test evaluates concrete's resistance to tensile stress. The procedure is as follows:

a) **Preparation of the specimen:** Cast cylindrical specimens with different proportions of fly ash and silica fume (150 mm in diameter and 300 mm in length).
b) **Curing:** After demoulding, leave the specimens in drinkable water for seven to twenty-eight days.
c) **Testing:** Apply a compressive load perpendicular to the cylinder's axis while the specimen is positioned between two platens of a compression testing apparatus.
d) **Evaluation of failure:** Note the greatest load at failure and use the formula Tensile Stress (MPa)=πDL2P to determine the split tensile strength, where P is the compressive load, L is the cylinder's length, and D is its diameter.

These techniques can be used to thoroughly assess the workability and strength characteristics of self-compacting concrete, guaranteeing that it is appropriate for a range of building applications.

RESULT

Eight concrete cube mixes measuring 150 x 150 x 150 mm and eight concrete cylinder mixes measuring 300 x 150 mm are made. These mixtures are made with varying percentages of fly ash replacement (10%, 20%, 30%, 40%), as well as silica fume replacement (5%, 7.5%, 10%).v

WORKABILITY RESULTS

The slump flow, V- funnel, L-box, and U-box values for each of the eight mixtures are displayed in the following table. The mix's slump flow is depicted in the figure.

Figure-1. Slump flow test.

Table-1. Workability for nominal mix.

Mix proportion	Slump flow test (mm)	V-funnel test		U-box	L-box
		T0 sec	T5 sec		
OPC	693	9	9	3	0.88
FA10%.	696	8	9	4	0.87
FA 20%.	697	8	8	4	0.89
FA30%	694	9	9	4	0.90
FA 40 %	688	8	9	4	0.88
FA30%SF5%	695	8	7	5	0.89
1	694	7	8	4	0.88
FA30%SF10%	687	9	9	5	0.86

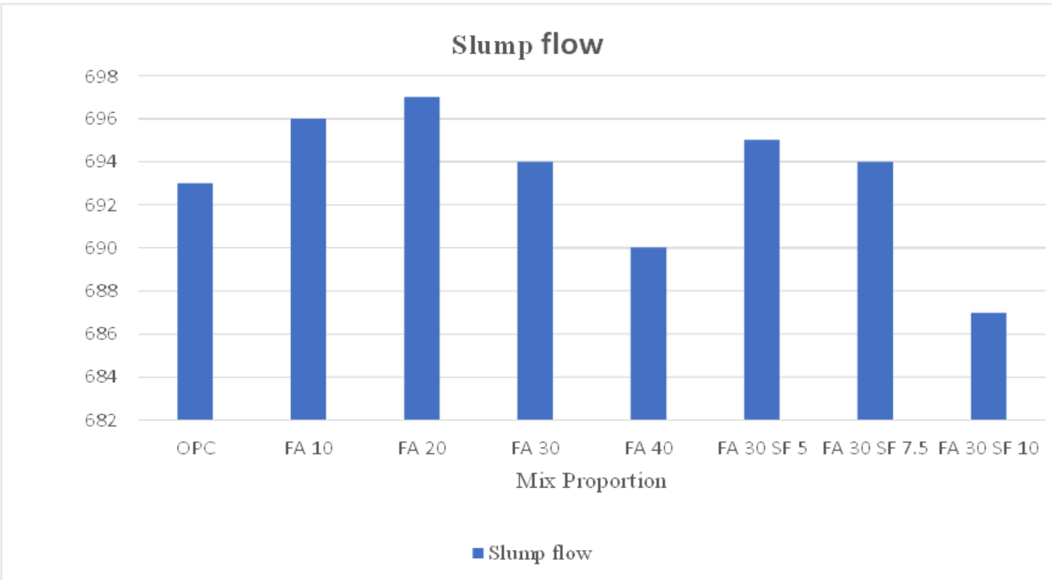

Figure-2. Slump flow v/s mix proportion.

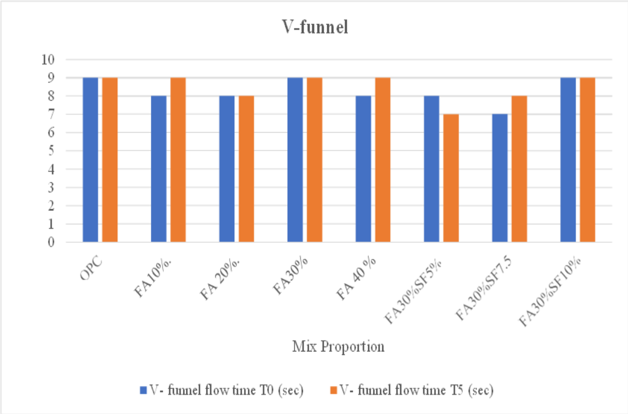

Figure-3. V-funnel v/s mix proportion.

COMPRESSIVE STRENGTH RESULTS

The experimental findings, which indicate the compressive strength for 7 and 28 days using fly ash and silica fume, are displayed in the table figures following the 7 and 28-day curing periods. The combined compressive strength values for fly ash and silica fume mixes are shown in the figures.

Figure-4. Compressive strength testing.

Table-2. Compressive strength of cubes.

MIX	7 DAYS MPA	28 DAYS MPA
OPC	14.35	41.02
FA10	14.57	41.64
FA 20%	14.68	41.97
FA30%	14.72	42.06
FA 40%	14.04	40.12
FA 30% SF 5%	16.35	46.72
FA 30% SF 7.5%	16.98	48.54
FA 30% SF 10%	15.90	45.43

SPLIT TENSILE STRENGTH RESULTS:

Figure-5. Split tensile strength testing.

Table-3. Split tensile strength of cylinders.

MIX	7 DAYS MPA	28 DAYS MPA
OPC	1.79	5.14
FA10	1.81	5.18
FA 20%	1.82	5.20
FA30%	1.87	5.34
FA 40%	1.78	5.10
FA 30% SF 5%	1.90	5.45
FA 30% SF 7.5%	1.91	5.54
FA 30% SF 10%	1.88	5.38

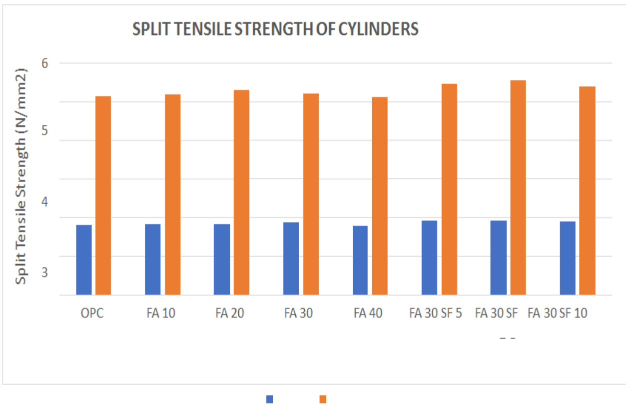

Figure-6. Split tensile strength v/s mix proportion.

CONCLUSIONS

When compared to traditional mixtures, the use of mineral admixtures, such as fly ash and silica fume, greatly improves the workability of concrete mixes. For self-compacting concrete (SCC), which depends on its capacity to flow and fill moulds without the need for mechanical vibration, this improvement is especially important. The precise ratios of these admixtures in the concrete mix are essential since they have a direct impact on the final concrete's mechanical qualities as well as workability.

This study found that using 30% fly ash and 7.5% silica fume was the best blend for obtaining the highest compressive and split tensile strengths. Fly ash's spherical particle shape and pozzolanic qualities, which aid in lowering the water-to-cement ratio while preserving the required consistency, improve workability. Because of its extremely small particles, silica fume increases the concrete's packing density, which improves workability and, eventually, durability.

Furthermore, it was shown that long curing times were essential for the growth of compressive strength. After 28 days of curing, the maximum strength values were noted, suggesting that the concrete's performance is continuously enhanced by the hydration processes. Further pozzolanic interactions between the mineral admixtures and the calcium hydroxide generated during cement hydration are made possible by this extended curing, which results in the development of more calcium silicate hydrate (C-S-H), which gives concrete its strength and durability.

Overall, the results highlight how crucial it is to carefully choose the amounts of silica fume and fly ash in concrete mixtures to maximize their mechanical and workability qualities. This study highlights the potential of employing mineral admixtures to improve the performance of self-compacting concrete in a variety of structural applications, offering practitioners and researchers in the field of construction useful insights.

REFERENCES

[1] Okamura H., Ozawa K. and Ouchi M. 2000. Self-compacting concrete. *Structural concrete*. 1(1): 3-17.

[2] Domone P. L. 2006. Self-compacting concrete: An analysis of 11 years of case studies. *Cement and concrete composites*. 28(2): 197-208.

[3] Brouwers H. J. H. and Radix H. J. 2005. Self-compacting concrete: theoretical and experimental study. *Cement and concrete research*. 35(11): 2116-2136.

[4] Concrete S. C. 2005. The European guidelines for self-compacting concrete. *BIBM, et al*, 22, 563.

[5] Goodier C. I. 2003. Development of self-compacting concrete. Proceedings of the Institution of Civil Engineers-Structures and Buildings. 156(4): 405-414.

[6] Petersson O., Billberg P. and Van B. K. 2004. A model for self-compacting concrete. In Production methods and workability of concrete (pp. 495-504). CRC Press.

[7] Khayat K. H. and De Schutter G. 2014. Mechanical properties of self-compacting concrete (14: 161). Springer.

[8] Gaimster R. and Dixon N. 2003. Self-compacting concrete. Advanced concrete technology. 3, 1-23.

[9] De Schutter G., Bartos P. J., Domone P. and Gibbs J. 2008. Self-compacting concrete (Vol. 288). Caithness: Whittles Publishing.

[10] Aslani F. and Nejadi S. 2012. Mechanical properties of conventional and self-compacting concrete: An analytical study. Construction and Building Materials. 36, 330-347.

[11] Elsayed M., Tayeh B. A., Aisheh Y. I. A., Abd El-Nasser N. and Abou Elmaaty M. 2022. Shear strength of eco-friendly self-compacting concrete beams containing ground granulated blast furnace slag and fly ash as cement replacement. Case Studies in Construction Materials. 17, e01354.

[12] Kavyateja B. V., Jawahar J. G. and Sashidhar C. 2020. Effectiveness of alccofine and fly ash on Mechanical Properties of ternary blended self-compacting concrete. Materials Today: Proceedings. 33, 73-79.

[13] Abdalhmid J. M., Ashour A. F. and Sheehan T. 2019. Long-term drying shrinkage of self-compacting concrete: Experimental and analytical investigations. Construction and Building Materials. 202, 825-837.

[14] Mustapha F. A., Sulaiman A., Mohamed R. N. and Umara S. A. 2021. The effect of fly ash and silica fume on self-compacting high-performance concrete. Materials Today: Proceedings. 39, 965-969.

[15] Aditto F. S., Sobuz M. H. R., Saha A., Jabin J. A., Kabbo M. K. I., Hasan N. M. S. and Islam S. 2023. Fresh, mechanical and microstructural behaviour of high-strength self- compacting concrete using

supplementary cementitious materials. Case Studies in Construction Materials. 19, e02395.

[16] Mahalakshmi S. H. V. and Khed V. C. 2020. Experimental study on M-sand in self-compactible concrete with and without silica fume. Materials Today: Proceedings. 27, 1061-1065.

[17] Nuruddin M. F., Chang K. Y. and Azmee N. M. 2014. Workability and compressive strength of ductile self-compacting concrete (DSCC) with various cement replacement materials. Construction and Building Materials. 55, 153-157.

[18] Chandana B. and Rao M. D. 2018. Experimental studies on self-compacting concrete with partial replacement of fly ash and silica fume. International Journal of Innovative Technology and Exploring Engineering. 7(8): 6-12.

[19] Falmata A. M., Sulaiman A., Mohamed R. N. and Shettima A. U. 2020. Mechanical properties of self-compacting high-performance concrete with fly ash and silica fume. SN Applied Sciences. 2, 1-11.

[20] Omar Mohamed Oraibi K. and Yenny Nurchasanah S. T. 2015. Mechanical Properties of Self Compacting Concrete Using Fly Ash (Doctoral dissertation, Universitas Muhammadiyah Surakarta).