Experimental Study on Self-Compacting Concrete Using Kevlar Fiber and Silica Fume

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***Abstract*—Self-Compacting Concrete (SCC) is an advanced form of concrete that flows and consolidates under its own weight without the need for mechanical vibration. This study investigates the enhancement of SCC properties through the incorporation of Kevlar fibers and the partial replacement of cement with silica fume. Kevlar fibers were added in varying proportions of 0.2%, 0.4%, 0.6%, and 1.0%, while silica fume was maintained at a constant 10% replacement level. The fresh properties of SCC were evaluated using slump flow, T_{50}, and V-funnel tests, whereas the hardened properties were assessed through compressive strength, split tensile strength, flexural strength, and Ultrasonic Pulse Velocity (UPV) tests. The results revealed that the inclusion of Kevlar fibers significantly improved tensile and flexural strength, while excessive fiber content reduced workability. The optimum performance was observed at 0.4% Kevlar fiber content, which demonstrated notable improvements in mechanical properties and durability. This study confirms that the combined use of Kevlar fibers and silica fume enhances the overall performance of SCC, making it suitable for high-strength and durable structural applications.**

Index Terms*—Self-compacting concrete, Kevlar fiber, Silica fume, Workability, Compressive strength, Split tensile strength.

I. INTRODUCTION

Self-Compacting Concrete (SCC) represents a significant advancement in modern concrete technology, offering superior flowability, filling ability, and passing ability without the need for external vibration. This unique characteristic reduces labor requirements, minimizes noise pollution, and ensures uniform compaction, particularly in structures with congested reinforcement [1]. Despite its advantages, SCC exhibits brittle behavior and is susceptible to cracking. To overcome these limitations, fiber reinforcement has been widely adopted to enhance ductility, toughness, and durability. Fiber-reinforced SCC has shown improved mechanical and durability properties compared to conventional concrete [2], [8].

Kevlar (Aramid) fibers are synthetic fibers known for their exceptional tensile strength, low density, high impact resistance, and excellent thermal stability. Their tensile strength-to-weight ratio is significantly higher than that of steel, making them highly suitable for structural applications requiring enhanced crack resistance and durability [3].

Silica fume, an ultrafine by-product of silicon and ferrosilicon alloy production, is widely used as a highly reactive pozzolanic material in high-performance concrete. Its fine particle size improves particle packing density and promotes pozzolanic reactions, thereby enhancing strength, impermeability, and durability [10].

The successful performance of SCC depends on its flow characteristics and stability, which are governed by appropriate mix design and adherence to established acceptance criteria [4]. The use of superplasticizers further improves workability by reducing water demand while maintaining high strength [6].

In this context, the present study investigates the synergistic effects of Kevlar fibers and silica fume on the fresh and hardened properties of Self-Compacting Concrete. The research aims to determine the optimum fiber content that balances workability with mechanical performance, thereby contributing to the development of high-strength, durable, and sustainable concrete for modern construction.

II. OBJECTIVE

The primary objective of this study is to improve the quality and strength of Self-Compacting Concrete (SCC) using Kevlar fiber and silica fume. Kevlar fiber is incorporated to enhance tensile strength and crack resistance, while silica fume is used to improve strength, durability, and microstructural density. The study aims to determine the optimum content of Kevlar fibers in SCC and evaluate their effects on the fresh and hardened properties when compared to conventional SCC. It further seeks to assess key mechanical properties, including compressive strength, split tensile strength, and flexural strength.

III. MATERIALS USED

1. CEMENT

Cement is a fine hydraulic binding material, typically produced from limestone, clay, and shale, which hardens when mixed with water to form a strong binding medium. It is an essential component in construction, used in concrete fresh and hardened properties of SCC with partial replacement of cement by silica fume.

Table 1. Properties of Cement

Properties	Results
Specific Gravity	3.12
Fineness	7.2%
Initial Setting time	40 min
Final Setting time	10 hours

AGGREGATE:

The grading and particle shape of fine aggregates are important factors in the production of self-compacting concrete (SCC). Fine aggregates with a rounded particle shape and smooth surface texture require less mixing water and are therefore preferred in SCC. In this project, locally available M-sand is used as the fine aggregate.

Among the various properties of aggregates, shape and gradation play a crucial role in SCC performance. Rounded aggregates improve flowability and reduce the risk of blockage for a given water-to-powder ratio when compared to angular and semi-rounded aggregates. Due to the highly flowable nature of SCC, a slightly higher proportion of flaky aggregates may be tolerated compared to conventional concrete; however, this needs to be carefully evaluated. In this study, 12.5 mm coarse aggregate is used as the coarse aggregate size.

Table 2. Properties of Fine Aggregate

Properties	Results
Specific Gravity	2.26
Water Absorption	0.8%
Fineness	29.50%

Table 3. Properties of Coarse Aggregate

Properties	Results
Specific Gravity	2.56
Water Absorption	0.5%
Fineness	21.49%

SILICA FUME:

Silica fume (also known as microsilica) is an ultrafine powder and a by-product of silicon and ferrosilicon alloy production. It is widely used as a highly reactive pozzolan in high-performance concrete. Being approximately 100 times finer than cement, silica fume significantly improves the strength, density, and durability of concrete

Fig.1. Silica fume

Table 4. Properties of Silica fume

Properties	Results
Specific Gravity	2.25
Fineness	6.9%
SiO_2 content	86%

KEVLAR FIBER:

Kevlar fiber is a strong and lightweight material with low density, good thermal stability, and excellent toughness. The incorporation of fine and closely spaced Kevlar fibers in concrete helps to produce a crack-resistant matrix and improves both the static and dynamic properties of concrete. However, the addition of Kevlar fibers to self-compacting concrete (SCC) can reduce workability and make the fresh mix stiffer. Therefore, chemical admixtures are used to improve flowability and reduce the water demand in the mix.

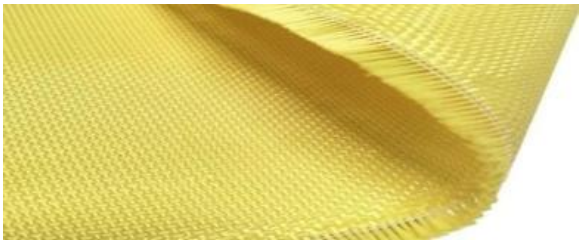

Fig.2. Kevlar Fiber

Table 5. Properties of Kevlar Fiber

Properties	Size
Length	20 mm
Diameter	0.16 mm
Aspect ratio	120
Density	1440 kg/m3
Tensile Strength	3600 MPa

VISCOSITY MODIFYING AGENTS (VMA):

Viscosity modifying agents (VMA) are used to improve the resistance of concrete to segregation and bleeding. They also help modify the flow properties and rheological behavior of mortar and concrete, allowing optimization of different types of concrete mixes. The addition of VMA enhances the stability of self-compacting concrete (SCC).

SUPER PLASTICIZERS (SP):

Superplasticizers (SPs), particularly polycarboxylate ether (PCE) based, are essential in self-compacting concrete (SCC) to achieve high flowability, stability, and high strength without vibration. They allow for 20 – 40 % reduction of water content.

IV. EXPERIMENTAL METHODS

1)Concrete Mix Design:

The final optimized mix for M25 grade self-compacting concrete was obtained through trial mixes. The selected mix consisted of 610 kg/m³ cement, 760 kg/m³ fine aggregate, 640 kg/m³ coarse aggregate, with a water content of 210 l/m³ (w/c = 0.34). Superplasticizer and viscosity modifying agent were used at 0.5% and 0.05% respectively to ensure adequate flowability and segregation resistance as per EFNARC guidelines.

Table 6. Mix Design Proportions

Cement kg/m³	FA kg/m³	CA kg/m³	Water L/m³	SP kg/m³	VMA kg/m³
610	760	640	210	3.05	0.3
1	1.22	1.08	0.34	0.5%	0.05%

2)Casting and Curing of Specimen:

The mixed concrete materials were cast into watertight cube moulds of size 150 mm × 150 mm × 150 mm and cylindrical moulds of size 200 mm × 300 mm. The concrete was poured into the moulds without any external compaction or tamping. The moulds were completely filled with self-compacting concrete (SCC) up to the top surface, and no trowelling was required for finishing. After filling, the moulds were kept undisturbed for setting under vibration-free conditions. The specimens were stored in a place free from vibration and disturbance. After 24 hours, the specimens were demoulded, marked, and immediately submerged in clean fresh water for curing. The curing periods adopted were 7 days, 14 days, and 28 days.

V. CONCRETE TESTS AND RESULTS

A. FRESH CONCRETE TESTS:

1)Slump flow test:

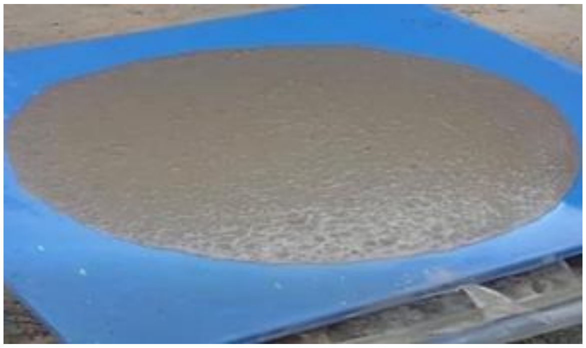

Fig.3. Slump flow test

The slump flow test is conducted to evaluate the horizontal flowability of concrete in the absence of obstructions. A standard slump cone with a base diameter of 200 mm, top diameter of 100 mm, and height of 300 mm is used for the test. According to EFNARC guidelines, the acceptable slump flow range for self-compacting concrete (SCC) is between 650 mm and 800 mm.

2) Slump flow T50 cm test:
The procedure for this test is same as for slump flow test. When the slump cone is lifted, start the stopwatch and find the time taken for the concrete to reach a 500 mm mark. This time is called T50 time. This is an indication of the rate of spread of concrete. A lower time indicates greater flowability. As per EFNARC it is suggested that T50 time may be 2 to 5 secs.

3) V-Funnel test:

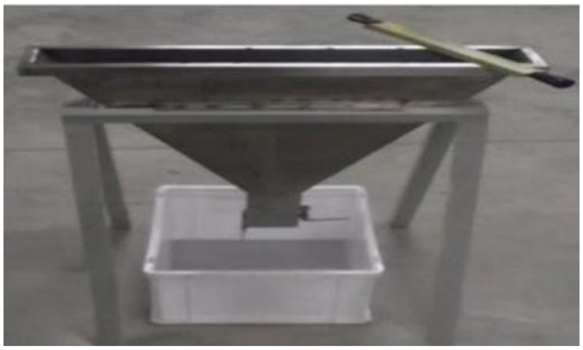

Fig.4. V-Funnel test

The V-funnel test is a standard procedure used to evaluate the viscosity and filling ability of freshly mixed Self-Compacting Concrete (SCC). It measures how quickly a set volume of concrete flows through a narrow opening, providing a simple indicator of how well the mix will flow into formwork and around reinforcement. As per EFNARC its suggested time is 8 to 12 secs.

Table 7. Fresh Properties of SCC Mixes

Mix ID	Slump Flow (mm)	T50(s)	V-Funnel (s)
Nominal SCC	690	3.0	6.5
SF10%KF0.2%	670	4.2	8.5
SF10%KF0.4%	650	4.9	11.0
SF10%KF0.6%	530	11.0	15.5
SF10%KF1.0%	380	-	19.0

B. HARDENED CONCRETE TEST:
The specimens cured in water were taken out, wiped dry, and their dimensions and weights were measured prior to testing. The bearing surfaces of the testing machine were thoroughly cleaned to remove any dust or foreign particles that could affect the contact with the compression plates. During testing, the cube specimens were carefully placed in the machine such that the load was applied to the cast side faces and not on the top and bottom surfaces. The maximum load at failure was recorded, and the mode of failure along with any unusual behavior was observed and documented.

1) Compressive strength test:
For the 28-day compressive strength test, the mix SF10% + KF0.2% showed an increase of 4.5% compared to the nominal mix. The mix SF10% + KF0.4% exhibited a 7.4% increase, which is the highest among all mixes. The mix SF10% + KF0.6% showed a marginal increase of 0.3% compared to the nominal mix. In contrast, the mix SF10% + KF1% showed a 7.6% decrease in strength. Overall, the mix SF10% + KF0.4% demonstrated the best compressive strength performance among all the mixes.

Fig.5. Compressive strength test

Table 8. Compressive strength test result

S.NO	%Replacement	Compressive Strength (N/mm^2)		
		7 days	14 days	28 days
1	SF0% + KF0%	34.95	46.89	53.08
2	SF10% + KF0.2%	35.70	50.33	55.48
3	SF10% + KF0.4%	37.10	51.45	57.02
4	SF10% + KF0.6%	35.55	47.94	53.26
5	SF10% + KF1%	31.95	45.57	49.04

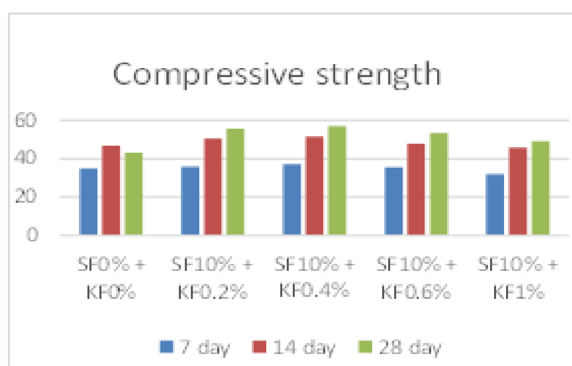

Fig.6. Compressive strength

2) Split tensile strength test:

For the 28-day Split tensile strength, the mix SF10% + KF0.2% showed an increase of 3.6% compared to the nominal mix. The mix SF10% + KF0.4% exhibited a 6.8% increase over the nominal mix. The mix SF10%+ KF0.6% showed a 4.8% increase compared to the nominal mix. In contrast, the mix SF10% + KF1% showed a decrease of 6.5% relative to the nominal mix. Among all the mixes, SF10% + KF0.4% demonstrated the highest strength compared to the other mixes.

Fig.7. Split tensile strength test

Table 9. Split tensile strength test result

S.NO	% Replacement	Split tensile Strength (N/mm^2)		
		7 days	14 days	28 days
1	SF0% + KF0%	3.25	3.77	5.26
2	SF10% + KF0.2%	3.61	3.95	5.45
3	SF10% + KF0.4%	4.52	4.65	5.62
4	SF10% + KF0.6%	4.24	4.12	5.51
5	SF10% + KF1%	3.72	3.99	4.92

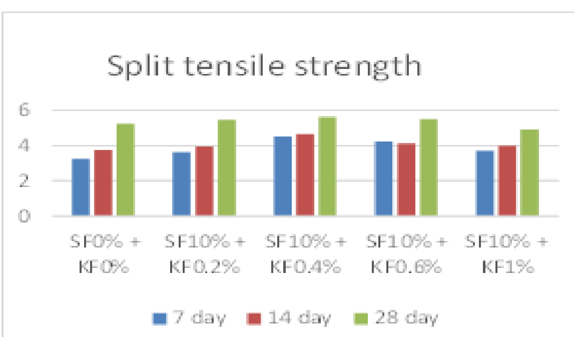

Fig.8. Split tensile strength

3) Flexural Behavior:

Reinforced beams containing 0.4% Kevlar fiber exhibited a 26.4% increase in ultimate load-carrying capacity (34.93 kN) compared to nominal self-compacting concrete (SCC) beams (27.63 kN). Furthermore, the deflection at equivalent load levels was lower in the fiber-reinforced beams.

Table 10. Flexural behavior result

S.NO	% Replacement	Initial crack load (KN)	Ultimate load (KN)
1	SF0% + KF0%	17.03	27.63
2	SF10% + KF0.2%	20.55	31.95
3	SF10% + KF0.4%	22.81	34.93
4	SF10% + KF0.6%	21.33	33.54
5	SF10% + KF1%	21.95	33.82

Crack pattern of RC beam:

The crack pattern in the beam initially showed very fine hairline cracks at the onset of loading, which gradually propagated toward the mid-span under single-point loading. The cracks were primarily concentrated near the mid-span due to the application of load at a single point. Experimental results indicated that all beams were initially uncracked. As the load approached the rupture strength, cracks began to form, with the first crack observed in all specimens. The mode of failure in all specimens was identified as flexural shear failure. It was also observed that self-compacting concrete beams without Kevlar fibers exhibited more extensive cracking compared to beams reinforced with Kevlar fibers.

Fig.9. Cracks on the RC beam

4) Ultrasonic Pulse Velocity test:

The Ultrasonic Pulse Velocity (UPV) test was conducted on a 28-day cured cube specimen measuring 150 mm × 150 mm × 150 mm.

Table 11. UPV test results

S.NO	% Replacement	Compressive strength (N/mm^2)	Pulse velocity (km/s)
1	SF0% + KF0%	53.65	4.06
2	SF10% + KF0.2%	54.77	4.18
3	SF10% + KF0.4%	55.94	4.26
4	SF10% + KF0.6%	54.36	4.11
5	SF10% + KF1%	50.23	4.02

VI. CONCLUSION:

An experimental investigation was conducted on Self-Compacting Concrete (SCC) incorporating Kevlar fibers and 10% silica fume as a partial replacement for cement. Kevlar fibers were added in proportions of 0.2%, 0.4%, 0.6%, and 1.0% by weight of cement. Fresh concrete tests revealed that mixes containing 0.2% and 0.4% Kevlar fibers satisfied EFNARC guidelines, whereas higher fiber contents reduced workability.

The hardened concrete results demonstrated significant improvements in mechanical properties. The SF10% +KF0.4% mix exhibited the highest compressive strength of 57.02 MPa at 28 days, representing a 7.42% increase over the nominal SCC, and achieved a 6.84% improvement in split tensile strength. Flexural studies further confirmed enhanced structural performance, with Kevlar fiber-reinforced SCC beams showing superior load-carrying capacity and reduced deflection compared to conventional SCC beams. Ultrasonic Pulse Velocity (UPV) results indicated good quality and uniformity in all mixes. Overall, the SF10% + KF0.4% mix was identified as the optimum composition for achieving superior strength, durability, and performance in SCC applications.

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