Flexural Behaviour of Fibre Reinforced Self Compacting Concrete Incorporating Cement Kiln Dust

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Abstract— Self-Compacting Concrete (SCC) is a specialized concrete that compacts solely through its own weight, eliminating entrapped air during pouring. This unique property grants SCC exceptional flowability, enabling it to fill voids and gaps effortlessly, even in densely reinforced areas, and maintaining a nearly horizontal level for uniform distribution and optimal structural integrity. SCC is particularly beneficial for complex formworks where conventional concrete struggles. It also incorporates industrial wastes like fly ash (FA) and cement kiln dust (CKD) as partial cement replacements, promoting sustainability and resource efficiency. Enhancing SCC's performance involves adding micro steel fibres in various percentages (0%, 0.25%, 0.50%, 0.75%, and 1%). These fibres improve the concrete's effectiveness by preventing crack propagation. Tests show that SCC without fibres excels in fresh properties, while SCC with 1% steel fibre demonstrates superior mechanical properties despite slightly reduced workability. Steel fibres also significantly reduce SCC shrinkage, boosting long-term durability and structural integrity. Analytical examination of RCC beams with varying steel fibre amounts using ABAQUS software indicates that SCC with 0.75% steel fibre provides the best balance of enhanced mechanical properties and manageable workability. Integrating steel fibres and industrial waste in SCC not only improves mechanical properties and durability but also supports sustainable construction by reducing reliance on traditional cement and promoting the reuse of industrial by-products.

Index Terms- Self Compacting Fibre Reinforced Concrete, Cement Kiln Dust, Micro Steel Fibre, Finite Element Analysis, Abaqus and Flexural Behavior.

I. INTRODUCTION

Self-compacting concrete (SCC) is a significant innovation in construction materials, merging convenience, quality, and sustainability. Unlike traditional concrete, SCC flows and fills molds independently, eliminating the need for mechanical compaction and reducing human error. This is achieved through a mix of high-quality aggregates, fine powders, superplasticizers, and viscosity-modifying admixtures, ensuring a smooth, consistent finish and minimizing labor-intensive processes. SCC's ability to flow and self-level makes it ideal for intricate formworks and densely reinforced structures, maintaining uniform distribution and optimal structural integrity.

SCC also promotes sustainability by using industrial wastes like fly ash (FA) and cement kiln dust (CKD) as partial cement replacements, reducing environmental impact and carbon footprint. To enhance performance, varying percentages of micro steel fibres (0%, 0.25%, 0.50%, 0.75%, and 1%) are added. These fibres prevent crack initiation and propagation, enhancing mechanical properties. While SCC without fibres excels in workability, SCC with 1% steel fibre shows superior mechanical properties, despite slightly reduced workability. Steel fibres also significantly reduce shrinkage, improving long-term durability.

Analytical studies using software like ABAQUS on RCC beams with different fibre amounts reveal that SCC with 0.75% steel fibre offers the best balance of mechanical properties and workability. This highlights the importance of precise mix design for optimal SCC performance, making it a reliable and sustainable choice for various construction applications.

II. MATERIAL COMPONENTS

The self-compacting concrete (SCC) in this project is composed of meticulously chosen materials to ensure high performance and durability. Ordinary Portland Cement (OPC) 53 grade is used for its strength, while coarse aggregates up to 12.5 mm in size ensure optimal packing. Manufactured sands (M sand), with high fines content enriched with rock dust, enhance the mix, adhering to ASTM and Indian standards for fines content. Fly ash (class F), a byproduct of lignite or ground coal combustion, and cement kiln dust (CKD), collected from cement kiln exhaust gases, are used as eco-friendly partial replacements for cement, contributing to the concrete's properties and sustainability.

Master Glenium SKY 8233, a next-generation superplasticizer based on modified carboxylic ether, is incorporated to enhance the fluidity, workability, and durability of SCC without compromising strength. Micro steel fibres, with diameters ranging from 0.2 to 0.5 millimeters, are added to improve the mechanical properties of the concrete. These fibres increase tensile strength, ductility, and crack resistance, while mitigating shrinkage and temperature-induced strains, enhancing long-term durability.

Micro steel fibres are particularly useful in applications where traditional reinforcement methods like rebar or mesh are challenging to install. Their incorporation into SCC is beneficial for industrial flooring, shotcrete, and precast concrete components, ensuring the material can withstand significant stresses and strains over time.

The combination of these materials ensures that SCC meets the demands of high-performance construction, providing superior structural integrity and sustainability. By leveraging OPC 53 grade cement, M sand, fly ash, CKD, superplasticizers, and micro steel fibres, SCC emerges as a modern solution for the evolving construction industry, offering enhanced performance, durability, and environmental benefits.

Table I: Properties of cement

NAME OF THE TEST	Table Column Head		
	Cement	Fly ash	CKD
Specific Gravity	3.15	2.53	2.7
Fineness	7%	10%	4%
consistency	32%	31%	-
Initial setting time	32min	60min	-

Table II: Test Results for materials

NAME OF THE TEST	Fine	Coarse Aggregate
Specific Gravity	2.53	2.83
Water absorption	1.9%	0.25%
Fineness Modulus	2.66	6.55
Sieve analysis	Zone II	

III. MIX DESIGN

The process of mix design involves selecting appropriate concrete materials and determining their proportions to achieve desired strength and durability at the lowest cost. This critical aspect of concrete technology ensures the final product meets specific performance criteria while being economically viable. Among various methodologies, the Okamura method is widely used for its effectiveness in producing high-quality concrete mixes. This method emphasizes balancing different components, such as cement, aggregates, water, and admixtures, to ensure optimal performance. By focusing on overfilling the spaces between aggregate particles, the Okamura method ensures a dense, compact structure, minimizing voids and reducing the required cement paste. This approach improves workability and durability while being cost-effective. Detailed calculations and adjustments are made based on material characteristics, ensuring consistent quality and performance. Implementing the Okamura method results in a homogeneous mix with enhanced strength and durability, suitable for a range of construction applications, thus playing a vital role in achieving high-performance concrete that meets structural and economic requirements.

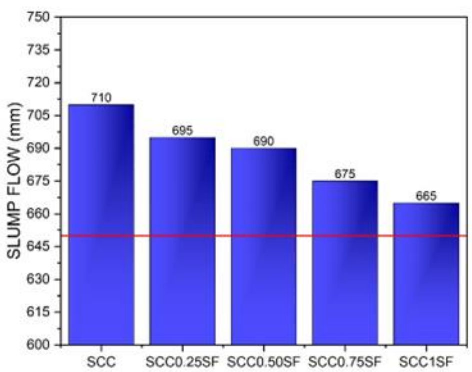
IV. EXPERIMENTAL INVESTIGATION

In this project, self-compacting concrete (SCC) was formulated using a blend of cement, fine aggregate, coarse aggregate, water, fly ash, and superplasticizer. Notably, cement kiln dust was incorporated as a 10% replacement for cement. Additionally, micro steel fibre was introduced into the mix at varying volumes, including 0.25%, 0.50%, 0.75%, and 1%. This meticulous combination of materials aimed to enhance the properties of the SCC, such as workability, durability, and resistance to cracking. By strategically adjusting the proportions of these components, the project sought to optimize the performance and suitability of the SCC for specific construction applications.

V. FRESH CONCRETE PROPERTIES

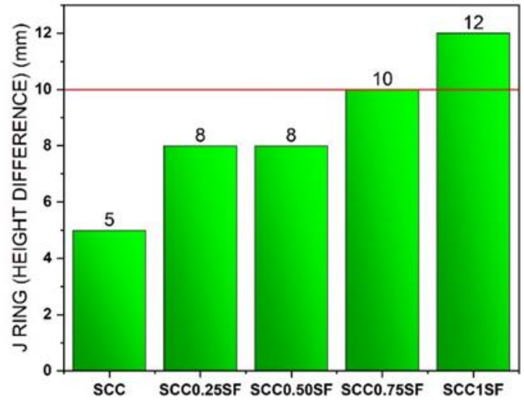
A comparison is made between the performance of self-compacting concrete (SCC) with added micro-steel fibre and the integration of cement kiln dust in its fresh state. The discussion focuses on key topics, including the variation in slump flow (as depicted in Figures 1.1) and the T50 cm slump flow value across different mixtures of fibre-reinforced SCC combined with cement kiln dust (illustrated in Figure 1.2). These figures provide visual representations of how the inclusion of micro-steel fibre and cement kiln dust influences the fresh properties of SCC, offering insights into their effects on workability and flow characteristics.

Figure I: Slump Flow for Varies MIX ID



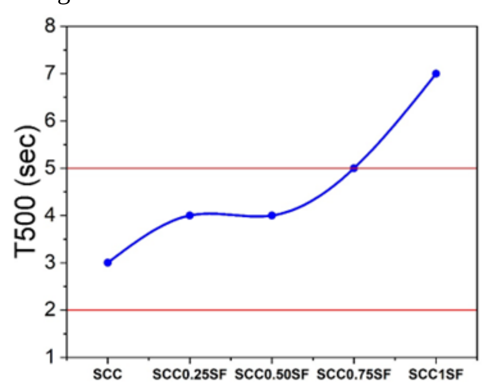
All mixtures demonstrated satisfactory workability, with flow values of at least 665 mm. Slump flow values ranging from 650 mm to 800 mm are typically considered suitable for self-compacting concrete (SCC), and all investigated mixtures fell within this range. However, higher fibre content led to a decrease in slump flow value, attributed to factors such as fibre interference, altered flow orientation, and clumping, resulting in increased viscosity

Figure II: J – Ring Height Difference for Varies Mix ID



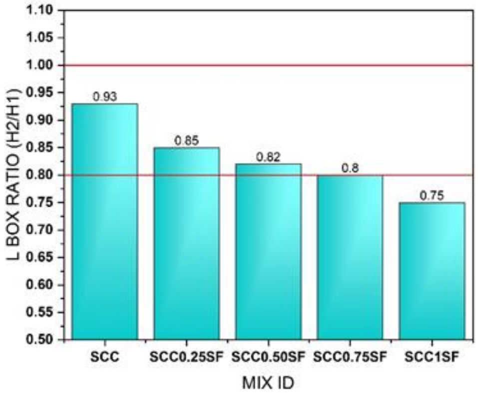
The results from the J-Ring Test depicted in Figure II reveal a notable trend: as the proportion of micro steel fibres increases, the passing ability of the concrete decreases. Consequently, this suggests that self-compacting concrete (SCC) exhibits greater workability compared to fibre-reinforced concrete. This observation underscores the influence of fibre content on the flow characteristics of concrete mixtures and highlights the trade-off between enhanced mechanical properties, attributed to fibre addition, and the workability of the SCC.

Figure III: T500 Time for Varies Mix ID



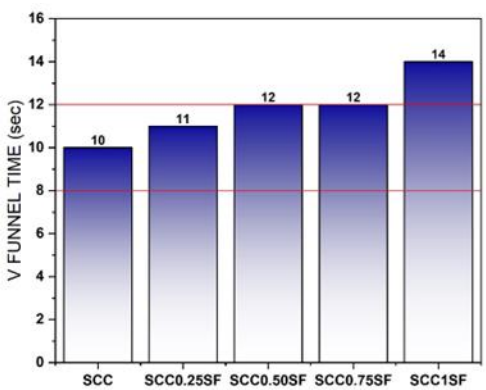
The data presented in Figure III, specifically the T500 mm test results, indicate that self-compacting concrete (SCC) requires less time to pass the 500mm distance compared to fibre-reinforced concrete. This finding suggests that SCC exhibits higher passing ability than other concrete mixes, highlighting its superior flow characteristics. The shorter time taken by SCC to traverse the specified distance underscores its enhanced workability and fluidity, which are crucial attributes in construction applications where ease of placement and uniform distribution are essential for achieving optimal performance and structural integrity.

Figure IV: L Box Ratio for Varies Mix ID



Based on the results of the L-Box test presented in Figure IV, it is observed that the disparity in height between the pouring point and the endpoint, where the concrete is expected to flow autonomously, is more pronounced for self-compacting concrete (SCC) compared to other concrete mixes. This indicates an enhancement in the self-leveling capabilities of SCC. The greater difference in level suggests that SCC exhibits superior flow and leveling properties, enabling it to fill molds and formwork more effectively without the need for excessive manipulation or intervention during placement.

Figure V: V-Funnel (5min) Time for Varies Mix ID

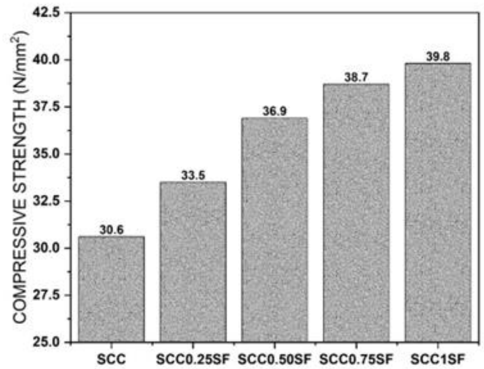


According to the findings from the V-Funnel test depicted in Figure V, it is evident that the viscosity of concrete, as indicated by the time taken to empty the funnel, is notably higher for SCC compared to other concrete mixes. This test is conducted five minutes after the concrete preparation.

VI. HARDENED PROPERTIES

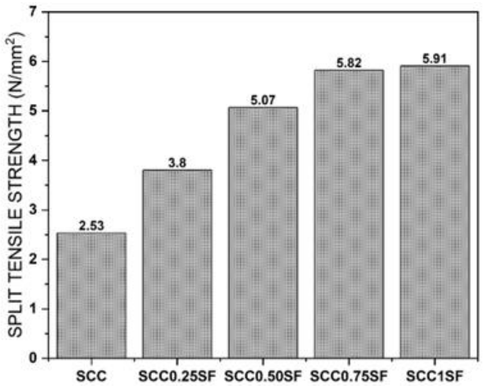
The comparison of self-compacting concrete (SCC) in its hardened state highlights several crucial aspects. Hardened properties of SCC mirror those of regular concrete, encompassing factors such as compressive strength, split tensile strength, flexural strength, and resistance to cyclic loading.

Figure VI: Compressive Strength for Varies Mix ID



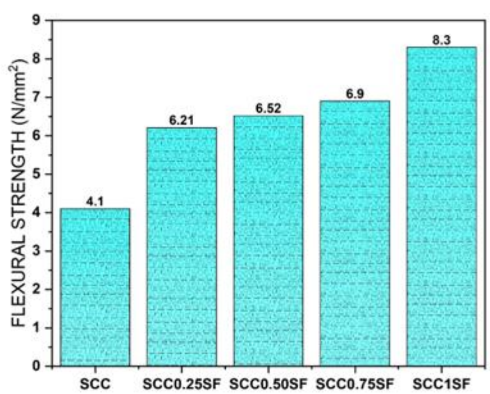
As depicted in Figure VI, there is a noticeable trend of increasing compressive strength in self-compacting concrete (SCC) with higher fibre percentages. Notably, SCC1SF, characterized by its elevated fibre content, exhibits significantly higher compressive strength compared to other mixtures. This observation underscores the positive influence of fibre reinforcement on the mechanical properties of SCC, highlighting its potential for enhancing structural performance and durability. The correlation between fibre content and compressive strength suggests the importance of optimizing fibre dosage to achieve desired concrete characteristics in various construction applications.

Figure VII Split Tensile Strength for Varies Mix ID



As depicted in Figure VII, there exists a direct correlation between the compressive strength and split tensile strength of concrete. The trend reveals that as the compressive strength of the concrete increases, so does its split tensile strength. This relationship underscores the importance of achieving high compressive strength in concrete, as it positively influences its tensile strength properties. Moreover, the incorporation of fibres further enhances the tensile strength of concrete compared to traditional non-fibre reinforced concrete. Notably, SCC1SF, characterized by its higher fibre content, exhibits superior tensile strength compared to other concrete blends, highlighting the efficacy of fibre reinforcement in improving mechanical properties.

Figure VIII: Flexural Strength for Varies Mix ID



As illustrated in Figure VIII, there is a clear trend indicating that the flexural strength of concrete increases with higher fibre content. The addition of fibres enhances the ability of the concrete to resist bending forces, thereby improving its flexural strength. Fibre-reinforced concrete compositions generally exhibit superior flexural strength compared to self-compacting concrete (SCC) without fibres. Consequently, SCC1SF, characterized by its higher fibre content, demonstrates robust flexural performance compared to other mixtures. This underscores the significance of fibre reinforcement in enhancing the flexural properties of concrete, particularly in applications requiring high resistance to bending stresses.

VII. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) conducted in software like Abaqus is a powerful computational tool used in engineering and scientific disciplines to simulate and analyze complex structural and mechanical systems. In FEA, the object under study is divided into small, geometrically simple elements interconnected at discrete points called nodes. Through this discretization process, the governing equations of physics are numerically solved for each element, considering factors such as material properties, boundary conditions, and applied loads.

Abaqus, renowned for its robustness and versatility, offers a comprehensive platform for conducting FEA across various engineering domains. Its user-friendly interface allows engineers to create intricate models, define material properties, and specify loading and boundary conditions with precision. Abaqus utilizes advanced algorithms to solve the resulting system of equations iteratively, accurately predicting the behavior of structures under static, dynamic, thermal, and Multiphysics conditions.

VIII. FLEXURAL TEST ON RCC BEAM

Figure IX: Flexural Damage Pattern for SCC

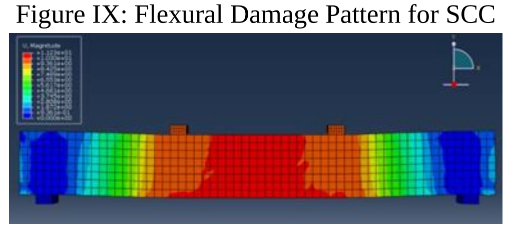


Figure X: Flexural Damage Pattern for SCC0.25SF

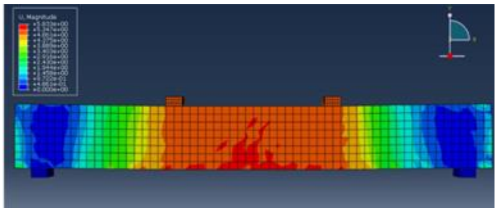


Figure XI: Flexural Damage Pattern for SCC0.50SF

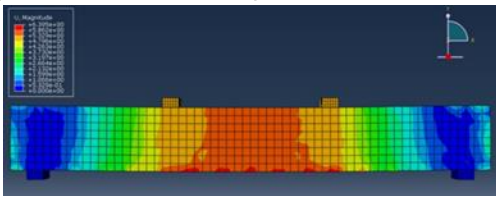


Figure XII: Flexural Damage Pattern for SCC0.75SF

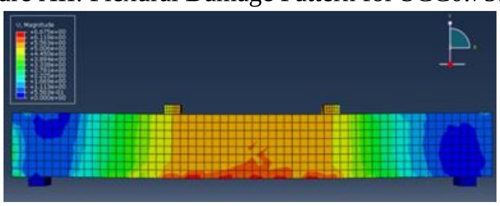
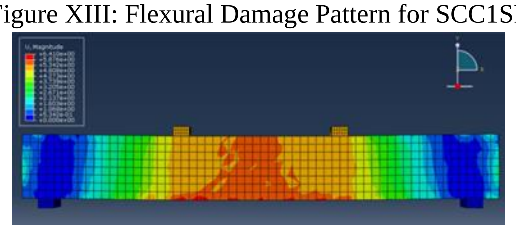


Figure XIII: Flexural Damage Pattern for SCC1SF



When a fibre-reinforced beam undergoes a two-point load test, also known as a four-point bending test, the inclusion of fibres significantly alters the beam's behavior and performance. In this test, bending and shear forces are applied at two specific points along the length of the beam.

Enhanced Flexural Strength: Incorporating fibres into the concrete matrix offers a primary advantage of increasing flexural strength. These fibres act as reinforcement, providing resistance against tensile stresses that often lead to beam failure. Compared to non-fibre-reinforced concrete, this reinforcement helps prevent and mitigate fractures, resulting in a substantial enhancement of flexural strength.

Reduced Crack Width: The presence of fibres contributes to a reduction in crack widths compared to non-fibre-reinforced concrete. This decrease in crack width is advantageous for improving durability by minimizing the ingress of detrimental elements such as water and chloride ions. By reducing crack propagation, the integrity of the concrete's structure is better preserved, leading to enhanced long-term performance and sustainability.

Figure XIV: Failure Load for All 5 Beam Models

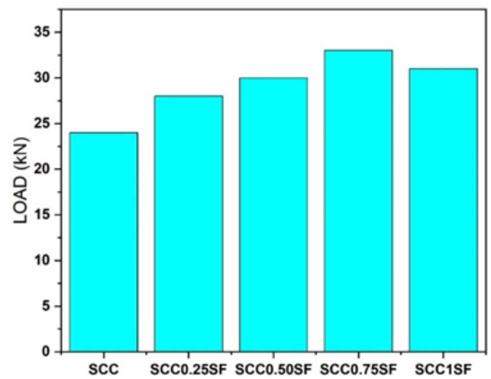
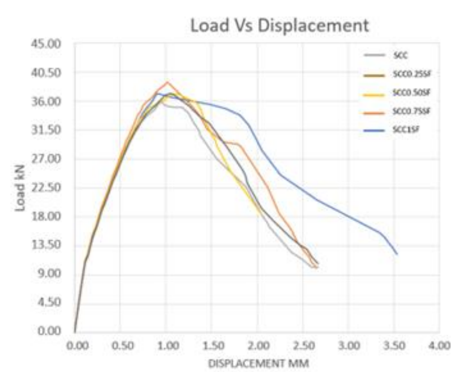


Table III Max Load& Displacement

MIX ID	MAX LOAD (kN)	DISPLACEMENT
SCC	34	0.51892
SCC0.25SF	36	0.77237
SCC0.50SF	37	1.23854
SCC0.75SF	39	1.24569
SCC1SF	38	1.24527

Figure XV: Load vs Displacement for Varies Mix ID



The preceding figures reveal a discrepancy between the ultimate failure load obtained from FEA software and the experimental data. As the fibre content increases, the ductility of the beam also rises. However, beyond a fibre content of 0.75% of the total concrete volume, the ultimate load starts to decrease. Consequently, SCC0.75SF exhibits the ability to withstand substantial loads while maintaining ductility.

CONCLUSION

- After examining fresh characteristics on concrete results, it is clear that SCCs with up to 35% fly ash and 10% cement kiln dust have greater workability than the other SCCs.
- The flow ability of self-compacting concrete keeps decreasing with the addition of micro steel fibre.
- Passing ability and other fresh properties are good for addition of 0.75% of micro steel fibre and they are within the limits of EFNARC guidelines.
- Micro steel fibre is added by 0.25%,0.50%,0.75%and 1% the specimen strength is increasing significantly for 0.75% and 1% compare to 0.50%,0.25% of micro steel fibre addition.
- When the flexural strength of RCC beams is examined using FEM, it is clear that after 28 days, the SCC0.75SF, which contains up to 35% fly ash, 10% cement kiln dust, and 0.75% micro steel fibre, outperforms the regular SCC.
- This demonstrates that the use of SCC0.75SF, which replaces up to 35% fly ash, 10% cement kiln dust, and 0.75% micro steel fibre in concrete beams, enhances load bearing ability.

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