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Utilisation of Bagasse Ash and Slag Sand as Cement and Fine Aggregate Replacements in Self-Compacting Concrete

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Abstract: This experimental study focuses on the performance of M50 grade Self-Compacting Concrete (SCC) incorporating Sugarcane Bagasse Ash (SCBA) as a supplementary cementitious material and slag sand as a substitute for natural fine aggregate. SCC mixes were first developed with 5%, 10%, and 15% replacement of cement by SCBA to determine the optimum percentage. Based on fresh and strength performance, 10% SCBA was identified as the optimum replacement level. Keeping SCBA constant at 10%, slag sand was then introduced at 10%, 20%, 30%, and 40% as a replacement for fine aggregate. The fresh characteristics were evaluated using slump flow, V-funnel, and L-box tests, while mechanical properties were studied through compressive, split tensile, and flexural strength tests. The results revealed that slag sand replacement up to 20% improved both workability and strength of SCC. Higher replacement levels showed a marginal decrease in performance. The optimum combination was obtained at 10% SCBA and 20% slag sand. The study demonstrates that agricultural and industrial by-products can be effectively utilized to produce sustainable high-strength SCC.
Keywords: Self-Compacting Concrete (SCC), Sugarcane Baggase Ash(SCBA), Slag Sand(SS), GGBS, M50 Grade Concrete, Sustainable Concrete.

I. INTRODUCTION

The increasing demand for concrete in modern infrastructure has led to extensive use of Ordinary Portland Cement (OPC), whose production is associated with high energy consumption and significant carbon dioxide emissions. To reduce the environmental impact of construction activities, researchers have focused on integrating sustainable supplementary cementitious materials and alternative aggregates into concrete. The use of agricultural and industrial by-products not only minimizes environmental pollution but also supports the conservation of natural resources.

Sugarcane Bagasse Ash (SCBA), a waste generated from sugar industries, has gained importance as a potential partial replacement for cement due to its high silica content and pozzolanic activity. When adequately processed through controlled burning and fine grinding, SCBA reacts with calcium hydroxide released during cement hydration, forming additional cementitious compounds that improve strength and durability. In parallel, slag sand, a by-product of the steel industry, has emerged as an effective substitute for natural river sand. Its favorable physical and chemical properties contribute to improved particle packing, reduced permeability, and enhanced long-term performance of concrete. Self-Compacting Concrete (SCC) is a high-performance concrete that flows under its own weight without the need for vibration, making it highly suitable for congested and complex structural elements. The use of SCBA and slag sand in SCC not only enhances fresh and mechanical properties but also significantly improves sustainability by reducing dependence on cement and natural sand. Therefore, the present study investigates the performance of M50 grade SCC incorporating SCBA as a partial cement replacement and slag sand as a fine aggregate replacement to achieve an eco-friendly and high-strength concrete suitable for sustainable construction practices.

II. REVIEW OF LITERATURE

Le et al. [1]demonstrate that blending burnt sugarcane bagasse ash into self-compacting concrete up to 15% stabilizes flow properties and elevates compressive and flexural strength over 28 and 56 days. It refines pore structure for better sulfate resistance and denser composition. The research highlights its value as a cost-effective, eco-conscious supplement for advanced concrete production.

Memon et al. [2]show that processed sugarcane bagasse ash as a cement substitute improves concrete's mechanical strength and durability via high silica content and amorphous structure. Mixes with 10-20% ash exhibit superior late-age compression, reduced water uptake, and enhanced resistance to acids, chlorides, and sulfates. This promotes sustainable practices by recycling waste and lowering carbon footprint in construction.

Prabhath et al.[3]conclude that sugarcane bagasse ash, when analyzed with XRD, FTIR, and SEM, boosts pozzolanic reactions in cement replacements, forming extra C-S-H gel. It reduces porosity and increases chemical attack resistance in aged concrete. The findings endorse fine SCBA as an efficient modifier for robust, eco-friendly structural mixes.

Abdalla et al.[4] synthesize 15 years of data showing sugarcane bagasse ash as a versatile pozzolanic enhancer for concrete's strength, durability, and microstructure. It forms dense C-S-H gel, improving ITZ quality and resistance to chlorides and sulfates, while cutting permeability. Despite ash variability challenges, standardized protocols enable its integration into high-performance self-compacting systems.

Ainomugisha et al.[5] ascertain that sugarcane bagasse ash in tropical eco-cements bolsters long-term strength through added C-S-H gel from pozzolanic activity. It curbs sulfate attacks and water absorption, refining microstructures as seen in SEM. Finer ash proves ideal for humid, hot climates, advancing sustainable infrastructure with waste recycling.

Elawady and Sanadet al.[6] establish that moderate sugarcane bagasse ash levels enhance concrete's compressive, splitting, and flexural strengths, alongside better workability with superplasticizers. It fosters denser microstructures via hydration products, reducing aggressive environment impacts. This supports dual goals of performance improvement and industrial waste repurposing.

Amjad et al. [7]verify that sugarcane bagasse ash as a viscosity modifier stabilizes fresh self-compacting concrete, improving mechanical and microstructural traits. Tests like slump-flow and durability show reduced risks and refined hydration at 28-56 days. SCBA acts as a dual rheology and strength booster, suitable for green construction synergies.

Wagh et al.[8]find that combining sugarcane bagasse ash with metakaolin and glass fibers in self-compacting concrete elevates compressive and flexural strengths while cutting permeability and chemical vulnerability. It promotes sustainable mixes by balancing early and late properties. The blend meets EFNARC standards, confirming its viability for durable structures.

Kalasur and Dwivedi et al.[9] affirm that sugarcane bagasse ash partially replacing cement maintains fresh concrete flow and boosts late-age compressive and flexural performance. Durability metrics like sorption and acid resistance improve due to refined pores. It advocates for SCBA in eco-efficient modern concrete for reduced resource consumption.

Daniel et al.[10] illustrate that sugarcane bagasse ash paired with recycled PET fibers significantly uplifts concrete's mechanical strength, durability, and crack resistance in later stages. Reduced water absorption and slower ion ingress stem from dense structures. This combination tackles environmental pollution from plastics and cement, balancing toughness and ductility.

Ullah et al.[11] confirm alkali-activated sugarcane bagasse ash binders yield early strength gains and low permeability under alkaline conditions. They resist sulfates effectively with compact matrices and minimal CO2 emissions. The approach offers sustainable alternatives to OPC systems, especially in sugar-rich areas.

Iro et al.[12] deduce that optimal sugarcane bagasse ash ratios in response surface methodology enhance compressive, tensile, and flexural strengths under varied curing. It improves durability via refined pores and C-S-H formation. SCBA proves cost-effective and green for high-performance concrete.

Ansari et al.[13] optimize sugarcane bagasse ash with recycled aggregates, boosting compressive strength and reducing permeability through statistical and experimental methods. It enhances sulfate and chloride resistance in denser matrices. The study supports eco-friendly concrete minimizing waste and environmental costs.

Girish et al.[14] validate processed slag sand as a fine aggregate in geopolymer concrete, improving mechanical, thermal, and durability properties. It reduces water absorption and boosts acid resistance with dense gels. Processed slag sand emerges as a sustainable, high-performance option for infrastructure.

Praveen Kumar et al.[15] prove that replacing natural sand with processed slag sand in self-compacting concrete elevates compressive, flexural, and split-tensile strengths. Durability against water, sorptivity, and chlorides improves due to angular particles. It promotes waste recycling for economical, green building materials.

Salihi et al.[16] exhibit that granulated blast furnace slag enhances concrete's compressive and tensile strengths with fine textures. It improves workability, acid resistance, and sustainability by replacing natural sand. GBFS supports eco-viable structural concrete through industrial byproduct use.

Zhang et al.[17] show that slag sand and particles improve concrete sustainability, durability, and bond strength in cement matrices. Mechanical gains include better compression and flexure, with acid resistance. It counters recycled aggregate weaknesses for structural reliability.

Wang et al.[18] reveal blast furnace slag's role in boosting self-compacting mortar's flow, viscosity, and passing ability. It enhances cohesion without flowability loss, via mineralogical bonds. Slag aggregate cuts material costs while maintaining performance.
Guendouz et al.[19] find that industrial blast furnace slag waste improves self-compacting sand concrete's density, strength, and durability. Tests show better compression, tension, and resistance to acids and frost. It minimizes pollution and encourages circular economy in construction.

III. MATERIALS AND ITS PROPERTIES

A. Materials

1) Cement

JSW Ordinary Portland Cement of 53 grade was used as the main binding material in the present investigation. OPC is manufactured by finely grinding clinker obtained through the calcination of limestone, clay, and corrective materials, followed by the addition of gypsum to control the setting process. The clinker mainly consists of tricalcium silicate (C_3S) and dicalcium silicate (C_2S), which are responsible for early and later-age strength development. The cement was procured from JSW Cement, Andhra Pradesh. The specific gravity of OPC 53 grade was found to be 3.15, indicating its suitability for producing high-strength self-compacting concrete.

2) Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag is a by-product derived from the iron and steel manufacturing process carried out in blast furnaces operating at temperatures of about 1500°C. During iron production, the non-metallic impurities separate as molten slag and float over the molten iron. This molten slag is rapidly quenched using water to form glassy granules with sand-sized particles. After drying, the granulated slag is finely ground to obtain GGBS, which possesses good cementitious and pozzolanic properties. The specific gravity of the GGBS used in this study was 2.8.

Table I Physical properties of GGBS

Property	Results
Fineness	3%
Specific gravity	2.85

3) Fine Aggregate and Coarse Aggregate

Natural river sand conforming to IS: 383–2016 specifications was used as fine aggregate. The sand was clean and free from clay, organic matter, and other harmful impurities. The grading satisfied Zone II requirements, ensuring adequate flowability, cohesiveness, and filling ability required for self-compacting concrete. Fine aggregate plays a vital role in achieving uniform flow and preventing segregation in SCC. Crushed angular coarse aggregates of 10 mm nominal size, conforming to IS: 383–2016, were used in this work. The aggregates were hard, clean, and free from flaky or elongated particles. Their angular nature provides better interlocking, improves mechanical strength, and reduces void content in the concrete matrix. The specific gravity of the coarse aggregate generally lies between 2.6 and 2.7.

4) Sugarcane Bagasse Ash (SCBA)

Sugarcane Bagasse Ash is an agricultural waste obtained from the combustion of sugarcane bagasse in sugar mills for power generation. When processed through controlled burning and fine grinding, SCBA becomes rich in reactive amorphous silica and exhibits strong pozzolanic activity. When used as a partial replacement of cement, SCBA reacts with calcium hydroxide to form additional C–S–H gel, resulting in improved later-age strength, enhanced durability, and reduced permeability. The utilization of SCBA also promotes sustainable construction by lowering cement consumption and effectively managing agricultural waste.

5) Slag Sand

Slag sand is a processed fine aggregate produced from granulated slag generated during steel manufacturing. The slag is crushed, screened, and graded to match the requirements of fine aggregates used in concrete. Compared to natural sand, slag sand possesses angular particles with a rough surface texture, which enhances the bond between the aggregate and cement paste, thereby improving strength. It also contributes to reduced permeability due to improved particle packing. The use of slag sand supports sustainable construction by conserving natural sand resources and utilizing industrial waste materials.

Table II Physical Properties of Slag sand

Property	Results
Fineness modulus	2.73
Zone	II
Bulk density (Loose)	1300 KN/m^3
Specific Gravity	2.7
Bulk density (Compacted)	1510 m^3

6) Superplasticizer

CERA Hyper Plast XRW-40 is a high-range water-reducing admixture based on advanced polycarboxylate ether (PCE) technology. It provides excellent dispersion of cement particles, leading to improved flowability and workability, which are essential properties of self-compacting concrete. The admixture reduces water requirement, enhances cohesiveness, and maintains stability of the mix without segregation. CERA XRW-40 conforms to IS 9103 and is suitable for producing high-strength, dense, and durable SCC mixtures.

IV. MIX PROPORTIONS

The mix design for the reference Self-Compacting Concrete (M0) of M50 grade was carried out in accordance with EFNARC recommendations and IS:10262 provisions. The control mix incorporated a binder composition of 70% cement and 30% GGBS along with fine aggregate, coarse aggregate, water, and superplasticizer. Sugarcane Bagasse Ash (SCBA) was introduced as a partial cement replacement at proportions of 5%, 10%, and 15% to determine the optimum content. Based on the optimum SCBA percentage, fine aggregate was subsequently substituted with slag sand at replacement levels of 10%, 20%, 30%, and 40%. A constant superplasticizer dosage of 1.2% CERA Hyper Plast XRW-40 was maintained for all concrete mixtures. The details of all mix combinations adopted in the study are presented in Table 6

Table III Mix Proportions Of Scc

Mixes Designation	Cement kg/m^3	GGBS kg/m^3	CTWP kg/m^3	Fine Aggregate kg/m^3	Slag sand kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	SP in %
M0(Referencemix)	370	159	-	875	-	873	180	1.2%
M1(5% ofSCBA)	351.5	159	18.5	875	-	873	180	1.2%
M2(10% of SCBA)	333	159	37.5	875	-	873	180	1.2%
M3(15% of SCBA)	314.5	159	55.5	875	-	873	180	1.2%
M4(10%of SCBA+ 10% of Slag sand)	333	159	37	787.5	87.5	873	180	1.2%
M5(10%of SCBA+ 20% of Slag sand)	333	159	37	700	175	873	180	1.2%
M6(10%of SCBA+ 30% of Slag sand)	333	159	37	612.5	262.5	873	180	1.2%
M7(10%of SCBA+ 40%of Slag sand)	333	159	37	525	350	873	180	1.2%

V. FRESH AND HARDENED PROPERTIES

The fresh properties of Self-Compacting Concrete (SCC) were evaluated to ensure compliance with EFNARC guidelines for flowability, passing ability, and segregation resistance. Slump flow test was conducted to assess the filling ability of the mixes, while the T time indicated the viscosity and rate of flow. The passing ability of SCC through congested reinforcement was determined using the L-box test, and the V-funnel test was used to evaluate flow time and viscosity. The results confirmed that all SCC mixes exhibited adequate self-compacting characteristics within the specified standard limits. The incorporation of mineral admixtures and superplasticizer significantly improved workability and stability, ensuring uniform flow without segregation or bleeding.

Table IV Fresh Properties

Mixes	Slump Flow in mm	L-Box ratio	Time in seconds
M0(Reference mix)	715	0.97	7.5
M1(5% SCBA)	700	0.95	8.2
M2(10% SCBA)	690	0.90	8.9
M3(15% SCBA)	680	0.88	9.7
M4(10%SCBA+10% slag sand)	695	0.92	9.2
M5(10%SCBA+20% slag sand)	680	0.89	9.8
M6(10%SCBA+30% slag sand)	670	0.85	10.6
M7(10%SCBA+40% slag sand)	655	0.82	11.4

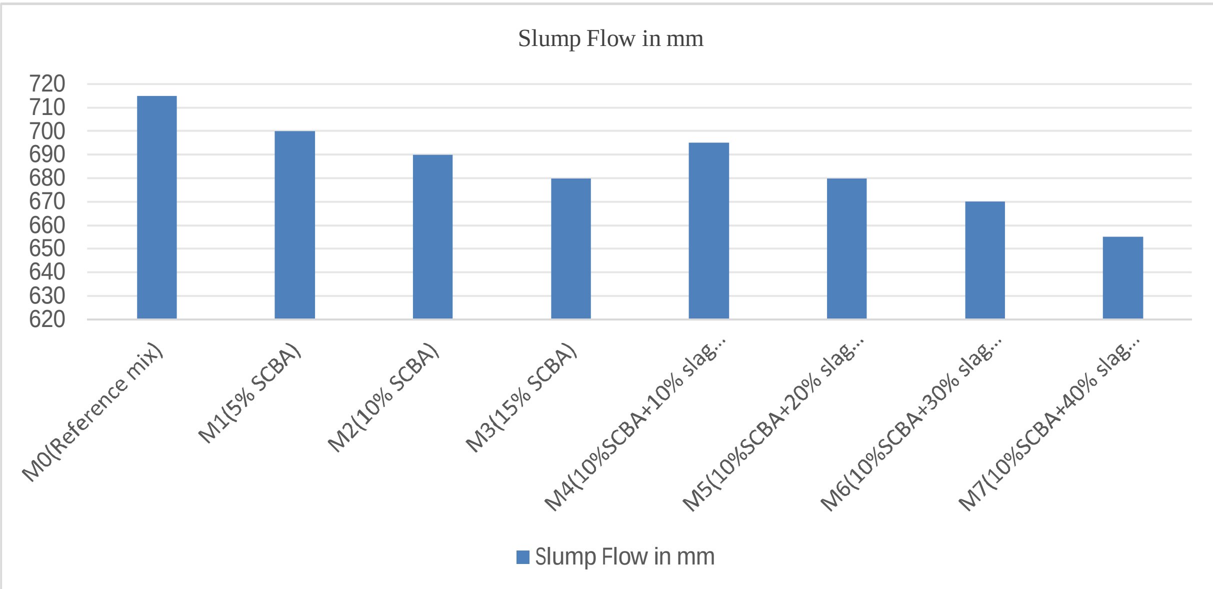

Fig I Slump flow

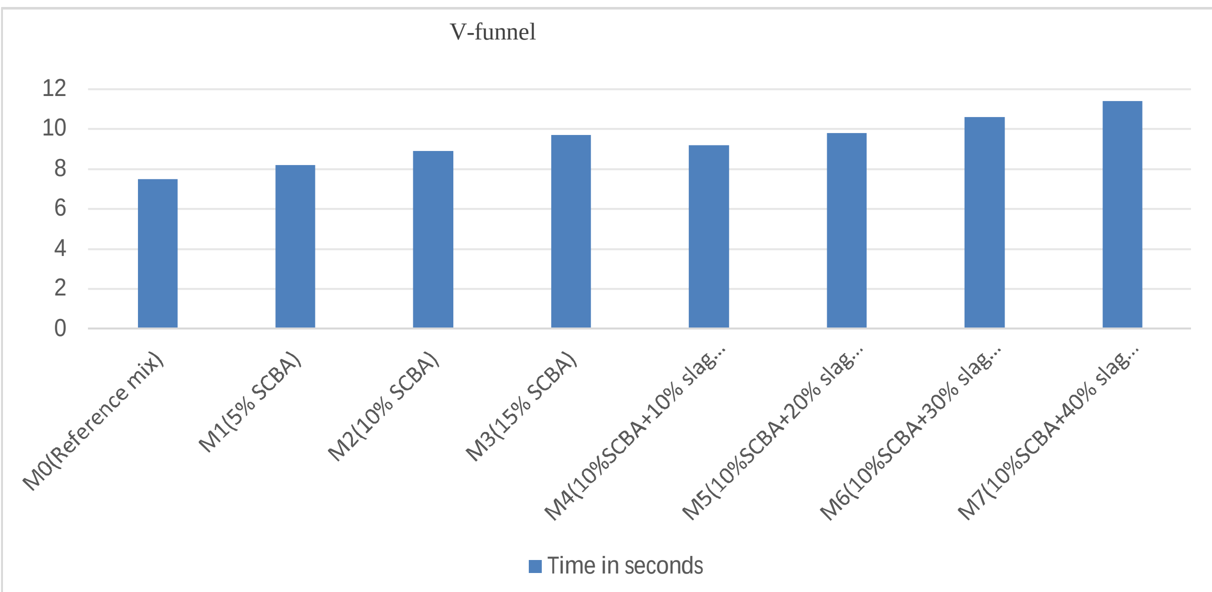

Fig II V-funnel

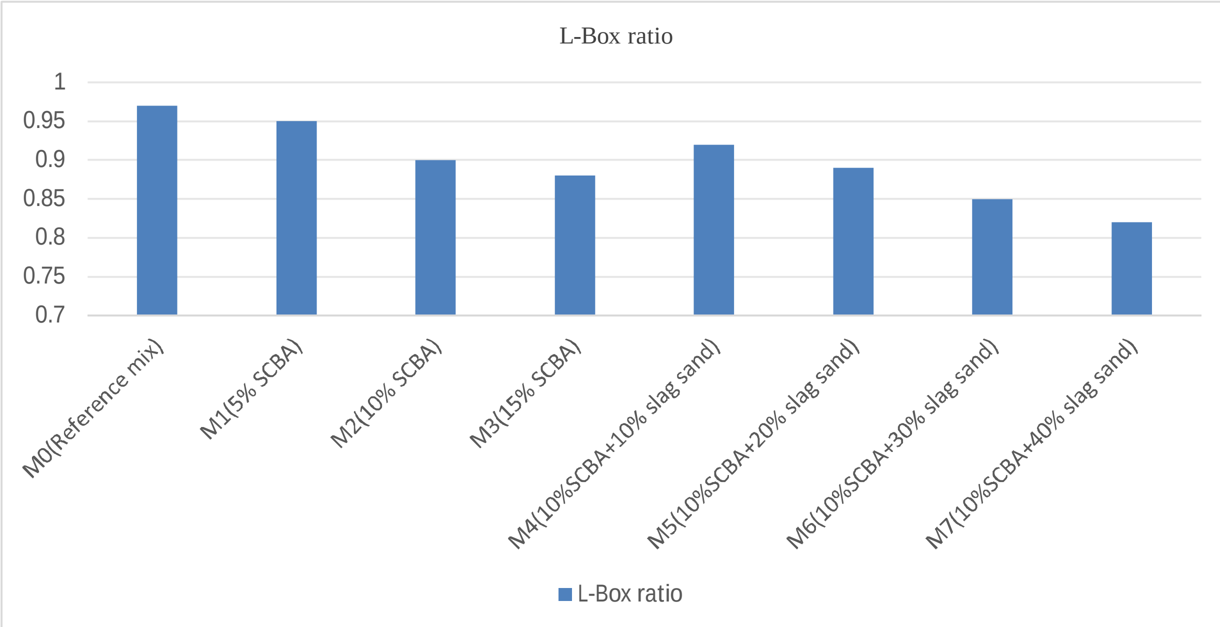

Fig III L-Box

Concrete specimens were fabricated to assess the mechanical performance of all SCC mixes. Standard cube specimens of 100 × 100 × 100 mm were used for compressive strength testing, while cylindrical specimens measuring 100 × 200 mm were prepared for split tensile strength evaluation. Flexural strength was determined using beam specimens of size 100 × 100 × 500 mm. All specimens were subjected to water curing for a period of 28 days prior to testing. The compressive, split tensile, and flexural strength results corresponding to each mix are reported in TableV**.**

Table V Compressive Strength

Mixes Designation	Compressive strength in N/mm^2 (7 Days)	Compressive strength in N/mm^2 (28 Days)
M0(Reference mix)	40.1	59.4
M1(5% SCBA)	42.9	60.2
M2(10% SCBA)	45.5	62.8
M3(15% SCBA)	38.4	57.4
M4(10%SCBA+10% slag sand)	46.5	63.1
M4(10%SCBA+20% slag sand)	47.2	64.5
M6(10%SCBA+30% slag sand)	42.6	61.8
M7(10%SCBA+40% slag sand)	38.5	56.2

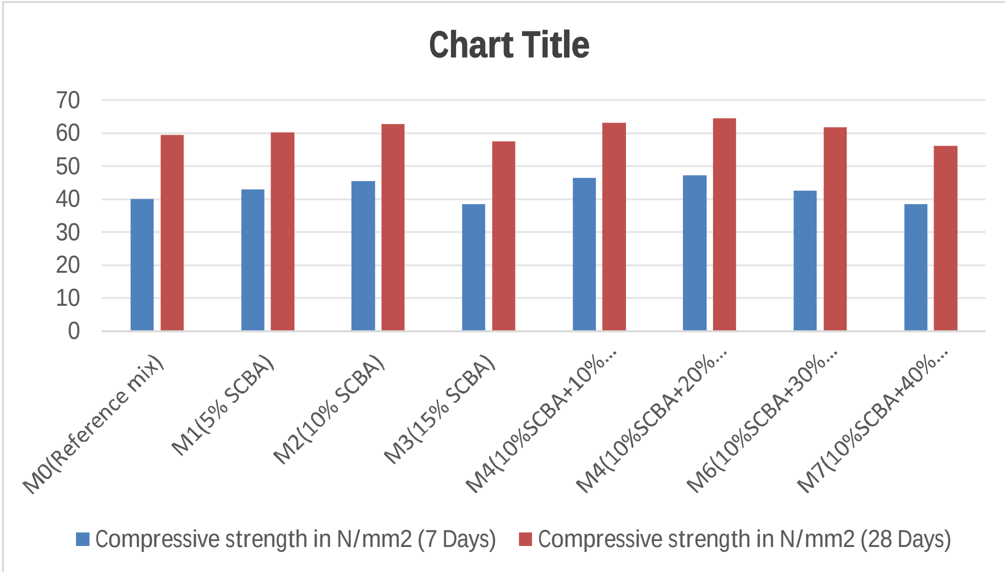

Fig IV Compressive strength of SCC

Table VI Split Tensile

Mixes	Split Tensile strength in N/mm^2 (28 Days)
M0(Reference mix)	4.39
M1(5% SCBA)	4.45
M2(10% SCBA)	4.47
M3(15% SCBA)	4.34
M4(10%SCBA+10% slag sand)	4.48
M5(10%SCBA+20% slag sand)	4.54
M6(10%SCBA+30% slag sand)	4.48
M7(10%SCBA+40% slag sand)	4.31

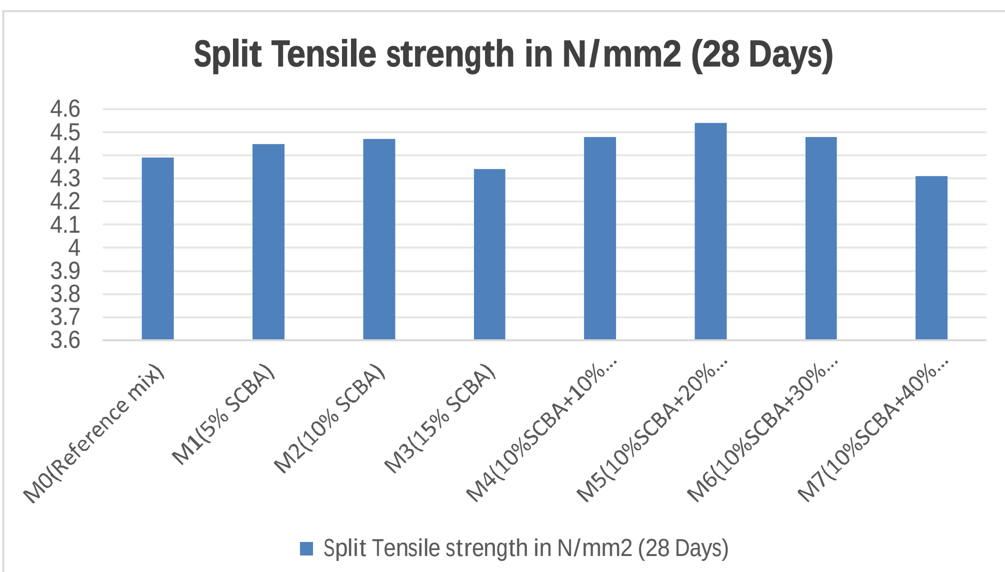

Fig V Split tensile strength of SCC

Table VII Flexural Strength

Mixes	Flexural strength test in N/mm^2 (28 Days)
M0(Reference mix)	5.38
M1(5% SCBA)	5.43
M2(10% SCBA)	5.56
M3(15% SCBA)	5.32
M4(10%SCBA+10% slag sand)	5.59
M5(10%SCBA+20% slag sand)	5.66
M6(10%SCBA+30% slag sand)	5.44
M7(10%SCBA+40% slag sand)	5.28

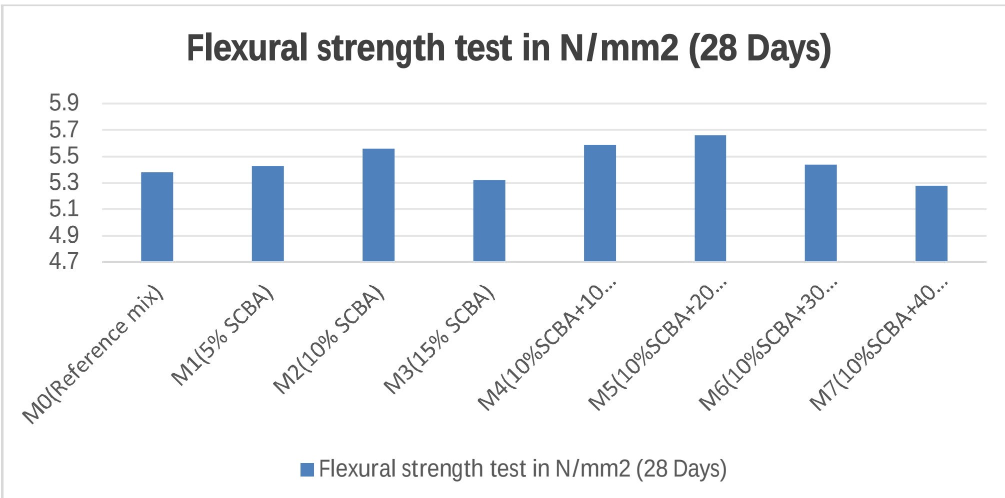

Fig VI Flexural strength of SCC

VI. CONCLUSIONS

1) All mixtures met the fresh property requirements specified by EFNARC guidelines. Although higher replacement levels slightly reduced flowability (slump flow decreased from 715 mm to 655 mm) and passing ability (L-box ratio from 0.97 to 0.82) while increasing viscosity (V-funnel time from 7.5 s to 11.4 s), the mixes retained satisfactory self-compacting behavior throughout the replacement range studied.
2) Replacing cement with SCBA alone showed beneficial effects up to 10%. The mixture containing 10% SCBA (M2) recorded the highest strength among SCBA-only mixes, with 28-day compressive strength reaching 62.8 MPa (5.72% higher than the control), along with noticeable improvements in split tensile and flexural strengths.
3) SCBA replacement beyond 10% proved detrimental. At 15% SCBA (M3), compressive strength fell to 57.4 MPa, confirming 10% as the upper safe limit for SCBA when used as the sole cement replacement.
4) Combining 10% SCBA with copper slag sand produced a clear synergistic improvement. The optimum performance was achieved with 10% SCBA + 20% copper slag sand (M5), which exhibited the highest values across all mechanical properties: 64.5 MPa compressive strength (+8.59%), 4.54 MPa split tensile strength (+3.42%), and 5.66 MPa flexural strength (+5.20%) at 28 days.
5) Increasing slag sand content beyond 20% (while keeping SCBA at 10%) led to a gradual strength reduction. At 40% slag sand (M7), compressive and split tensile strengths dropped below the control values, primarily due to the higher angularity and water demand of the slag particles at elevated dosages.
6) The results demonstrate that controlled incorporation of SCBA and copper slag sand not only maintains the self-compacting characteristics but also enhances the mechanical performance of SCC, simultaneously promoting the valorization of agro-industrial and metallurgical by-products.

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