

Experimental Analysis of Self Compacting Concrete using Bagasse Ash, Metakaolin and Glass Fiber

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Abstract. Self-compacting concrete (SCC) is a concrete that has the capacity to flow under its own weight without segregation. SCC has the ability to pass through the closed reinforcement, fill all the spaces of the formwork without segregation. In India, industrial and agricultural waste are produced in large quantities. Use of these wastes as a replacement for cement or sand gives a solution to the problem of disposal of these wastes. It decreases the cost of the structure as well as CO₂ emissions. This project is aimed at identifying the optimum amount of agricultural waste bagasse ash and metakaolin as replacements for cement with and without 0.1% GF and compared the fresh and strength properties of self-compacting concrete with the control mix. The result shows that the SCCB10M5 mix has better flowability as compared to others, and the strength properties were highest for the SCC1B10M5 mix.

Keywords: Self-compacting concrete, fresh properties, hardened properties

1. Introduction

Self-compacting concrete (SCC) is characterized by its exceptional deformability, strong resistance to segregation, and ability to be filled without vibration in severely reinforced or limited areas. Since its creation in Japan in the late 1980s, SCC has found widespread use across several countries for a range of objectives and structural configurations [1]. Recent developments in SCC research have concentrated on adding additional cementitious substances with the goal of reducing solid waste disposal issues. Utilizing these waste materials in the production of concrete has the potential to conserve a substantial amount of energy and financial resources [2], [3] [4]. The requirement for Portland cement has increased in recent years as a result of the rising desire to develop the urban built environment [5]. Reduced the impact on the environment by conserving natural resources [6]. Carbon emissions were reduced when cementitious qualities were substituted for cement [7].

India is the world's second-largest sugarcane grower after Brazil, which releases 44,000 tonnes of bagasse ash daily. This waste is utilized in cogeneration facilities, to make paper and pulp because of its fibrous character, and to produce power [8]. A byproduct of sugar production is bagasse ash (SBA). Bagasse is the fibrous waste material that remains after sugarcane is harvested. The ash obtained by burning fibrous bagasse at a temperature of around 6000–8000C is rich in amorphous silica and has good pozzolanic qualities [9]. According to ASTM C618, SBA is categorized as a Class F type of material [10]. Over 300 million tonnes of SBA are manufactured annually in India [11]. SBA may be utilized as an additional cementitious material since it is high in silica [12]. Comparing cement to SBA ratios of 30%, the compressive strength indicated a higher value than those of 10 and 20% [13]. By substituting 10% of BA for cement in SCC, the flexural strength elevated by 10.46% [14].

Metakaolin (MK), a relatively new mineral additive, is employed as a supplementary cementing substance in SCC. High-purity kaolin clay is converted into metakaolin by calcining it at temperatures between 6500 and 8000 C [15]. When MK is utilized as a partial substituted for cement, the compressive, flexural, and splitting tensile strengths as well as the ultrasonic pulse velocity of SCC are enhanced [16]. The durability of concrete is improved by adding 5% MK [17][18]. MK substantially improves the pore structure of concrete, improving its resistance to permeability and chloride ion transport, which deteriorates the matrix [19]. The fresh properties of SCC are enhanced when the percentage of SBA and MK is up to 15% as a result of partial cement replacement [20]. When 10% MK is substituted for cement, the strength grows by 26.80% at 56 days[21].

For SCC, an optimal proportion of glass fibre (GF) inclusion is 0.8 % [22]. As glass fibre concentration rises, the slump flow diameter decreases [23]. The addition of GF resulted in a large increase in the tensile and flexural strengths as well as a slight improvement in the compressive strength [24]. Addition of 0.5 to 1.5% of GF by weight of cement results in an increase in flexural strength of 3.1% to 11.9% [25]. The inclusion of 0.6 % of GF resulted in an 8% improvement in compressive strength [26].

The goal of this study is to construct SCC with a satisfying resolution to environmental problems by employing both SBA and MK as cement-replacing materials with 0.1 percent glass fibre. Through an experimental programme, the fresh

and hardened characteristics of the suggested SCC are comprehensively investigated. This research would add knowledge about the use of industrial and agricultural wastes to create environmentally friendly concrete. Figure 1 reveals the Network visualization of a cluster diagram.

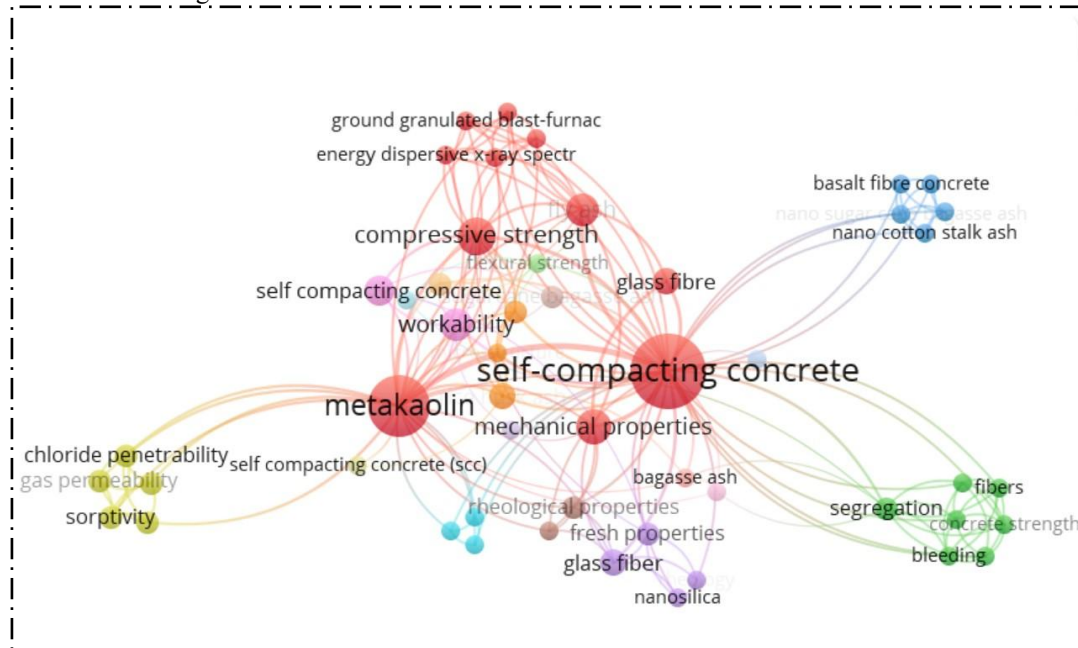


Figure 1: Network visualization of a cluster created by using the keywords of research papers

2. Material used

OPC43 grade, complying with IS 8112 (IS8112) was used in all compositions. A sugar mill at Devhala, India, produced SBA. The ash that had been dumped was gathered, allowed to dry, and then sieved. The source of MK was Apple Chemie Pvt. Ltd. in India. The chemical composition of cement, SBA, and MK as determined by X-ray fluorescence is shown in Figure 2. A viscoflux 5507 high-range water-reducing admixture conforming to ASTM C494 and IS 9103-1999. AC-Gel-Build was used as the viscosity modifying admixture in SCC, conforming to IS 9103-1999. Figure 3 reveals the images of SBA, MK, and GF. The specific gravity of fine aggregate, 10 mm, and 20 mm coarse aggregate was 2.68, 2.86, and 2.90, respectively. Cement has a specific gravity of 3.15. The specific gravity of SBA and MK is 1.9 and 2.6. According to the X-ray fluorescence study on SBA, this substance is a major source of silica in the mixture since it has a higher SiO_2 concentration (74.4%) than the other particles. Metakaolin is a major source of aluminium and silica in the mixture, as shown by the higher amounts of Al_2O_3 (37.1%) and SiO_2 (54.9 %). Figure 4 reveals the (Scanning electron microscopy) SEM images of SBA, MK and GF. SBA particles shows the porous and irregular structure. MK particles were both spherical and angular, with smooth surfaces of varying diameters. Width of GF is around 17 μm .

3. Mixture SCC Proportions

The mix design is achieved as per the recommendation of EFNARC [28]. Table 1 displays the components of the SCC mixes. Mixtures were prepared containing cement replaced with SBA and MK in 10, 5%, and 10%, respectively, with and without 0.1% of GF. The water contents were maintained at 180 litres/ m^3 in all mixtures. Superplasticizer was added at a concentration of 1 to 1.4% by weight of cement, to provide the desired fluidity. The addition of viscosity modifying admixture (VMA) ranged from 0.3 to 0.35.

4. Experimental Programme

A total of six mixes were prepared, and fresh and strength properties were examined. In accordance with EFNARC guidelines, the fresh properties of the SCC were evaluated to determine its passing ability and flowability. Once the concrete mixes were prepared, specimens were cast and cured for 7, 14, 28 and 56 days at room temperature in a curing tank available in the laboratory. For this study, compressive strength (CMS) was measured using 15 cm cubes, while flexural strength (FS) and split tensile strength (STS) were assessed using beams of dimensions 10 cm $\times$ 10 cm $\times$ 50 cm and cylinders measuring 15 cm in diameter and 30 cm in length, respectively. All concrete mixes adhered to the specifications of IS 516 and IS 5816.

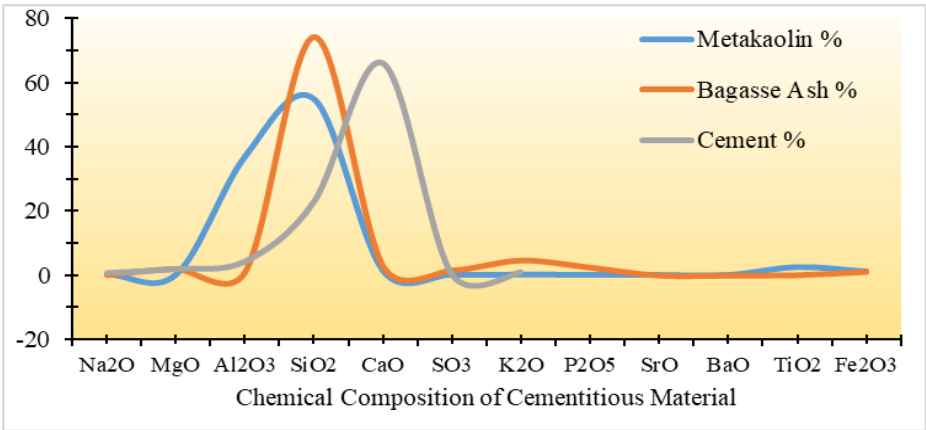


Figure 2: Chemical Composition of Cementitious material

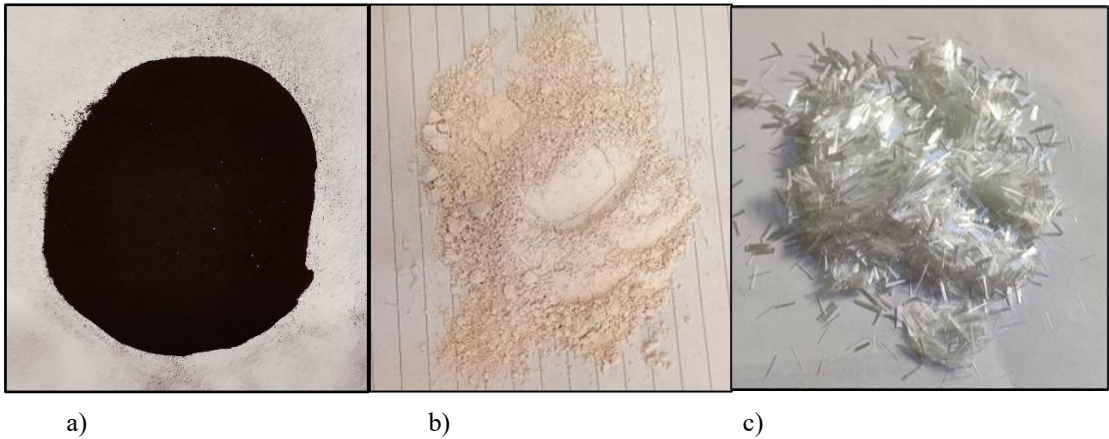
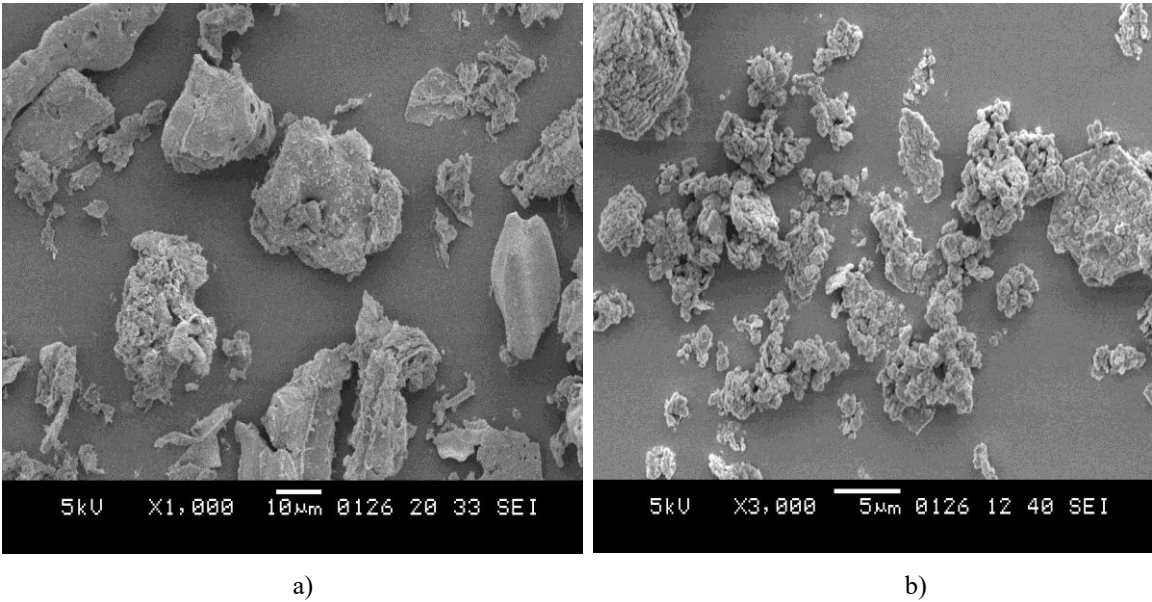
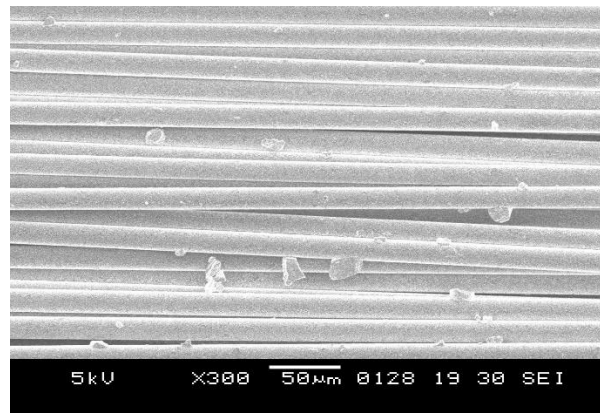


Figure 3: Images of a) SBA, b) MK and c) GF





c)

Figure 4: SEM Images of a) SBA, b) MK and c) GF

Table 1: Mix Proportions for developed SCC

Mix ID	Cement	SBA	MK	Aggregates		GF	Superplasticizer	VMA
				Coarse	Fine			
			(kg/m ³)			(%)	(%)	(%)
SCC	450.0	0.0	0.0	831.0	1000.0	0.0	1.0	0.3
SCC1	450.0	0.0	0.0	830.0	1000.0	0.1	1.1	0.3
SCCB10M5	382.5	45.0	22.5	794.2	1000.0	0.0	1.4	0.35
SCCB10M10	360.0	45.0	45.0	789.8	1000.0	0.0	1.4	0.35
SCC1B10M5	382.5	45.0	22.5	794.2	1000.0	0.1	1.4	0.35
SCC1B10M10	360.0	45.0	45.0	789.8	1000.0	0.1	1.4	0.35

5. Results and Discussion

5.1 Fresh Properties - Slump Flow (SLF) and T-50cm SLF Test

The T-50cm SLF and SLF data for each of the investigated combinations are shown in Figure 5. The desired SLF for all mixes was 650 mm. The slump flow increases from 699 mm to 721 mm for SCCB10M5. With the addition of 0.1% GF, the slump flow decreases from 2.1 to 3.4%. The minimum value of the slump flow is 675 mm for the SCC1 mix. As seen in Figure 5, as the slump increases, the T-50cm SLF time decreases, which shows good flowability. The T-50cm slump flow time for the control mix is 3.7 sec. The time decreases from 3.7 sec to 3.5 sec for SCCB10M5, which results in good flowability of SCC. The T-50cm SLF time was enhanced to 4.9 sec with the addition of 0.1% of GF for the control mix. After accumulating 0.1% GF, a 17.14% surge in the slump flow time for the SCCB10M5 was observed. When the percentage of SBA + MK was increased from 0% to 15% as a replacement of cement, the T50cm SLF time was decreased from 3.7 sec to 3.5 sec, and the slump flow increased from 699 mm to 721 mm. MK and BA were more closely integrated, maintaining a suitable level of workability [29], [30]. Fibers enhance the mix's internal friction, reducing flowability and decreasing slump flow [31]. This result indicates that the addition of SBA + MK increases the flowability, while adding GF decreases the flowability of SCC mixtures.

5.2 V-Funnel (VFN) and L-Box (LB) Test

As seen in Figure 6, the VFN duration was 7.2 sec to 11.6sec. Substitution of SBA + MK to OPC made the VFN flow time of fresh concrete stably reduced, as demonstrated in Figure 6. The greatest quantity of OPC replacement (SCC1B10M10) had the longest VFN flow duration, measuring 54% longer than the control mix (SCC). Especially, SCC mix-group associated with SBA and MK (10% and 5%), the VFN time was shortest by 4% compared to the control mix. Under the influence of the concrete's own weight, the L-Box test evaluates the degree of compactability and the ability of the densely crowded reinforcement to pass. There is a strong correlation between the high blocking ratio value and the increased passage ability of the mixture, and vice versa. The blocking ratio ranges from 0.82 to 0.94. The H2/H1 ratio enhanced from 0.91 to 0.94 for SCCB10M5 as compared to the control mix. The H2/H1 ratio was 0.92 for SCC1B10M5. For traditional applications, these ranges are an excellent choice. Additionally, there was no evidence of segregation or bleeding in any of the SCC combinations collected.

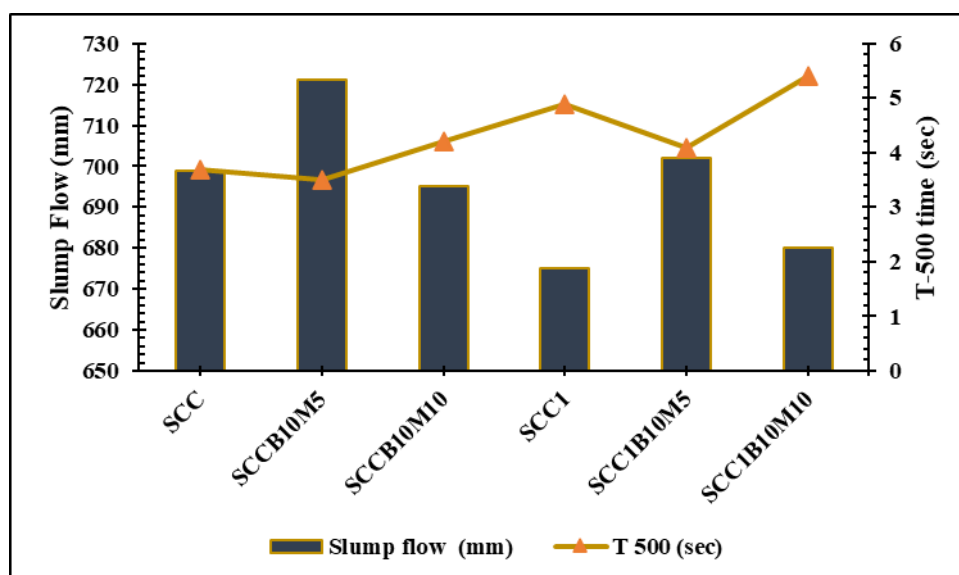


Figure 5: Correlation between the SLF and T-500 slump flow for SCC

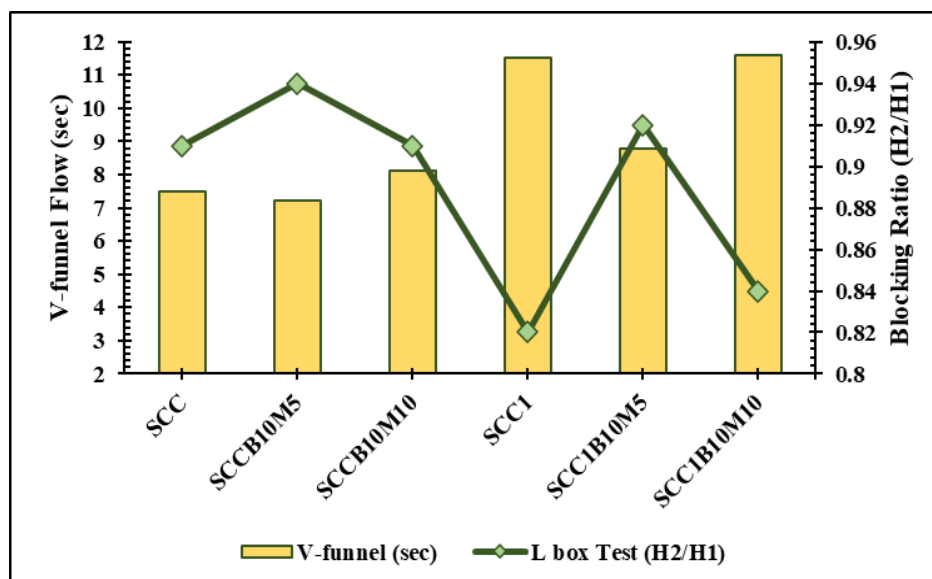


Figure 6: Correlation between the VFN flow time and blocking ratio for SCC

5.3 Strength Properties: Compressive Strength (CMS)

The CMS of SCC mixes was determined using concrete cubes of size 150 mm following IS 516 [32]. All concrete mixes were tested after curing for 7, 14, 28, and 56 days as shown in Figure 7. The SCC control mix had CMS of 43.10 and 46.10 MPa at 28 and 56 days, respectively. The SCC mixes with 10% SBA + 5% MK and 10% SBA + 10% MK showed strengths of 48 MPa and 45.10 MPa, subsequently, which were higher than 11.4 and 4.6% than those of the control mix at 28 days. The maximum increases in CMS were observed for the mix SCC1B10M5 after 28 and 56 days of curing, at 18.3% and 19.7% respectively. With the addition of 0.1% glass fiber, the CMS of self-compacting concrete increases up to 6.3%. The cement to water ratios has a major impact on the workability and CMS[33]. The strength increased with age due to the pozzolanic action of SBA and MK[34] [30]. MK had a more favorable effect on CMS [35], [36]. The SBA helps to fill the pores in the mixture, which improves the CMS [37].

5.4 Flexural Strength (FS)

Figure 8 reveals the flexural strength for all SCC mix at 7, 14, 28 and 56 days. The flexural strength for the control SCC mix at 28 and 56 days of curing was found to be 5.2 MPa and 5.95 MPa, respectively. The mix SCCB10M5 and SCCB10M10 observed flexural strengths of 6.10 and 5.95 MPa at 28 days, which were 17.3 and 14.4% greater than those of the control mix. The maximum increases in flexural strength were observed for the mix SCC1B10M5 after 28 and 56 days of curing, at 33.6% and 26.8%, respectively. With the addition of 0.1% of glass fiber, a remarkable increase in flexural strength was noted, up to 14%. The C-S-H gel produced by the pozzolanic reaction of calcium hydroxide and silica aids in filling the spaces and creating dense concrete [38]. Fiber addition enhanced the concrete's FS and STS by reducing dissemination of cracks [22].

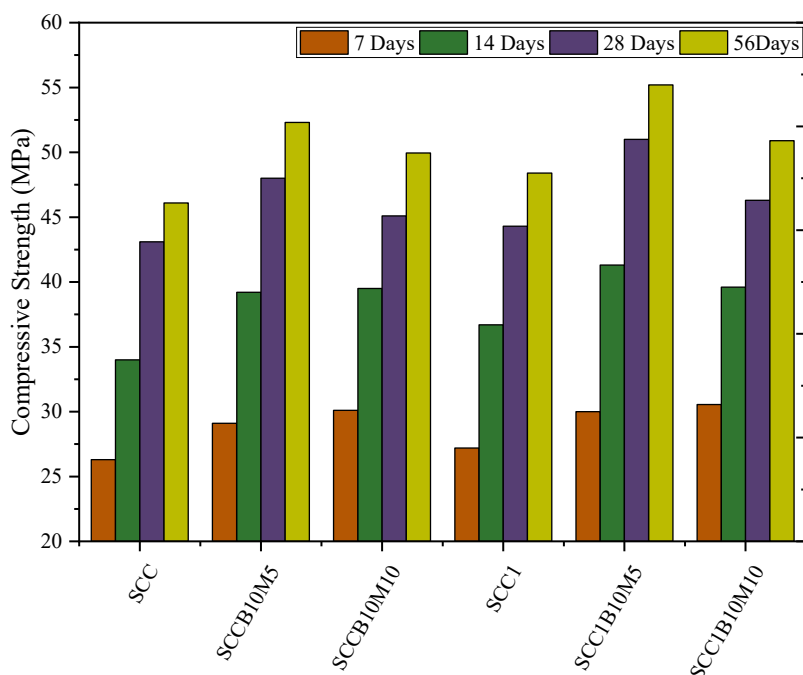


Figure 7: Compressive strength chart for SCC

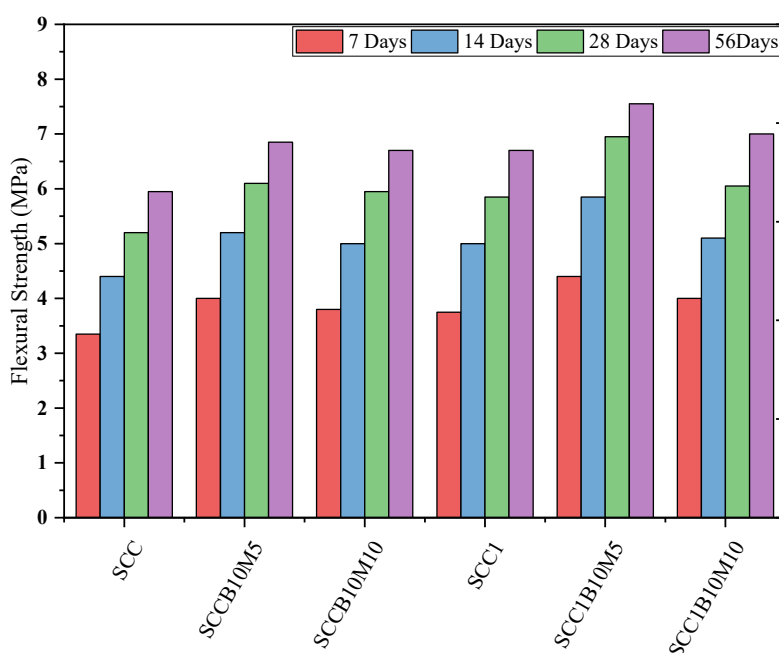


Figure 8: Flexural strength chart for SCC

5.5 Split Tensile Strength (STS)

Figure 9 represents the splitting tensile strength for all developed SCC. The splitting tensile strength of the control SCC mix after 28 and 56 days was found to be 4.5 and 5.15 MPa, respectively. All the mixes containing SBA, MK, and GF reveals the greater splitting tensile strength than the control mix. The maximum increase of 24.4% and 22.3% in strength was observed for SCC1B10M5 mixes at 28 and 56 days, respectively, when compared to the strength achieved for the control mix. With the addition of 0.1% of glass fiber, remarkable increase in split tensile strength was noted, up to 13.1%. The CMS, FS, and STS of the SCC with 10% SBA, 5% MK, and 0.1% GF mix were 12.8%, 25.7%, and 22.2% more significant at 56 days compared to the control mix [30]. The pozzolanic characteristics of MK are responsible for the STS improvement [35].

Figure 10 illustrated the relationship between CMS and two other hardened properties of concrete: FS and STS. In comparison to the STS ($R^2 = 0.7377$), the FS shows a greater association ($R^2 = 0.8074$) with CMS, indicating that compressive strength is a more accurate indicator of FS performance. These findings reveal the interrelationship among hardened properties and justify the use of CMS as a key indicator for structural analysis and quality control. A good linear correlation was observed (figure 10) between the compressive and flexural strengths with $R^2 = 0.889$ and the split tensile strengths with $R^2 = 0.827$.

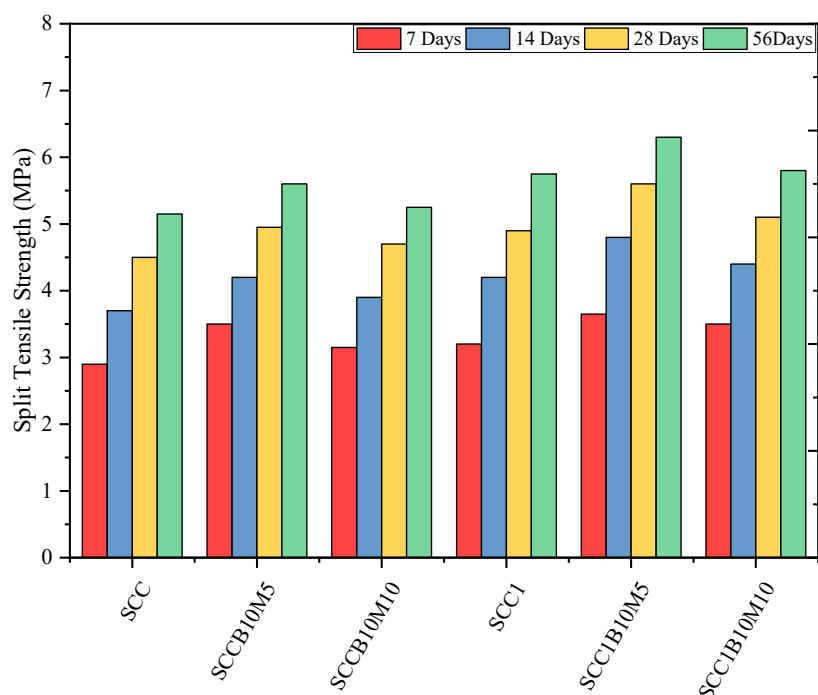


Figure 9: Split tensile strength chart for SCC

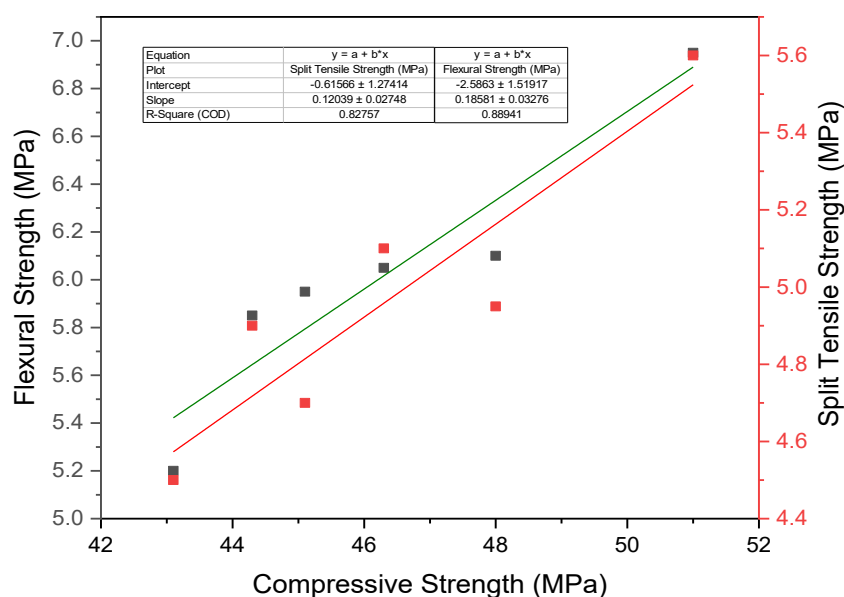


Figure 10: Correlation of the Compressive Strength with the Flexural and Split tensile Strength

5.6 Comparative Analysis

Table 2 reveals the comparison of present research work with previous studies. The effects of SCMs on the fresh and hardened properties of self-compacting concrete (SCC) are given in the table. These SCMs consist of SBA, BFS, MK, SIF, RHA, and GGBS. Generally, SBA employed between 0 and 30%, either by itself or in combination with BFS, SBA consistently shown reduced workability and varied effects on CMS based on dosage. Up to 25% of passing ability, CMS, FS, and STS often increased by MK, especially at replacement levels of 10% to 15%. However, other studies reported that using MK at more dosages or in combination with other SCMs reduced CMS and STS.

It's standard practice for conducting tests such as SLF, T50cm SLF, VFN timings, L-Box, WAb, and UPV. MK enhances C-S-H gel formation, reduces pore structures, and minimizes microcracks, according to microstructural study conducted by SEM, XRD, and EDX. In accordance with the present investigation, workability and mechanical strength have been improved by combining 10% SBA with 5–10% MK. The SCC1B10M5 mix showed significant improvements in CMS (19.7%), FS (26.8%), and STS (22.3%).

Table 2: Comparative Analysis of Previous Studies with Present Research Work

Source	SCM	Replacement carried (%)	Tests Conducted	Remarks
[39]	SBA and BFS	10, 20, 30% and 10, 20, 30%	FD, SF, T500. and V-funnel times, WAb, CMS, UPV, SA, ER	With the inclusion of SBA and BFS, workability decreases.
[1]	SBA	0 – 20% @ 5%	SF, T500. and V-funnel times, CMS, DN, CA	CMS for developed mixtures is equivalent to control mix.
[40]	SBA	0 – 25% @ 5%	WAb, CMS, STS, UPV	SBA inclusion in SCC results in a decrease in CMS and STS.
[41]	SBA	0 – 15% @ 5%	WAb, CMS	strong pozzolanic activity decreased porosity and capillary water absorption and strengthened concrete.
[42]	MK and SIF	3, 5, 8, 11, 15, 20 and 25% each	T500. and V-funnel times, L-Box Test, CMS, DS	In SCC, MK boosted blocking ratio, improving passing ability. The CMS increased by increasing MK content at 28 days.
[43]	GGBS, MK, and SIF	25, 50, 75 and 100% (GGBS) 0 to 20% @ 5% (MK and SIF)	SF, T500. and V-funnel times, L-Box Test, CMS, STS	With 10, 15, and 20% MK, slump flow increased from 680 to 690, 715, and 730mm. CMS and STS reduces with the addition of MK in SCC mix.
[44]	MK	0 to 15% @ 5%	SF, T500. and V-funnel times, L-Box Test, CMS, FLS, STS, BS, RCPT	Workability increase upto 5% inclusion of MK. MK increased CMS, FS, and STS by 1, 8.1, and 5.26 percent.
[45]	MK	0 to 20% @ 4%	SF, T500. and V-funnel times, Segregation ratio, CMS, WAb, DS, SEM	CMS was enhanced by 27.3% with 12% MK.
[46]	MK and RHA as replacement of fine aggregate	0 to 15% @ 5% and 0 to 30% @ 10%	SF, T500. and V-funnel times, L-Box Test, CMS, STS, SEM, XRD	SF increases from 680 to 695mm for 5MK and 15MK10RHA mix. Cement substitution up to 15% MK and 10% RHA increases CMS and STS. XRD and SEM showed more homogenous structure and CSH gel formation with 15% MK.
[47]	MK	0 to 15% @ 5%	SF, T500. and V-funnel times, L-Box Test, CMS, STS, SEM, XRD	CMS and STS increases for replacement of cement up to 10%MK. Reduced microcracks and CSH gel formation was revealed in the mix blended with MK.
[19]	MK	0 to 15% @ 5%	WAb, CMS, WL, RCPT, EDX, SEM	WAb and % reduction in CMS minimize with the addition of MK. Refined pores and homogeneous structures were shown in M10
Present Study	SBA and MK	10% SBA and 5% and 10% of MK	SF, T500. and V-funnel times, L-Box Test, CMS, FS, STS	SBA and MK enhanced workability with small SP dose increase. SCC1B10M5 enhanced CMS, FS, and STS by 19.7, 26.8, and 22.3%.

FD – Fresh Density, DN – Density, SF – Slump Flow, WAb – Water Absorption, CMS – Compressive Strength, FLS – Flexural Strength, STS – Splitting Tensile Strength, BS – Bond Strength, UPV – Ultrasonic Pulse Velocity, SA – Sulfate Attack, ER – Electrical Resistivity, CA – Cost Analysis, MK – Metakaolin, SIF – Silica Fume, BFS - Blast Furnace Slag, RHA - rice husk ash, GGBS - ground granulated blast furnace slag, DS - Drying shrinkage, F&T - Freezing and thawing, RCPT - Rapid chloride permeability test, SEM – Scanning electron microscopy, XRD – X-ray Diffraction, EDX - Energy Dispersive X-ray spectroscopy, WL – Weight Loss, Supplementary Cementitious Material - SCM

6. Conclusions

1. The flowability of self-compacting concrete was enhanced with the addition of SBA and MK, and the flowability was reduced with the addition of GF.

2. Maximum flowability was observed for the SCCB10M5 mix as the slump flow increased from 699 to 721 mm and the T-500 time decreased from 3.7 to 3.5.
3. The maximum increases in compressive strength were observed for the mix SCC1B10M5 after 28 and 56 days of curing, at 18.3% and 19.7%, respectively. With the addition of 0.1% glass fiber, the compressive strength of self-compacting concrete increases up to 6.3%.
4. The combination SCC1B10M5 is very effective, as the compressive strength, flexural strength, and split tensile strength were enhanced by 19.7, 26.8, and 22.3%, respectively, at the age of 56 days.

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