Research Article

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Environmentally Sustainable Self-compacting Geopolymer Concrete Rheological and Strength Properties Using Ground Granulated Blast Furnace Slag

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ABSTRACT

This research emphasizes the manufacturing and performance testing of a green Self-Compacting Geopolymer Concrete with GGBS as the main binder. A/B ratios ranging from 0.40 to 0.60 on the rheological and mechanical behavior of SCGC in ambient curing conditions was studied. Properties of fresh concrete were evaluated by applying EFNARC-suggested slump flow, T50 cm, L-box, and V-funnel, to measure flow ability and viscosity. The mechanical performance was measured by compressive, split tensile, flexural, and modulus of elasticity at 7 and 28 days. Among the mixes, the maximum performance was noted for Mix ID-3 having an A/B ratio of 0.50 with the best values of CS (39.6 MPa), STS (4.86 MPa), FS (5.42 MPa), and MOE (31,276 MPa) at 28 days. These results verify that an A/B ratio of 0.50 remarkably improves the overall performance of GGBS-based SCGC, testifying to its potential as a green substitute for traditional concrete, thus supporting environmentally friendly construction and lower carbon emissions.

Keywords: Low-Carbon concrete; Sustainable construction materials; Alkaline activator solution; Workability.

1. INTRODUCTION

Concrete is the world's most employed building material due to its versatility, strength, and pervasiveness (Vigneshkumar *et al.* 2024a). It is central to infrastructure development, housing, and transport systems. However, its key binding element, Ordinary Portland cement (OPC), is associated with severe environmental drawbacks (Vigneshkumar *et al.* 2024b). OPC manufacturing is energy-intensive and involves calcining limestone, which is a large carbon dioxide (CO_2) emitter. Studies indicate that cement production contributes approximately 7–8% of global CO_2 emissions and is thus a major contributor to climate change and ecological devastation (Alagarsamy *et al.* 2025a).

In the wake of the growing emphasis on sustainable development and climate resilience, the construction industry is being pushed to embrace environmentally friendly alternatives (Alagarsamy *et al.* 2025b). Researchers and engineers are looking for low-carbon materials and technologies that will reduce the environmental footprint of construction without compromise in performance. In this regard, GPC has emerged as a promising alternative to the traditional OPC-based concrete (Maheswaran *et al.* 2024).

GPC is a new building material produced by the alkaline activation of industrial by-products with high aluminosilicate contents, such as fly ash, metakaolin, and Ground Granulated Blast Furnace Slag (GGBS) (Muniyasamy *et al.* 2025). Unlike OPC concrete, geopolymer concrete does not rely on limestone-based clinker and thus evades the CO_2 emission due to its calcination (Santhanam *et al.* 2022a). The geopolymer concrete has enhanced resistance against chemical attacks, reduced permeability, and improved long-term durability (Santhanam *et al.* 2022b). It is found to be in harmony with sustainable building rules and supports waste valorization and circular economy activities (Santhanam *et al.* 2022c).

A more advanced form of geopolymer concrete, Self-Compacting Geopolymer Concrete (SCGC), combines the environmental advantages of geopolymer with the superior workability traits of Self-Compacting Concrete (SCC) (Sherwani *et al.* 2025). SCGC self-sets under gravity, filling complex formworks and engulfing the reinforcement without external vibration (Bahmani and Mostofinejad, 2025). This reduces labor requirements, avoids segregation, and forms a dense homogeneous matrix (Ahmed and Mantawy, 2025). SCGC is particularly advantageous in precast works, high-rise buildings, and infrastructure construction where workability and constructability are critical (Manikandan *et al.* 2025).

Among various aluminosilicate precursors, Steel mill by-product GGBS has been highly promising in geopolymer usage (Manjunath *et al.* 2025). GGBS holds a high percentage of calcium, silica, alumina, and magnesium and enhances the early strength and setting characteristics of GPC, especially under ambient curing conditions (Kavya *et al.* 2025). The dense calcium concentration supports the formation of calcium silicate hydrate-type gels and geopolymer gels, forming hybrid binding systems with better durability and strength (Benaicha *et al.* 2025).

The effectiveness of geopolymerization is highly dependent on the content and amount of the alkaline activator (Prabha and Santhi, 2025). Broadly, NaOH and Na_2SiO_3 are combined as the dissolvers of the aluminosilicate precursors to initiate polymerization (Sivasankar *et al.* 2025). The ratio of alkaline activator to binder (A/B), NaOH molarity, and the Na_2SiO_3/NaOH ratio are key parameters governing the fresh and hardened properties of SCGC (Nasir *et al.* 2025). These parameters control workability, setting time, strength development, and microstructure of the final product (Thatikonda *et al.* 2024). High amounts of alkaline solution, however, can produce high viscosity, low flow ability, or delayed setting, while low levels of activator can lead to incomplete geopolymerization (Kanagaraj *et al.* 2024).

Although several studies have examined either the rheological or mechanical properties of self-compacting geopolymer concretes, very few have systematically correlated both aspects under varying activator-to-binder ratios, particularly when GGBS is used as the sole binder under ambient curing. This gap limits the optimization of mix design for practical applications. The present research work is centered on the evaluation of rheological and mechanical characteristics of SCGC based on GGBS as the primary binder. The study investigates the influence of varying A/B ratios in the range 0.40 to 0.60 on fresh and hardened SCGC properties. For establishing the workability and self-compacting characteristics of the mixtures, a set of normalized rheological tests were conducted, including slump flow, T50 cm flow time, L-box, and V-funnel tests, in accordance with EFNARC guidelines. These are the most important tests that determine the flow ability, passing ability, and viscosity behavior of the concrete required to achieve even compounding without the use of mechanical compaction. Besides, the mechanical performances of the SCGC mixes were evaluated by performing compressive strength, split tensile strength, flexural strength, and modulus of elasticity tests at different curing ages. The experimental program sought to establish the optimum A/B ratio that ensures proper self-compacting characteristics as well as durability of the structure, thereby ensuring practical applicability of GPC as an environment-friendly alternative to OPC-based systems under ambient conditions.

2. MATERIALS AND METHODS

2.1 GGBS

The GGBS used in this study was obtained from the JSW plant, Salem, and exhibited a specific gravity of 2.9. Dominance of calcium oxide (CaO, 37.36%), silica (SiO_2, 35.13%), alumina (Al_2O_3, 16.82%), and magnesium oxide (MgO, 7.25%) was confirmed through X-ray fluorescence analysis. Physical appearance of the GGBS employed in the current study is shown in Figure 1.

Fig. 1: GGBS

2.2 Alkaline Activator

The A/B solution employed in the research herein was a 1:2.5 mixture of NaOH and Na_2SiO_3. The specific gravities of NaOH and Na_2SiO_3 were 1.47 and 1.60. The alkaline activator solution is presented in Figure 2.

Fig. 2: Alkaline activator

2.3 Aggregates

Coarse aggregate of size 12.5 mm was utilized. The material had a specific gravity value of 2.83 and a fineness modulus value of 7.16. M-sand is a by-product from quarry crushing and was employed as fine aggregate, with the value of specific gravity being 2.73 and a fineness modulus value of 2.65. The physical appearance of aggregates utilized in this study is depicted in Figure 3.

2.4 Super Plasticizers

MasterGlenium Sky 8233, a recently developed modified polycarboxylic ether superplasticizer, was employed in the study to enhance the flow ability and workability of the mix. An admixture of density 1080 kg/m³ was obtained from Astra Chemicals, Chennai. Figure 4 shows the superplasticizers.

2.5 Mix Composition

The fixed binder dosage was 450 kg/m³ of GGBS for five different A/B mixes. The alkaline activator utilized was NaOH 12M and Na2SiO3, which was mixed at a weight ratio of 1:2.5. The A/B value was changed between 0.40 and 0.60 to examine its effect on workability and strength development. For extended flow properties, a polycarboxylate ether-type superplasticizer was used at 2% of binder weight 9 kg/m³. Further, 12% additional water 54 kg/m³ was used to enhance the mixing efficiency and the casting performance. The recommended mix proportions of SCGC are given in Table 1.

Fig. 3: Aggregates

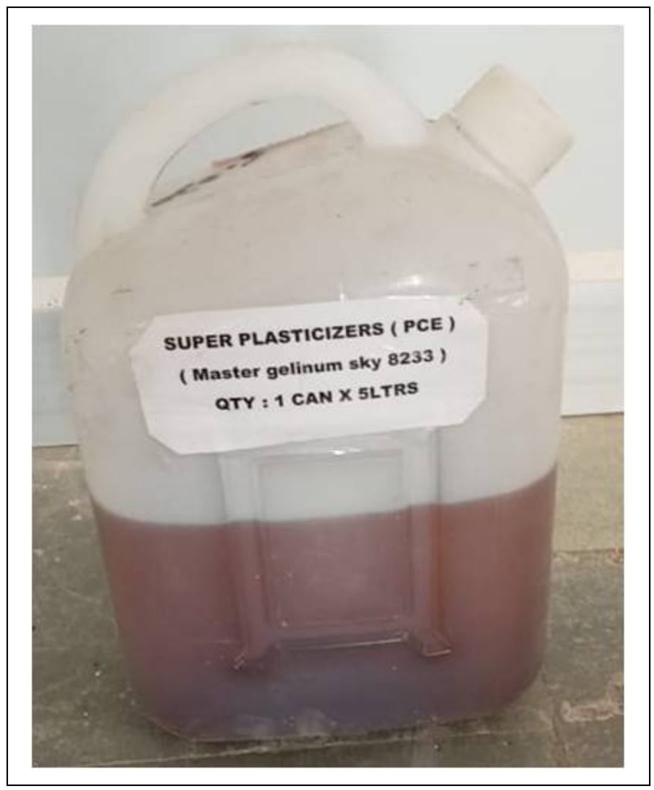

Fig. 4: Superplasticizers

2.6 Blending, Casting, Process and Curing

The mixing process began with the GGBS and saturated surface-dried aggregates, which were then mixed using a 100 L pan mixer for approximately 2.5 minutes to achieve a homogeneous mix. Following the dry mixing, the alkaline solution, superplasticizer, and extra water were added step by step to the mix. The wet mixing was extended to 3 minutes to get a homogeneous mixture of all the ingredients. After casting, the Self-Compacting Geopolymer Concrete specimens were removed from the mold and subsequently cured at ambient room temperature until the corresponding test ages. Figure 5: mixing and curing of SCGC.

Table 1. shows the SCGC mix details

Mix ID	Mix proportion in kg/m^3								
	A/B Ratio	GGBS	Fine Aggregate	Coarse Aggregate	NaOH	Na_2SiO_3	Molarity	SP	Extra Water
Mix ID-1	0.40	450	961	786	51.43	128.57	12	9	54
Mix ID-2	0.45	450	961	786	57.86	144.64	12	9	54
Mix ID-3	0.50	450	961	786	64.29	160.71	12	9	54
Mix ID-4	0.55	450	961	786	70.71	176.79	12	9	54
Mix ID-5	0.60	450	961	786	77.14	192.86	12	9	54

3. TESTING PROGRAMME

3.1 Fresh State Properties of SCGC

The fresh properties of the Self-Compacting Geopolymer Concrete (SCGC) mixtures were evaluated using slump flow, T50 cm, L-box, and V-funnel tests. The slump flow test measured the horizontal spread of concrete after demolding to assess flow ability. The T50 cm test recorded the time for the mix to reach a 50 cm spread, providing an indication of viscosity and flow rate. The L-box test evaluated the passing ability of the concrete, quantified as the ratio of heights in vertical (H1) and horizontal (H2) sections, with higher H2/H1 ratios indicating better passing capacity. The V-funnel test measured the time taken for the concrete to flow through a narrow funnel, providing a further assessment of flow ability and viscosity.

3.2 Mechanical Properties of SCGC

Compressive strength of SCGC was tested on 100 × 100 × 100 mm cube specimens using a CTM according to IS: 516-1959 at 7 and 28 days of curing (Sharma and Meena, 2025). Split tensile strength of SCGC was tested on 100 × 200 mm cylindrical specimens according to IS: 5816-1999 at all curing ages (Singh and Anand, 2024). Flexural strength was tested on 100 × 100 × 500 mm prisms using a 400 kN UTM at 7 and 28 days, following IS: 516-1959 (Paswan et al. 2025). Modulus of elasticity was determined on 150 × 300 mm cylinders at 28 days following IS: 516-1959, using a strain gauge extensometer to record axial deformations under uniaxial loading at 1.4–1.6 kg/min.

Fig. 5: Mixing and curing of SCGC

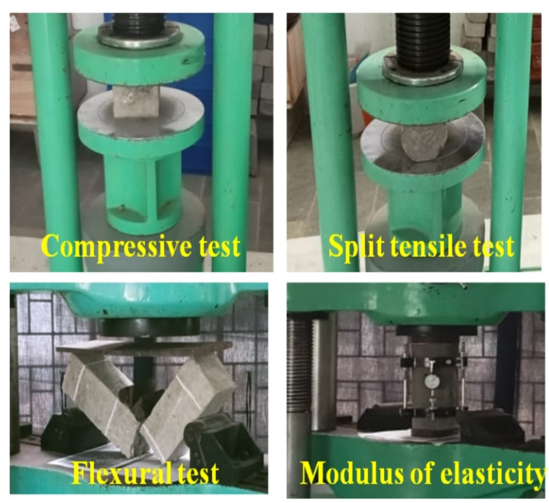

Fig. 6: Mechanical properties of SCGC

4. RESULTS AND DISCUSSION

4.1 Slump Flow Test

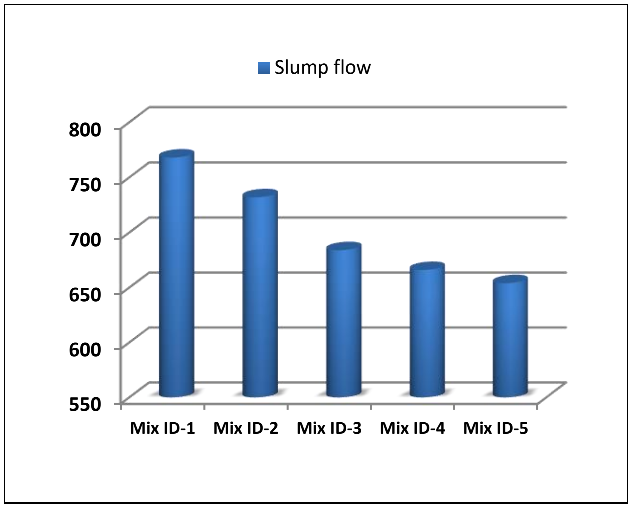

Fig. 7: Slump flow test

Figure 7 Slump flow values for various alkaline binders of GGBS-based SCGC mixes. Results showed slump flow decreases with an increase in alkaline binders of the mix, indicating a decrease in workability of the concrete mix. According to the EFNARC recommendation, large capacity is displayed when the slump flow value of SCGC falls between 650 mm and 800 mm. In this slump flow test, the slump flow for Mix ID-1 was 768 mm, whereas it decreased to 732 mm for Mix ID-2, 684 mm for Mix ID-3, 666 mm for Mix ID-4, and to 654 mm for Mix ID-5.

4.2 T50cm Flow Test

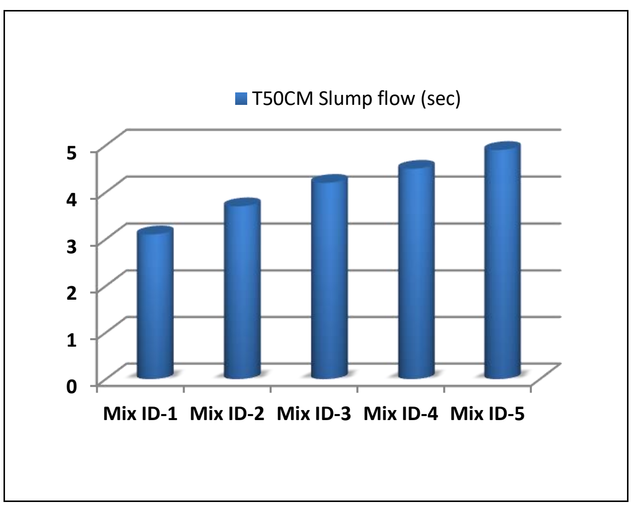

Fig. 8: T50cm slump flow

Flow times for the different alkaline binders of GGBS-based SCGC mixtures for the T50cm slumps are presented in Figure 8. The mixture showed a steady increase in T50cm time with the increase in alkaline binders, signifying higher viscosity and slower flow. The T50cm time was 3.1 seconds for the Mix ID-1. This increased to 3.7 seconds for Mix ID-2, to 4.2 seconds for Mix ID-3, to 4.5 seconds for Mix ID-4 and to 4.9 seconds for Mix ID-5. Increasing the A/B ratio enhances particle interactions and gel formation, leading to higher mixture viscosity and slower flow, thus providing a mechanistic explanation for the T50 cm trends.

4.3 V-funnel Flow Time

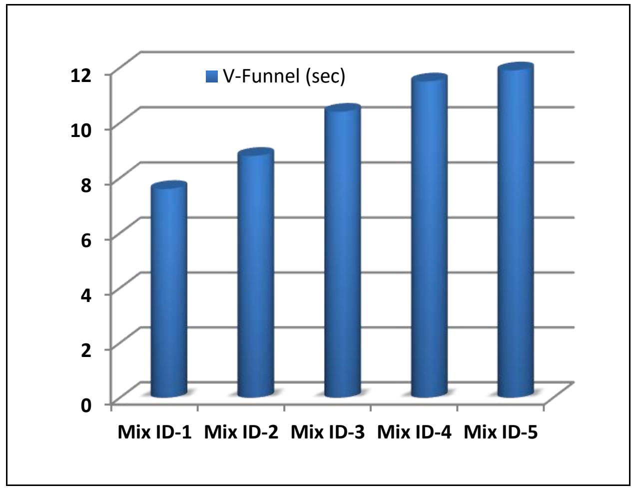

Fig. 9: V-funnel test

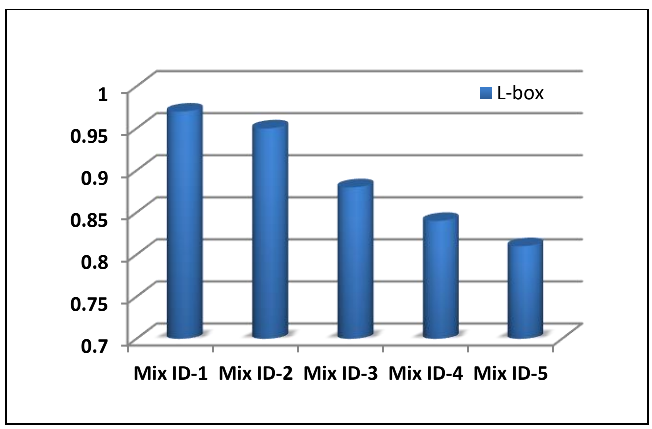

Fig. 10: L-box test

V-funnel test, as depicted in Figure 9. For SCGC mixtures, the acceptable V-funnel time ranges between 6 and 12 s. The results for mixtures based on GGBS are between 7.6 and 11.9 s. The flow time for Mix ID-1 was 7.6 seconds, increasing progressively with increasing alkaline binders: 8.8 seconds for Mix ID-2, 10.4 seconds for Mix ID-3, 11.5 seconds for Mix ID-4, and 11.9 seconds for Mix ID-5. Compare the V-funnel times with previous studies on GGBS-based SCGC, showing that the measured times 7.6 and 11.9 seconds are consistent with reported ranges 7 and 12 seconds, confirming adequate flow ability while maintaining higher binder reactivity.

4.4 L-box Test

Figure.10 illustrates SCGC mix L-box values ranging between 0.82 and 0.99. Mix ID-1 0.99 and Mix ID-2 0.97 passed well, but Mix ID-5 was the lowest 0.82, which means lower flow. With the rise in the A/B ratio, a general reduction in the L-box values was observed due to increased activator content increasing viscosity and preventing flow. Mix ID-3 0.90 supplied an equal performance within the EFNARC-defined range of 0.8–1.0, establishing its readiness for SCGC uses.

4.5 Compressive Strength

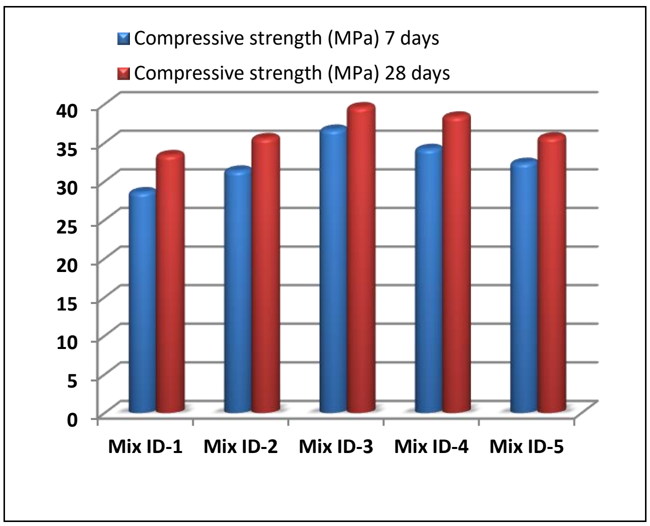

Fig. 11: Compressive strength

Figure 11 demonstrates the CS development of SCGC mixtures at 7 and 28 days. The Mix ID-1 revealed the CS of 28.6 MPa at 7 days and 33.4 MPa at 28 days. In comparison to this, Mix ID-2 attained 31.4 MPa and 35.6 MPa at 7 and 28 days with an increase of 9.79% and 6.58%, respectively. Mix ID-3 had the best performance, with 36.7 MPa at 7 days and 39.6 MPa at 28 days, representing strength increases of 28.32% and 18.56% compared to the control. Mix ID-4 had compressive strengths of 34.2 MPa and 38.4 MPa, representing increases of 19.58% at 7 days and 14.97% at 28 days. Mix ID-5 had 32.4 MPa and 35.7 MPa, representing increases of 13.28% and 6.89%. The observed variations in compressive strength differences arise from the activator-to-binder ratio Mix ID-3 optimized, while others had lower gains due to minor porosity.

4.6 Split Tensile

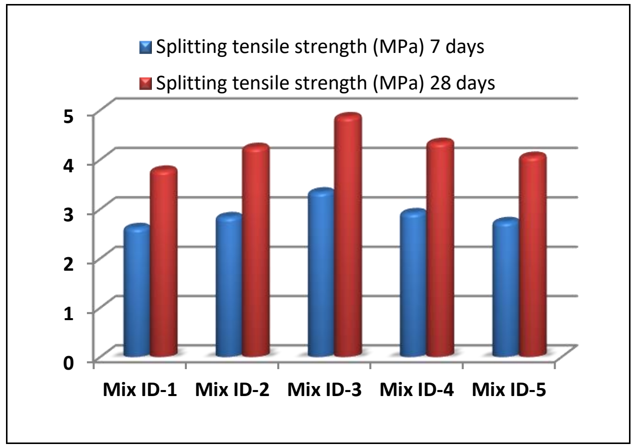

Fig.12: Split tensile

Figure 12 displays the STS strength of SCGC at 7-28 days. Compared to Mix ID-1, Mix ID-2 to Mix ID-5 indicated increases in strength by 8.39%, 27.48%, 11.45%, and 4.58% at 7 days, and 12.16%, 28.57%, 14.81%, and 7.40% at 28 days, respectively. Maximum enhancement was always noted in Mix ID-3, confirming that the optimal alkaline binder ratio for achieving maximum tensile strength is 0.50. This confirms the beneficial effect of balanced activator content towards enhancing the optimum mechanical performance of GGBS-based SCGC.

4.7 Flexural Strength

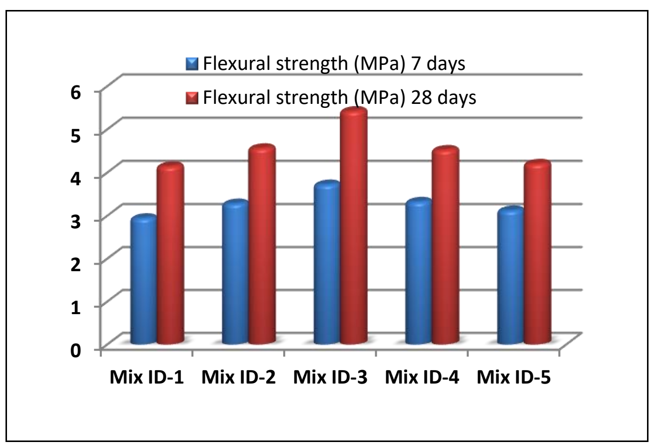

Fig. 13: Flexural strength test

Figure 13 shows the FS results of SCGCs of all five mix combinations. Out of them, Mix ID-3 was found to have the highest flexural strength, 3.72 MPa at 7 days and 5.42 MPa at 28 days. Comparison with Mix ID-1 showed that the gains in strength development for all mixtures with varying alkaline binder ratios, 0.45 to 0.60, were very high. At 7 days, the strength gains are 11.56%, 26.53%, 12.92%, and 6.12% for Mix ID-2 to ID-5, respectively. At 28 days, the respective gains were 10.14%, 30.91%, 9.17%, and 1.44%. These results prove that the use of a higher alkaline binder ratio positively influences flexural strength development, and Mix ID-3 was the best in developing early-age as well as long-term flexural performance. The improvements in flexural strength are attributed to higher alkaline binder ratios enhancing aluminosilicate dissolution, promoting gel formation and matrix densification, which improves stress transfer under loading. Mix ID-3 achieved the optimal balance, resulting in maximum early-age and long-term flexural performance.

4.8 Modulus of Elasticity

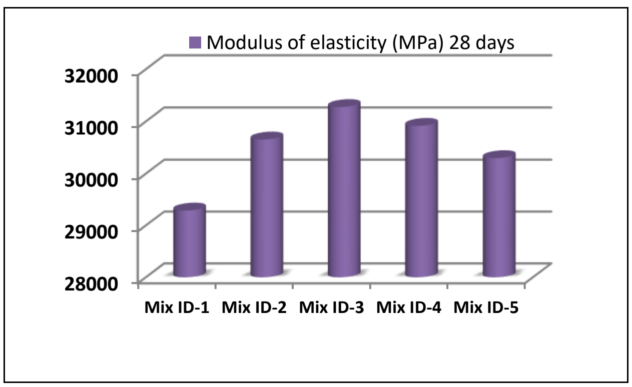

Fig. 14: Modulus of elasticity test

Figure 14 illustrates the MOE of the SCGCs mixtures at 28 days, indicating significant variation in the various alkaline binder mix proportions. The highest modulus value of 31,276 MPa was registered by Mix ID-3, followed by Mix ID-4 at 30,915 MPa, and Mix ID-2 at 30,654 MPa. Mix ID-5 and Mix ID-1 had lower readings of 30,297 MPa and 29,288 MPa, respectively. Compared to Mix ID-1, MOE increased by 4.63% in Mix ID-2, 6.78% in Mix ID-3, 5.55% in Mix ID-4, and 3.44% in Mix ID-5. The increase in MOE in Mix ID-3 shows that a denser and more rigid matrix is being formed due to the optimized alkaline binder ratios.

5. CONCLUSIONS

The mechanical and rheological characteristics of sustainable cement green concrete with GGBS as the primary binder were examined in this investigation. A/B ratios between 0.40 and 0.60 were investigated under normal curing conditions. The alkaline binder ratio had a considerable influence on the new properties of SCGC. Growing the A/B ratio resulted in a reduction of slump flow and L-box but an augmentation in the values of T50 cm and V-funnel times, indicating lower flow ability and passing ability because of increased mix viscosity. All the SCGC mixes demonstrated improved compressive strength with a higher A/B ratio up to 0.50. Optimum mix A/B = 0.50 exhibited the highest CS of 36.7 MPa and 39.6 MPa, which are respective increments of 28.32% and 18.56% over the control mix. Optimum mix attained the greatest STS (3.34 MPa and 4.86 MPa) and FS (3.72 MPa and 5.42 MPa), all of which are higher than those of the other mixes. These improvements once again promote the efficacy of the 0.50 A/B ratio to enhance early-age and long-term mechanical properties. Optimum mix 31,276 MPa, the maximum modulus of elasticity was found, which showed an increase of 6.78% over that of the control mix. The overall performance trends, identifies as the optimum mix, and connects the findings to the sustainability advantages of GGBS-based SCGC.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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REFERENCES

Ahmed, A. M. A. and Mantawy, I. M., Additive construction of low embodied carbon concrete: Geopolymer concrete, *J. Build. Eng.,* 111, 112984(2025). https://doi.org/https://doi.org/10.1016/j.jobe.2025.112984

Alagarsamy, V., Christy, C. E. F., Muthiah, M. and Alengaram, U. J., Influence of alkaline binders on the workability and strength of self compacting geopolymer concrete, *Zastita Mater.m* 66(2), 280-291(2025a). https://doi.org/10.62638/ZasMat1181

Alagarsamy, V., Christy, C. E. F., Muthiah, M. and Alengaram, U. J., Investigation of superplasticizer influence on rheological and strength properties of self-compacting geopolymer concrete, *Mater. Prot.,* 66(2), 440–450(2025b). https://doi.org/10.62638/ZasMat1258

Bahmani, H. and Mostofinejad, D., Sustainable self-compacting concrete: Performance optimization using calcium oxide-activated slag and sugar factory lime waste, *Constr. Build. Mater.,* 492, 142956(2025). https://doi.org/10.1016/j.conbuildmat.2025.142956

Benaicha, M., Jalbaud, O., Roguiez, X., ALaoui, A. H. and Burtschell, Y., Exploring rheological properties of self-compacting concrete: mineral and chemical admixture impacts, *Arch. Civ. Mech. Eng.,* 25 (2025) 128. https://doi.org/10.1007/s43452-025-01196-5

Kanagaraj, B., Anand, N., Raj R. S. and Lubloy, E., Behavioural studies on binary blended high strength self compacting geopolymer concrete exposed to standard fire temperature, *Ain Shams Eng. J.,* 15(2), 102394(2024). https://doi.org/10.1016/j.asej.2023.102394

Kavya, B. R., Kumar, S. M. N., Rahul, N. and Shrikanth, A. S., Comparative study on the mechanical properties of geopolymer concrete containing GGBS and fly ash using experimental analysis and artificial neural network, *Asian J. Civ. Eng.,* 26(8), 3233–3244(2025). https://doi.org/10.1007/s42107-025-01367-y

Maheswaran, M., Christy, C. F., Muthukannan, M., Arunkumar, K. and Vigneshkumar, A., Parametric Study on Strength Performance of Geopolymer Concrete Using Industrial By-Products, in: S. Sahoo, N. Yedla (Eds.), Recent Advances in Mechanical Engineering, *Springer* 113–124(2024). http://dx.doi.org/10.1007/978-981-97-1080-5_10

Manikandan, P., Kumar, V. P. and Vasugi, V., Strength and microstructural characteristics of sustainable aluminosilicate binder using waste glass powder and ground granulated blast furnace slag, *Innovative Infrastruct. Solutions.,* 10(3), 105(2025). https://doi.org/10.1007/s41062-025-01920-3

Manjunath, R., Pushya, J. R., Kumar, K. A. A. and Shetty, K. K., Performance evaluation of coffee husk ash based one-part self compacting alkali activated slag concrete mixes, *Innovative Infrastruct. Solutions.,* 10(6), 245(2025). https://doi.org/10.1007/s41062-025-02044-4

Muniyasamy, M. K., Alagarsamy, V. and Kumar, M. D., Development of Self-compacting Geopolymer Concrete Paver Blocks Using Sustainable Materials for Medium Traffic Conditions, *J. Environ. Nanotechnol.,* 14(2), 196–201(2025). https://doi.org/10.13074/jent.2025.06.2521529

Nasir, N. A. M., Nadarajah, A., Johari, M. U. M., Bakar, N. A., Safiee, N. A. and Aziz, F. N. A. A., Performance of high-content waste ash geopolymer-based composites for sustainable construction, *Arch. Civ. Mech. Eng.,* 25(4), 228(2025). https://doi.org/10.1007/s43452-025-01284-6

Paswan, R. K., Kumar, P., Kumar, V. and Sembeta, R. Y., Mechanical properties of alkali activated slag binder based concrete at elevated temperatures, *Discover Sustainability.,* 6(1), 744(2025). https://doi.org/10.1007/s43621-025-01542-w

Prabha, M. K. and Santhi, A. S., Ternary blended steel wool fibre reinforced self-compacting concrete: A sustainable approach, *Struct.,* 80, 109732(2025). https://doi.org/10.1016/j.istruc.2025.109732

Santhanam, K. and Ramadoss, R., Conservation & restoration of historic mortars at Alamparai fort with valley conical arch, Tamilnadu, India, *Constr. Build. Mater.,* 339, 127619(2022a). https://doi.org/10.1016/j.conbuildmat.2022.127619.

Santhanam, K. and Ramadoss, R., Restoration of an ancient temple at Parvathamalai in Tamil Nadu to preserve cultural heritage, *Eur. Phys. J. Plus.,* 137(5), 549(2022b). https://doi.org/10.1140/epjp/s13360-022-02741-4

Santhanam, K. and Ramadoss, R., The effect of alkali activation on the durability, mechanical properties, and characterization of alccofine-modified air lime mortar, *Eur. Phys. J. Plus.,* 137(9), 1057(2022d). https://doi.org/10.1140/epjp/s13360-022-03280-8

Sharma, A. and Meena, R. V., Optimized high-performance concrete using Styrene–Butadiene Rubber and hybrid fibers: enhancing fresh, mechanical, durability, and microstructural properties for sustainable construction, *Asian J. Civ. Eng.,* 26(4), 1635–1654(2025). https://doi.org/10.1007/s42107-025-01271-5

Sherwani, A. F. H., Abdulrahman, P. I., Younis, K. H., Mohammed, A. S. and Zrar, Y. J., Compressive strength modeling of the eco-friendly self-compacting rubberized concrete with fly ash and ground granulated blast furnace slag additives, *Innovative Infrastruct. Solutions.,* 10(2), 61(2025). https://doi.org/10.1007/s41062-024-01811-z

Singh, S. and Anand, V., Innovative enhancement of self-compacting concrete using varying percentages of steel slag: an experimental investigation into fresh, mechanical, durability, and microstructural properties, *Asian J. Civ. Eng.,* 25(8), 6073–6090(2024). https://doi.org/10.1007/s42107-024-01163-0

Sivasankar, S., Gurusamy, M., Prasath, S. R., Sounthararajan, V. M., Investigating the impact of various parameters on the properties of fly ash geopolymer concrete using a hybrid optimisation approach, *Int. J. Pavement Eng.,* 26(1), 2427869(2025). https://doi.org/10.1080/10298436.2024.2427869

Thatikonda, N., Mallik, M., Sarella, V. R. and Dubey, S., Evaluation of self-compacting geopolymer concrete properties containing different water glass solutions, *Sustainable Chem. Pharm.,* 41, 101680(2024). https://doi.org/10.1016/j.scp.2024.101680

Vigneshkumar, A., Christy, C. F., Muthukannan, M., Alengaram, U. J., Maheswaran, M. and Jeyaraj, N. J., Study of silicon dioxide nanoparticles on the rheological and mechanical behaviors of self-compacting geopolymer concrete, 15(3), 365-374(2024b). https://doi.org/10.1556/1848.2024.00794

Vigneshkumar, A., Christy, C. F., Muthukannan, M. and Alengaram, U. J., Fresh, hardened properties and microstructural analysis on the effect of NaOH molarities of industrial by-products based self-compacting geopolymer concrete, *Int. Rev. Appl. Sci. Eng.,* 16(2), 242-264(2025). https://doi.org/10.1556/1848.2024.00867

Vigneshkumar, A., Christy, C. F., Muthukannan, M. Maheswaran, M., Arunkumar, K. and Devi, R. K., Experimental investigations on fresh and mechanical properties of fly ash and ground granulated blast furnace slag self-compacting geopolymer concrete, *Mater. Today Proc.,* (2024a). https://doi.org/10.1016/j.matpr.2024.01.051