

EXPERIMENTAL INVESTIGATION ON THE MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE INCORPORATING SUGARCANE BAGASSE ASH

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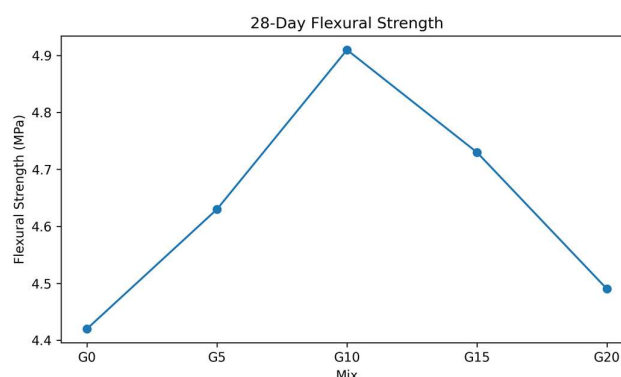
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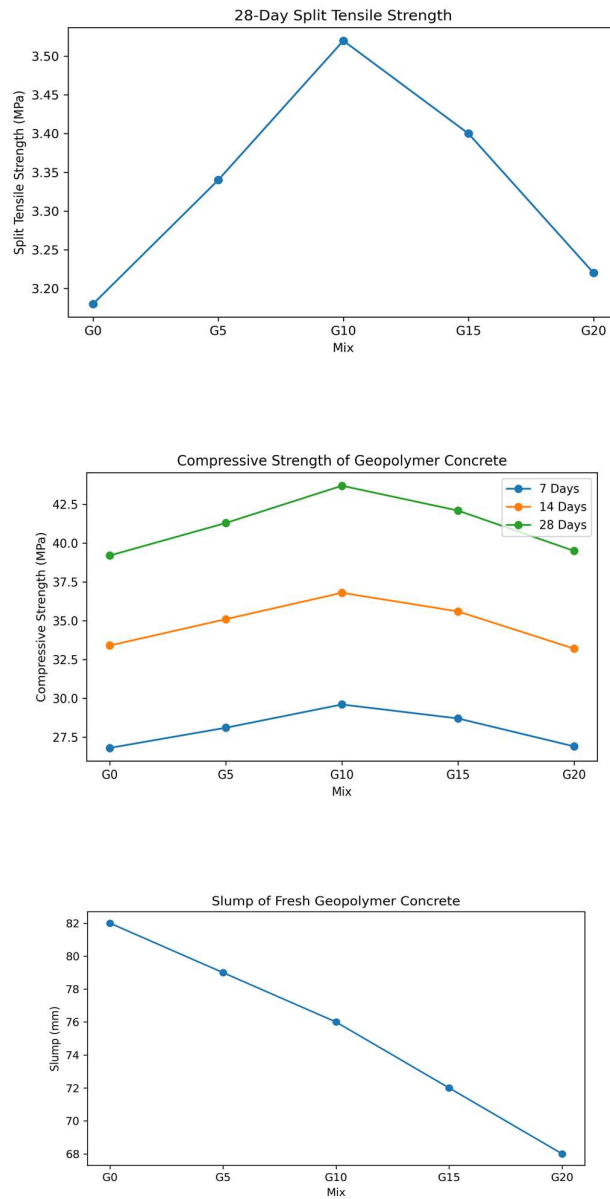
Abstract:

Geopolymer concrete is a sustainable alternative to conventional cement concrete because it can utilize alumino-silicate-rich industrial and agricultural wastes as binder constituents. The present study investigates the effect of Sugarcane Bagasse Ash (SCBA) as a partial replacement of Class F Fly Ash in geopolymer concrete and evaluates the resulting mechanical performance. Five mixtures were prepared by replacing Fly Ash with 0%, 5%, 10%, 15%, and 20% SCBA, designated as G0, G5, G10, G15, and G20, respectively. A 12 M Sodium Hydroxide solution and Sodium Silicate were used as alkaline activators, with the $\text{Na}_2\text{SiO}_3:\text{NaOH}$ ratio maintained at 2.5:1. Fresh concrete workability was assessed using the slump test, while hardened properties were evaluated through compressive strength, split tensile strength, and flexural strength tests. Compressive strength was measured at 7, 14, and 28 days, while tensile and flexural tests were performed at 28 days. The results show a consistent increase in strength up to 10% SCBA replacement, followed by a reduction at higher replacement levels. The G10 mixture achieved the highest 28-day compressive strength of 43.70 MPa, split tensile strength of 3.52 MPa, and flexural strength of 4.91 MPa. In addition to the experimental investigation, Linear Regression, Decision Tree Regression, and Random Forest Regression were applied for predictive analysis. The reported model comparison gave R^2 values of 0.89, 0.93, and 0.97, respectively, with the Random Forest model also reporting the lowest error measures in the comparison table. The study demonstrates the potential of controlled SCBA utilization in geopolymer concrete and the usefulness of regression-based prediction for reducing experimental effort.

Keywords: Geopolymer concrete; Sugarcane Bagasse Ash; Fly Ash; compressive strength; split tensile strength; flexural strength; regression analysis; Random Forest; sustainable construction

1. Introduction





Concrete is one of the most widely used construction materials, but conventional cement production is associated with substantial energy consumption and carbon dioxide emissions. These environmental concerns have encouraged the development of alternative binders and sustainable concrete technologies. Geopolymer concrete uses alumino-silicate-rich materials activated by alkaline solutions and therefore provides an approach for reducing dependence on Portland cement while simultaneously utilizing waste materials.

Class F Fly Ash is commonly used as a geopolymer precursor because of its silica and alumina content. Sugarcane Bagasse Ash is an agricultural residue produced from the combustion of sugarcane bagasse in sugar industries. Its utilization in construction materials can provide a route for waste management and resource conservation. In the present investigation, SCBA is used as a partial replacement of Class F Fly Ash.

The study considers five SCBA replacement levels—0%, 5%, 10%, 15%, and 20%—and evaluates workability and three important mechanical properties. The research also incorporates computational regression models to examine whether experimental strength trends can be predicted from the available dataset.

The objectives are to: (i) develop geopolymer concrete using Class F Fly Ash and SCBA; (ii) study the effect of SCBA replacement on compressive, split tensile, and flexural strengths; (iii) compare the performance of the different mixes; (iv) identify the replacement level associated with the highest measured mechanical performance; and (v) evaluate Linear Regression, Decision Tree Regression, and Random Forest Regression for strength prediction.

2. Review of Related Research

The thesis literature review reports that geopolymer concrete has been investigated as a low-carbon alternative to conventional concrete and that Fly Ash-based systems can provide useful mechanical and durability characteristics. Studies on SCBA have emphasized its silica-rich nature, pozzolanic activity, and potential contribution to sustainable concrete. The reviewed work also identifies the importance of alkaline activator concentration, activator ratio, curing conditions, and mix proportions in determining geopolymer performance.

The reviewed literature further indicates growing use of computational and regression approaches for concrete property prediction. Linear Regression provides a simple relationship between inputs and outputs, while Decision Tree Regression can capture nonlinear relationships through recursive data partitioning. Random Forest Regression combines multiple decision trees and is intended to improve stability and prediction accuracy.

The research gap identified in the thesis is the limited combined investigation of SCBA-based geopolymer concrete, comprehensive mechanical testing, and comparative regression prediction. The present work addresses this gap by integrating laboratory testing with three regression approaches.

3. Materials and Experimental Methodology

3.1 Materials

The principal binder materials were Class F Fly Ash and Sugarcane Bagasse Ash. Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) were used as the alkaline activators. Natural river sand and crushed coarse aggregate were used as fine and coarse aggregates, respectively. Potable water was used for solution preparation and laboratory operations.

3.2 Mix Proportions

Five geopolymer concrete mixtures were prepared by keeping the total binder proportion and aggregate quantities constant while varying the Fly Ash–SCBA proportion. The experimental matrix was designed so that the effect of SCBA replacement could be examined systematically.

Mix	Fly Ash (%)	SCBA (%)	Fine Aggregate (kg/m ³)	Coarse Aggregate (kg/m ³)
G0	100	0	650	1200
G5	95	5	650	1200
G10	90	10	650	1200
G15	85	15	650	1200
G20	80	20	650	1200

3.3 Alkaline Activator

A 12 M Sodium Hydroxide solution was prepared before casting and allowed to cool. The Sodium Silicate to Sodium Hydroxide ratio was maintained at 2.5:1 for all mixtures. The activator condition was kept constant across the experimental matrix to minimize variability attributable to the alkaline solution.

3.4 Specimen Preparation and Testing

Cube specimens of 150 mm × 150 mm × 150 mm were used for compressive strength testing. Cylinders of 150 mm × 300 mm were used for split tensile strength testing, and beams of 100 mm × 100 mm × 500 mm were used for flexural strength testing. Three specimens were tested for each mix and the average was used for analysis. Compressive strength was measured at 7, 14, and 28 days. Split tensile and flexural strengths were measured at 28 days.

Test	Specimen	Age	Standard
Slump	Fresh concrete	Fresh	IS 1199:2018
Compressive strength	150×150×150 mm cube	7, 14, 28 days	IS 516 (Part 1):2021
Split tensile strength	150×300 mm cylinder	28 days	IS 5816:1999
Flexural strength	100×100×500 mm beam	28 days	IS 516 (Part 2):2021

3.5 Regression Analysis

The experimental dataset was used for predictive analysis. The selected input variables included Fly Ash percentage, SCBA percentage, fine aggregate, coarse aggregate, NaOH molarity, Na₂SiO₃/NaOH ratio, and curing age. The output variables were compressive strength, split tensile strength, and flexural strength. The models considered were Linear Regression (LR), Decision Tree Regression (DTR), and Random Forest Regression (RFR). The thesis reports evaluation using R², RMSE, MAE, MSE, and MAPE. A higher R² and lower error values indicate closer agreement between experimental and predicted results.

For the Random Forest model, the thesis describes an 80% training and 20% testing split for the model development discussion. The reported training performance was R² = 0.97, RMSE = 1.85 MPa, and MAE = 1.32 MPa, while the testing performance was R² = 0.94, RMSE = 2.45 MPa, and MAE = 1.7892 MPa.

4. Results and Discussion

4.1 Slump

Mix	SCBA (%)	Slump (mm)
G0	0	82
G5	5	79
G10	10	76
G15	15	72
G20	20	68

The slump decreased progressively from 82 mm for G0 to 68 mm for G20. The thesis attributes this behavior to the finer and porous nature of SCBA, which can absorb more alkaline solution and reduce the free paste available for lubrication. Despite the reduction, the reported values were considered workable for normal placement and compaction.

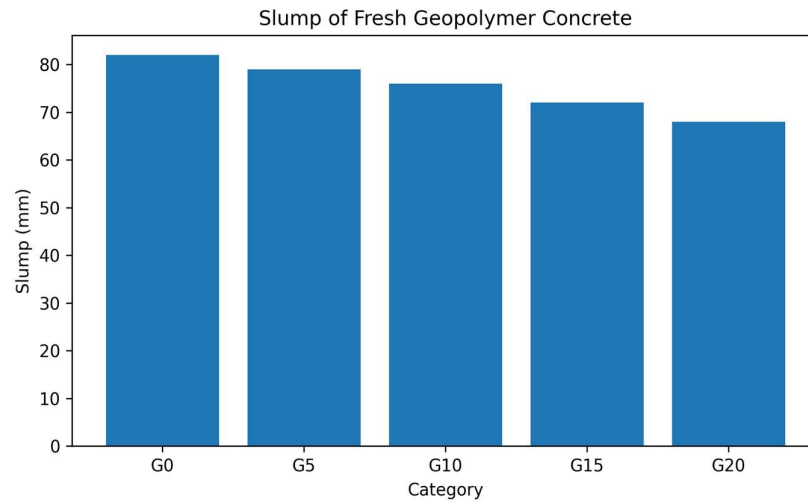


Figure 1. Slump variation with SCBA replacement.

4.2 Compressive Strength

Mix	SCBA (%)	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
G0	0	26.80	33.40	39.20
G5	5	28.10	35.10	41.30
G10	10	29.60	36.80	43.70
G15	15	28.70	35.60	42.10
G20	20	26.90	33.20	39.50

All mixes gained strength with curing age. At 28 days, the compressive strength increased from 39.20 MPa for G0 to 41.30 MPa for G5 and reached 43.70 MPa for G10. It then decreased to 42.10 MPa for G15 and 39.50 MPa for G20. Thus, within the investigated range, the highest measured compressive strength occurred at 10% SCBA replacement. Relative to G0, the G10 value represents an increase of about 11.5%. The reduction at 15% and 20% indicates that the strength benefit observed at lower replacement levels was not maintained when SCBA content was increased further.

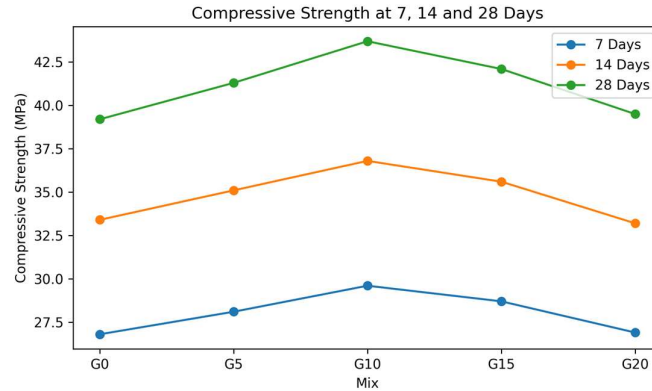


Figure 2. Compressive strength at 7, 14 and 28 days.

4.3 Split Tensile Strength

Mix	SCBA (%)	Average Load (kN)	28-day Split Tensile Strength (MPa)
G0	0	182	3.18
G5	5	191	3.34
G10	10	201	3.52
G15	15	194	3.40
G20	20	184	3.22

The split tensile strength followed a pattern similar to compressive strength. The value increased from 3.18 MPa for G0 to 3.34 MPa for G5 and 3.52 MPa for G10, followed by reductions to 3.40 MPa and 3.22 MPa for G15 and G20. The G10 mixture therefore recorded the highest split tensile strength. The thesis relates the improvement up to 10% to particle packing, geopolymer gel formation, and a denser matrix, while the decline at higher replacement levels is associated with reduced availability of reactive alumino-silicate material and partially reacted particles.

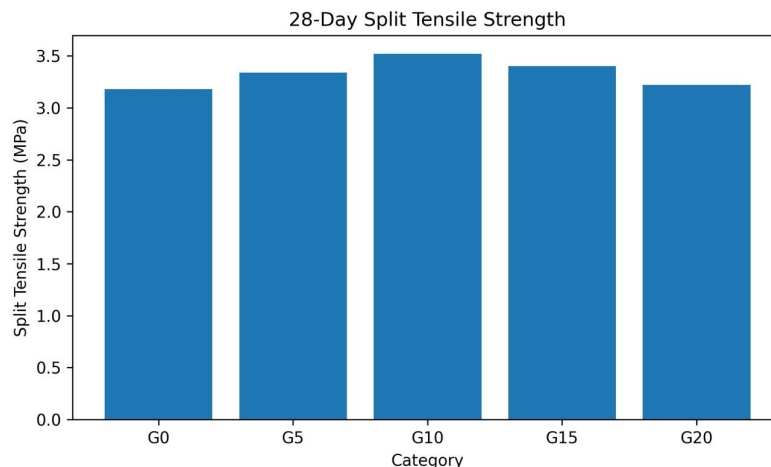


Figure 3. 28-day split tensile strength.

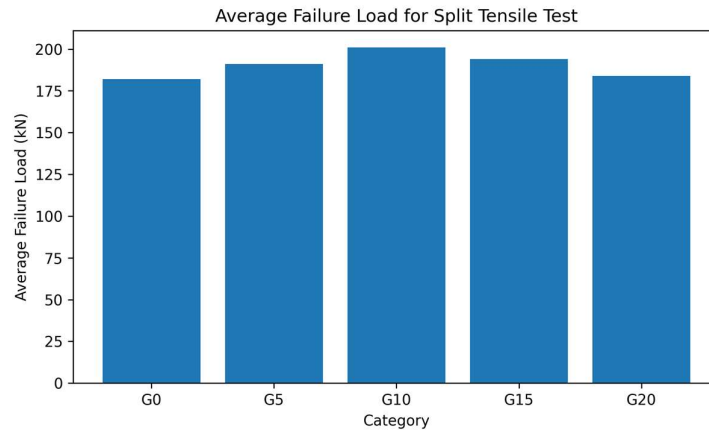


Figure 4. Average failure load for split tensile test.

4.4 Flexural Strength

Mix	SCBA (%)	Average Failure Load (kN)	28-day Flexural Strength (MPa)
G0	0	18.6	4.42
G5	5	19.5	4.63
G10	10	20.8	4.91
G15	15	20.0	4.73
G20	20	18.9	4.49

Flexural strength increased from 4.42 MPa for G0 to 4.63 MPa for G5 and 4.91 MPa for G10. At higher SCBA contents it decreased to 4.73 MPa for G15 and 4.49 MPa for G20. The 4.91 MPa value for G10 corresponds to an improvement of approximately 11.1% over the control mix. The thesis associates the increase with improved geopolymerization, particle packing, and matrix densification.

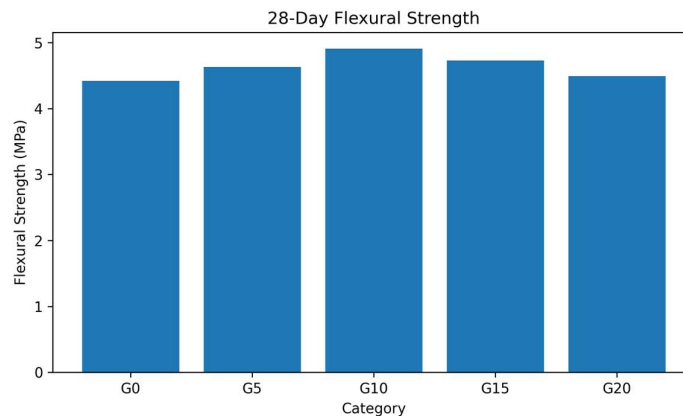


Figure 5. 28-day flexural strength.

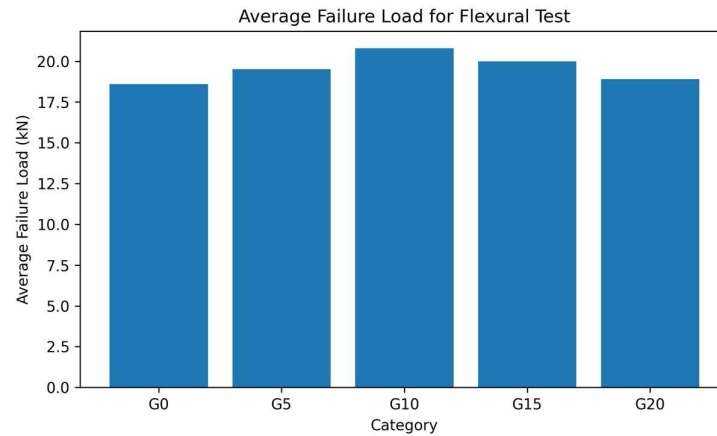


Figure 6. Average failure load for flexural test.

4.5 Overall Experimental Trend

The three hardened-property results show a common pattern: strength increased up to 10% SCBA replacement and decreased at 15% and 20%. On the basis of the measured compressive, split tensile, and flexural strengths, G10 produced the highest values among the investigated mixtures. This result identifies 10% SCBA replacement as the optimum level within the tested range for the present experimental programme.

5. Predictive Regression Analysis

The thesis compares three regression models using the experimental dataset. The 28-day compressive strength comparison shows close agreement between measured and predicted values for all three models.

Mix	Experimental (MPa)	Linear Regression (MPa)	Decision Tree (MPa)	Random Forest (MPa)
G0	39.20	39.05	39.28	39.18
G5	41.30	41.08	41.37	41.29
G10	43.70	43.42	43.81	43.69
G15	42.10	41.86	42.18	42.11
G20	39.50	39.18	39.62	39.48

The predicted values closely follow the experimental trend, including the increase to G10 and subsequent reduction. The reported performance comparison is summarized below.

Model	R ²	RMSE	MAE	MSE	MAPE (%)
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Linear Regression	0.89	4.25	3.10	18.06	8.75
Decision Tree Regression	0.93	3.10	2.20	9.61	6.20
Random Forest Regression	0.97	2.05	1.45	4.20	3.8093

The reported metrics show progressively higher R^2 and lower error values across the three models in the thesis comparison table. Random Forest Regression is reported with $R^2 = 0.97$, RMSE = 2.05 MPa, MAE = 1.45 MPa, MSE = 4.20, and MAPE = 3.8093%. These values indicate close agreement between the predicted and experimental dataset used for the comparison. The thesis also reports separate Random Forest training and testing metrics, with R^2 values of 0.97 and 0.94, respectively.

It should be noted that the reported model metrics depend on the dataset construction, selected inputs, train-test procedure, and evaluation method. Therefore, the reported values describe the performance for the dataset and modelling procedure used in this study and should not be interpreted as universal performance values for all geopolymers concrete datasets.

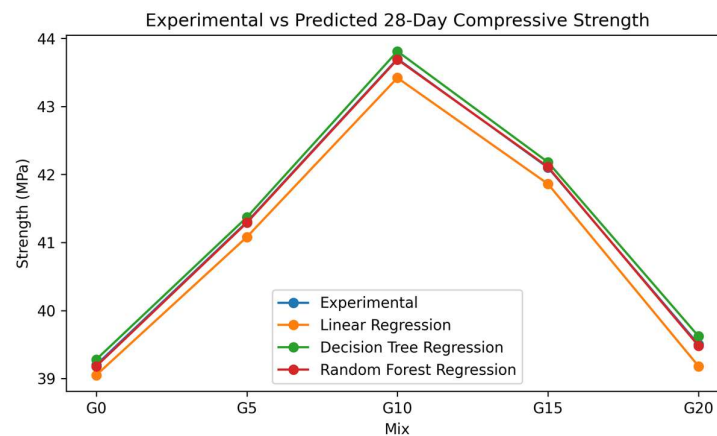


Figure 7. Experimental versus predicted 28-day compressive strength.

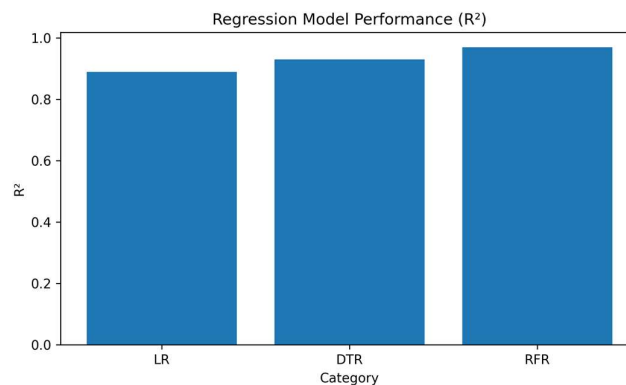


Figure 8. Regression model performance based on R^2 .

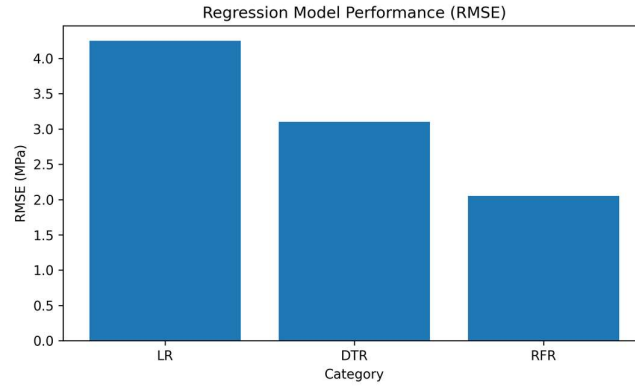


Figure 9. Regression model performance based on RMSE.

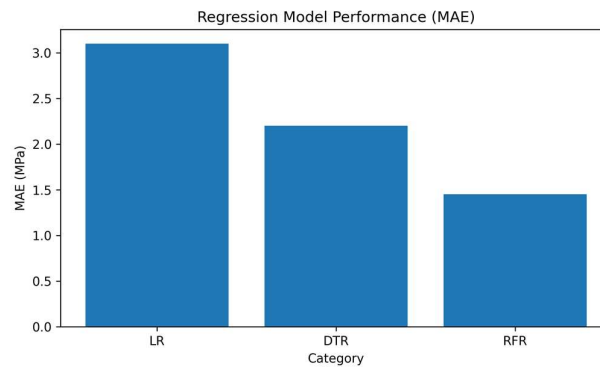


Figure 10. Regression model performance based on MAE.

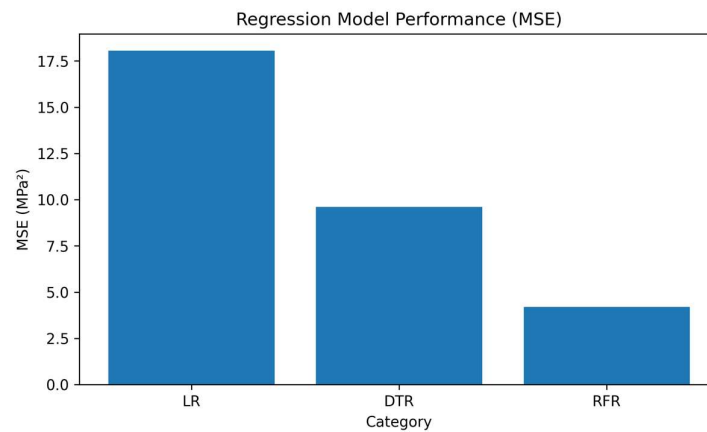


Figure 11. Regression model performance based on MSE.

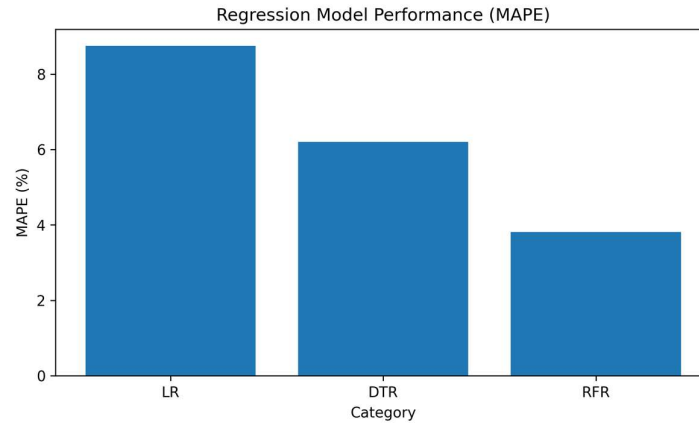


Figure 12. Regression model performance based on MAPE.

6. Discussion

The experimental findings indicate that SCBA content has a non-linear influence on geopolymer concrete performance. The initial increase in strength from G0 to G10 can be associated, as discussed in the thesis, with improved particle packing, geopolymer gel development, and matrix densification. Beyond 10%, the decline in mechanical properties suggests that increasing SCBA content does not continuously improve the binder system. The simultaneous reduction in slump also indicates that increasing SCBA changes fresh-state behavior and may require careful control of liquid and activator conditions.

The consistency among compressive, split tensile, and flexural strength trends strengthens the experimental observation that G10 provides the highest measured mechanical performance in the investigated series. However, the study covers replacement levels only up to 20% and uses fixed activator conditions; consequently, the findings are specific to the experimental range and materials adopted.

The regression analysis adds a data-driven component to the experimental investigation. The close predicted values in the 28-day compressive-strength comparison demonstrate that the selected models can reproduce the observed trend for the available dataset. Random Forest provides the lowest reported error measures in the thesis comparison, while Linear Regression provides a simpler baseline relationship. Such models can be used as supplementary tools for screening mix combinations before extensive laboratory testing.

7. Conclusions

1. Sugarcane Bagasse Ash can be incorporated as a partial replacement of Class F Fly Ash in geopolymer concrete within the investigated replacement range of 0–20%.
2. Slump decreased progressively from 82 mm for G0 to 68 mm for G20 as SCBA content increased.
3. Compressive strength increased with curing age for all investigated mixes.
4. The 28-day compressive strength increased from 39.20 MPa for G0 to 43.70 MPa for G10 and then decreased at higher SCBA replacement levels.
5. The highest 28-day split tensile strength was 3.52 MPa for G10, compared with 3.18 MPa for G0.
6. The highest 28-day flexural strength was 4.91 MPa for G10, compared with 4.42 MPa for G0.
7. Within the experimental range, 10% SCBA replacement (G10) produced the highest measured values of compressive, split tensile, and flexural strength.
8. The regression comparison reported R^2 values of 0.89, 0.93, and 0.97 for Linear Regression, Decision Tree Regression, and Random Forest Regression, respectively.

9. The reported Random Forest model had the lowest RMSE, MAE, MSE, and MAPE in the model-comparison table and closely reproduced the experimental compressive-strength trend.
10. The combined experimental and regression approach provides a basis for sustainable material development and data-driven screening of geopolymer concrete mixtures.

8. Future Scope

Investigate SCBA replacement levels beyond 20% and use smaller increments around the 10% region.

Study the influence of different NaOH molarities and Sodium Silicate-to-NaOH ratios. Evaluate durability properties such as water absorption, acid/sulphate resistance, chloride penetration, and long-term exposure behavior.

Include microstructural and chemical characterization to better explain the observed strength changes.

Develop larger and independently validated datasets for regression and machine-learning models.

Compare additional prediction algorithms and assess their robustness using independent validation datasets.

References

1. Davidovits, J. (2012). Geopolymer concrete as a sustainable alternative to conventional cement concrete. Geopolymer Institute, Technical Paper No. 24.
2. Provis, J. L., et al. (2012). Chemical and microstructural characteristics of alkali-activated materials. *Journal of the American Ceramic Society*, 95(1), 32–45.
3. Hardjito, D., & Rangan, B. (2013). Fly ash-based geopolymer concrete. *ACI Materials Journal*, 110(3), 250–258.
4. Nath, P., & Sarker, P. (2014). Effect of fly ash and slag on the performance of geopolymer concrete. *Materials & Design*, 53, 502–510.
5. Bahurudeen, B., et al. (2015). Potential utilization of Sugarcane Bagasse Ash as a supplementary cementitious material. *Cement and Concrete Composites*, 63, 110–121.
6. Rerkpiboon, R., et al. (2015). Influence of sugarcane bagasse ash on the mechanical properties of concrete. *Engineering Structures*, 100, 25–34.
7. Bahurudeen, B., et al. (2016). Pozzolanic reactivity and microstructural properties of Sugarcane Bagasse Ash. *Materials Characterization*, 118, 153–162.
8. Santos et al. (2017). Durability characteristics of concrete containing Sugarcane Bagasse Ash.
9. Khankhaje et al. (2018). Effect of alkaline activators and curing conditions on geopolymer concrete performance.
10. Sata et al. (2019). Engineering properties of fly ash-based geopolymer concrete.
11. Yadav et al. (2020). Physical and chemical characteristics of Sugarcane Bagasse Ash.
12. Amran et al. (2021). Review of geopolymer concrete mechanical and durability properties.
13. Farhan et al. (2022). Durability performance of geopolymer concrete under different environmental conditions.
14. Alaneme et al. (2023). Systematic review of agro-waste-based geopolymer concrete.
15. Ojha, & Aggarwal. (2023). Mix design approaches for low-calcium fly ash-based geopolymer concrete.
16. Kumar et al. (2024). Influence of Sugarcane Bagasse Ash on the mechanical properties of geopolymer concrete.
17. Nguyen et al. (2025). Computational regression applications for geopolymer performance prediction.
18. Rihan et al. (2025). Statistical and predictive regression models for fly ash and Sugarcane Bagasse Ash-based geopolymer concrete.