



Applicability of the response surface method in the optimization of compressive strengths of banana-fiber-reinforced concrete using waste glass as partial cement replacement

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Abstract

Natural fibers and pozzolan have gained prominence in the development of concrete; however, there are few studies that have considered the combination of banana fiber and waste glass powder. In this work, 0.5%, 1.0%, and 1.5% banana fiber (BF) was employed as fiber reinforcement, while glass powder (GP) was used as pozzolan, partially replacing cement at 10%, 20%, and 30%. Using the response surface method (RSM), the experimental data on the 7-, 28-, and 56-day concrete compressive strengths were analysed, modeled and optimized via the response surface approach. The result revealed that the variables played an important role on the trend of the 7-, 28-, and 56-day compressive strengths. The optimal combination of 1.0%, 1.1%, and 1.0% banana fiber at 17.4%, 20.8%, and 21.0% GP cement replacement yielded improvements of 11.0, 22.1, and 27.0% over the reference concrete at 7, 28, and 56 days, respectively. The developed predictive models for compressive strength were affirmed to be statistically fit for future prediction.

Keywords RSM (response surface method) · Fiber-reinforced concrete · Banana fiber · Waste glass · Cement replacement · Compressive strength optimization

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Introduction

Concrete is a composite combination of cement, fine and coarse aggregates, water, and a few additives that hardens via a chemical reaction [1, 2]. It is used often in structural applications for the construction of buildings, bridges, walkways, and towering constructions. Properties, quality, and durability of concrete are depending on mixture composition, load application, and temperature stability of the environment of application. The composition of the mixture, including the kind and quantity of cement, aggregates, water content, and additives, has a significant impact on the strength of concrete. These factors establish the service strengths, porosity and water absorption capacity, permeability and suction inclinations, and densities. In addition, the kind and duration of curing have a significant effect on the strength and durability of concrete materials. In addition to exposure to cold conditions, sulfate and chloride attack, load bearing capability is another element influencing the longevity of concrete for a particular application [3]. To guarantee optimal performance while in service, concrete mixtures are meticulously formulated with the finest possible circumstances in mind.

Cracks such as plastic shrinkage, expansion crack, settling fractures, and autogenous cracks are common in concrete [4, 5]. In order to reduce the harmful impact of these fissures, fibers are added to the concrete mix. The fibers used in this procedure are both natural and synthetic [6, 7]. In many applications, fiber-reinforced concrete (FRC) is gaining a competitive edge over conventional concrete. It has been shown that the inclusion of fibers improves the mechanical characteristics of cement composite owing to the self-healing and fracture propagation prevention tendencies given by these fibers [8, 9]. Steel, polypropylene, polyester, carbon, nylon, and acrylic have shown their uniqueness in FRC development [10, 11]. Natural fibers such as banana, jute, pineapple, coconut basalt, hemp, and sisal are used in the production of fiber-reinforced concrete [12, 13]. The use of natural fibers into concrete has given rise to sustainable fiber-reinforced concrete (SFRC), which is gaining popularity in structural concrete design.

A difficulty connected with the use of natural fibers in cement-based media is the potential for deterioration due to alkaline hydrolysis, which degrades the molecular chains of the fibers, resulting in a loss of strength. Wei and Meyer [14, 15] propose the use of pozzolan as a method for resolving the deadlock.

Typically, the hydration process in cement composites is accompanied by the formation of hydrated lime ($\text{Ca}(\text{OH})_2$), which accounts for 10 to 30 percent of the volume of the hydration products [16]. This creates an alkaline environment which is detrimental to the fibers. Reducing the content of hydrated lime in the system is advantageous for the durability of the fibers. Additionally, lime's contribution to the strength of concrete is negligible. By means of a pozzolanic reaction, hydrated lime is transformed into calcium silicate hydrate (C–S–H) or calcium aluminosilicate hydrate (C–A–S–H), which considerably contribute to the strength of cement composite. Therefore, the use of pozzolan in cementitious composites contributes to the decrease of alkaline medium and the enhancement of C–S–H/C–A–S–H-producing strength. The use of glass powder as a pozzolan in several investigations has shown remarkable results [17]. By recycling and reusing waste glass products in concrete, their environmental effect has been decreased and sustainability has been encouraged. Glass waste is non-biodegradable; hence, recycling into metals as reinforcement [18, 19] and burned ceramics [20, 21] as well as concrete is the subject of continuing study. In this research, a combination of banana fiber and waste glass powder is used as components in concrete mix in an effort to produce a more sustainable eco-concrete. As was previously noted, concrete mixes are meticulously formulated for optimal performance. In the majority of research, the optimal mixture was determined by trial and error; however, there are few studies that use an optimization strategy in their design.

Recently, optimization approaches have been used to determine the optimal blend designs. Sinkhonde et al. [22] used tire rubber powder as a partial substitute for coarse aggregate and burned brick powder as a partial replacement for cement. Thirteen formulas were created using central composite design, and cost and 28-day compressive strength were tested as responses. Cost reduction and compressive strength maximization are objectives of the simultaneous optimization procedure. At 5% burned clay brick powder and 5.8% waste tire rubber powder, the optimum cost-effective and strength-maximizing mixture was reached. Similarly, Hamada et al. [23] improved the strength of a lightweight concrete using nano-palm oil fuel ash as a partial cement replacement (0, 15, 30% replacement) and palm oil clinker as a partial coarse aggregate replacement (0, 50, 100% replacement). Properties determined were ultrasonic pulse velocity, flexural strength, and splitting strength. The optimal combination for desired simultaneous performance is 5.23 percent nano-palm oil fuel ash replacement and 6.5 percent palm oil clinker replacement. Guneyisi et al. [24] determined the optimal ratio of fly ash to metakaolin in the formulation of concrete mixture. In the research, fly ash was employed as a partial cement substitute at 10% and 20% replacement, whereas metakaolin was used at 5% and 10% replacement. As a function of the factors, the compressive strength after 90 days, chloride permeability, water absorption, and sorptivity were assessed. The objective of optimization was to enhance compressive strength while minimizing other parameters. For the 90-day curing period, simultaneous optimization was achieved at 13.3% fly ash replacement of cement and 10% metakaolin replacement of cement.

Haque et al. [25] introduced rice husk ash as a partial cement replacement at 0, 15, and 30% and glass fiber (proportions of 0.04, 0.06, and 0.08%) as a crack inhibitor in concrete using a central composite design. The 7-, 14-, and 28-day compressive and splitting strengths were measured, and the best response was achieved by replacing 16.05% of the cement with rice husk ash and 0.08% with glass fiber. In addition, Ahmed et al. [26] investigated the optimization of waste glass and condensed milk tin fibers utilized as additions in concrete. In accordance with the response surface approach, the optimal mix combination of 20.436% glass powder replacement of cement and 0.843% fiber proportion was achieved. Through this optimization technique, concrete composite has obtained the desired results. Other studies involving combination of natural fibers and waste glass powder are included in studies [27–29].

In this work, sodium hydroxide was used to alkalinize the fiber. Through alkalization, lignin and hemicellulose concentrations tend to decrease, fiber surface roughness is enhanced, resulting in greater matrix adherence, and cellulose crystallinity is enhanced. Additionally, via

alkalinization, calcium carbonate sediments are formed on the surface of the fibers, filling in holes and forming a hydrolysis-resistant layer [30, 31]. By using this method, a fiber with greater structural durability is generated for cementitious composite [32]. In the previous studies reviewed in this section, none focused on the combination of fiber using waste glass as cement replacement in the cementitious composite. This is a focus of this study. The choice of banana fiber and glass powder in present report is attributed to the abundance of the materials within the purview of the research. Furthermore, response surface method was adopted in present study to develop predictive models for future prediction of compressive strength at compressive strength at 7, 28, and 56 days after curing.

Materials and methods

Materials

Ordinary Portland cement (42.5), fine sand (0.1–4.75 mm size range and fineness modulus of 2.78), gravel coarse aggregates (4.75–16 mm size range), collected waste glass, and banana fiber were employed in this investigation. The materials were treated by washing discarded glass under running water, crushing it using a laboratory crusher, and grinding it. The waste glass was further crushed using a ball mill for six hours, and the resulting powder was screened to – 23 micron passing. This size of waste glass was chosen because to the well-established fact that glass powder smaller than 75 microns in size is useful as a pozzolan [33]. Banana fiber was collected, rinsed with running water, and air-dried for 48 h. The fiber was then treated for 30 min with 10% NaOH at 100 °C [32]. The next step was washing with distilled water, followed by oven-drying at 60 °C. As noted by Caballero et al. [34] and Gong et al. [35], the fibers were chopped to a length of 25 mm before being infused into the concrete

Table 1 Chemical composition of fiber

Material	Cellulose	Hemicellulose	Lignin	Others
Raw banana fiber (%)	50.5	23.6	14.1	11.8
Modified banana fiber (%)	56.3	18.6	12.1	13.0

Table 2 Properties on input variables

Constituents	Fine sand	Gravel	Glass powder	Cement
Specific gravity	2.67	3.4	2.86	3.169
Moisture content	2.11	1.3	–	–
Specific area	1542 cm ² /kg	1741 cm ² /kg	2784 cm ² /g	3638cm ² /Kg
Fineness modulus	1.99	2.7	1.59	1.33

mixture. The water-to-cement ratio was maintained at 0.35 per the example of Panda et al. [36].

Properties of input materials

According to Table 1, the alkaline-treated fiber exhibited a progressive increase in cellulose content relative to the untreated fiber. Similarly, to the results of Reddy et al. [37] and Loganathan et al. [38], hemicellulose and lignin concentrations are lower in the treated than in the untreated.

The properties of fine sand, coarse gravel, glass powder, and cement are compared and contrasted in Table 2. According to the information that was presented, the specific gravities of fine sand, coarse gravel, glass powder, and cement, in that order, are as follows: 2.67, 3.40, 2.86, and 3.169. The amount of moisture found in fine sand and gravel has been measured and found to be < 5%. Cement has the highest specific area, which indicates that there is a significant potential for chemical interaction within the system. Cement and GP both are fine as determined by the fineness modulus.

The chemical components of the various types of input materials, including fine sand, coarse gravel, glass powder, and cement, are outlined in Table 3. Fine sand, coarse gravel, and glass powder all contain significant amounts of silica, but coarse gravel also contains a significant quantity of alumina, whereas the amount of alumina present in glass powder and cement is minimal. Both fine sand and glass powder have a significant quantity of sodium dioxide (Na₂O), which is a potential in increasing the alkalinity of the medium. The input materials may include traces of additional components in very low concentrations. The glass powder satisfies the requirements for a pozzolan

Table 3 Chemical constituent of input materials

Constituent	Fine sand	Coarse gravel	Glass powder	Cement
SiO ₂	74.88	75.66	69.7	21.77
Al ₂ O ₃	4.22	14.37	2.07	4.88
CaO	1.02	0.78	8.3	65.9
Fe ₂ O ₃	1.62	1.88	0.25	0.03
MgO	1.14	0.08	3.11	0.63
Na ₂ O	5.49	2.05	12.9	1.40
Others	9.27	3.53	1.86	4.29
LOI	2.36	1.65	1.81	1.10

as laid forth by ASTM C 618 [39], since the combined amounts of SiO_2 , Al_2O_3 , and Fe_2O_3 are lower than 70% of the total weight of the powder.

Concrete mix and curing.

For reference, the control mix was prepared by mixing cement, fine aggregate, and coarse aggregate in the weight ratio of 1:1:2 for an aggregate mixture of 100 kg. For the composite mixture, glass powder was utilized as a partial cement replacement at 10, 20, and 30 percent, and banana fiber was used to replace a portion of the fine aggregate. Table 4 displays the formulation of the design. According to the table, 10 concrete mixtures were produced. The concrete mixture was poured into a 150-mm prism mold (compressive strength test) and tempered to minimize the void content. After 24 h, samples of brick were taken from the mold and cured for 7, 28, and 56 days under a polyethylene sheet.

Evaluation of compressive strength.

After each curing period, samples were collected, oven-dried at 100 °C for six hours, and then subjected to ASTM C1314 compressive strength testing (2018) [40]. The universal testing equipment (Istron 3369) was used at a strain rate of 5×10^{-3} /s and employing 1KN load. As the compressive strength, the ratio of the load to failure to the cross-sectional area was measured. Three samples of each formulation were evaluated, and the average results were recorded. The 7-, 28-, and 56-day compressive strengths of the control (reference concrete) are 14.5 MPa, 20.8 MPa, and 23.6 MPa, respectively.

Table 4 The mix design

Run order	% Glass powder replacement of cement	Banana fiber
0 (control)	0	0
1	10	0.5
2	20	0.5
3	30	0.5
4	10	1.0
5	20	1.0
6	30	1.0
7	10	1.5
8	20	1.5
9	30	1.5

Experimental analysis by response surface method (RSM)

The laboratory observations' real data were entered into the Design Expert 13 program for response surface analysis. RSM is a valid mathematical and statistical method for analyzing laboratory results involving the simultaneous interaction of two or more factors [41]. At a confidence level of 95%, analysis of variance is conducted to determine whether the input components' contribution to the observed results is substantial or insignificant. If the probability value, or p-value, is less than 0.05, then the effect of the input variable on the response is significant. If the p-value is greater than 0.05, the contribution is negligible [42]. Additionally, RSM develops a mathematical formula for the interaction between the input variables [43]. These model equations are constructed in a way that allows them to anticipate the responses in relation to the input variables. RSM also provides a 3D graphic (surface plot) illustrating how the input factors interact and the influence on the response trend. Similarly, the RSM is equipped with a 2D graphic that illustrates how modifying parameters result in a variety of response values for each combination of parameters. Using the RSM, optimization for the desired mix formulation in optimizing the compressive strength is attained.

Results and analysis

Two-Factor analysis

Analysis of variance

Table 5 displays the results of the analysis of variance of the compressive strength of the proposed concrete. The effect of banana fiber on the 7-day, 28-day, and 56-day compressive strengths of the concrete is less than 0.05 percent. On this basis, it may be inferred that banana fiber

Table 5 Analysis of variance for compressive strength

Source	7th day	28th day	56th day
A-Banana fiber	0.0003	0.0019	0.0012
B-% GPR	0.0727	0.0006	0.0004
AB	0.4664	0.7550	0.7509
A ²	0.0002	0.0004	0.0002
B ²	0.0181	<0.0001	<0.0001
Model	0.0007	0.0003	0.0002
R ²	0.9867	0.9884	0.9857
R ² (adjusted)	0.9811	0.9851	0.9857
R ² (predicted)	0.9629	0.9679	0.9744
Adeq Prec	33.45	55.06	59.45

contributed marginally to the compressive strength of the concrete, regardless of curing time. Regarding the curing durations, the table additionally displays the p-value of factor B (replacement of cement with glass powder). Substitution of glass powder for cement had no significant effect on 7-day compressive strength (p-value > 0.05). According to Islam et al. [44], the effective pozzolan reaction employing glass powder as a cement substitute occurs after seven days; hence, glass powder has no significant impact on the compressive strength of concrete at early ages. This work supports the claim of Islam et al. [44] as regards the marginal contribution of glass powder to 7-day compressive strength. Cross-interaction between the components AB had no effect on the 7-day, 28-day, and 56-day compressive strengths of the concrete (p-values were greater than 0.05). Contrarily, the square interactions between individual factors (AA and BB) had a significant impact on the property for all curing durations studied.

The p-values of the models are less than 0.05, indicating their significance at the 95% confidence level [45]. The coefficient of determination R^2 is more than 0.95 for each of the 7-, 28-, and 56-day compressive strengths. This indicates the precision with which the model can depict the link between the experimental variables and the determined responses with < 5% variance. The divergence between the predicted and adjusted R^2 for compressive strength throughout the three periods investigated is 0.2, portraying the models are adequate in representing the observed values. Equations 1, 2, and 3 express the quadratic function for models in relation to the number of curing days. Correlation between the fitted model and the experimental result is determined by the coefficient of correlation of the models. In this report, the correlation coefficient is more than 0.95, inferring that the models adequately describe the data. Consequently, the models can interpret experimental data with > 95% accuracy. Adequate precision (Adeq. Prec.) is implemented for predicting the signal-to-noise ratio, which enables comparison of anticipated and experimental results within the design

space [45]. The adequate precision values for the compressive strength investigated with the given values exceeding 4. It demonstrates that the generated mathematical models (Eqs. 1, 2, and 3) for the responses are able to predict the responses within the design space and validates the result of the variance analysis in determining the relevance of the variable inputs. Table 3 Mathematical models for compressive strength at varying ages

$$CS_7 = 10.4000 + 8.1000A + 0.0817B + 0.0050AB - 3.6000A^2 - 0.0020B^2 \quad R^2 = 0.9867 \tag{1}$$

$$CS_{28} = 1.7667 + 15.9333A + 1.3683B + 0.0050AB - 7.4000A^2 - 0.0320B^2 \quad R^2 = 0.9884 \tag{2}$$

$$CS_{56} = 4.3111 + 18.2667A + 1.3467B + 0.0050AB - 8.4667A^2 - 0.0312B^2 \quad R^2 = 0.9857 \tag{3}$$

Surface plot

Figure 1 illustrates the surface plots of the compressive strength of the concrete at the various periods of curing. The surface plot for 7-day compressive strength is shown in Fig. 1a. As shown in the graph, the addition of 0.5 to 1.0% fiber while utilizing glass powder to replace cement at 10 to 30% resulted in an increase in strength. As observed, the strength of glass powder exhibited a linear relationship with no significant influence on compressive strength, demonstrating no appreciable change. Based on the graph (Fig. 1a), the addition of 1.0 to 1.5% fiber led to a drop in strength. Figure 1b demonstrates that the addition of 0.5 to 1.0% fibers to a concrete mixture containing 10 to 20% glass powder as a cement substitute increased the 28-day compressive strength. However, a drop in 28-day compressive

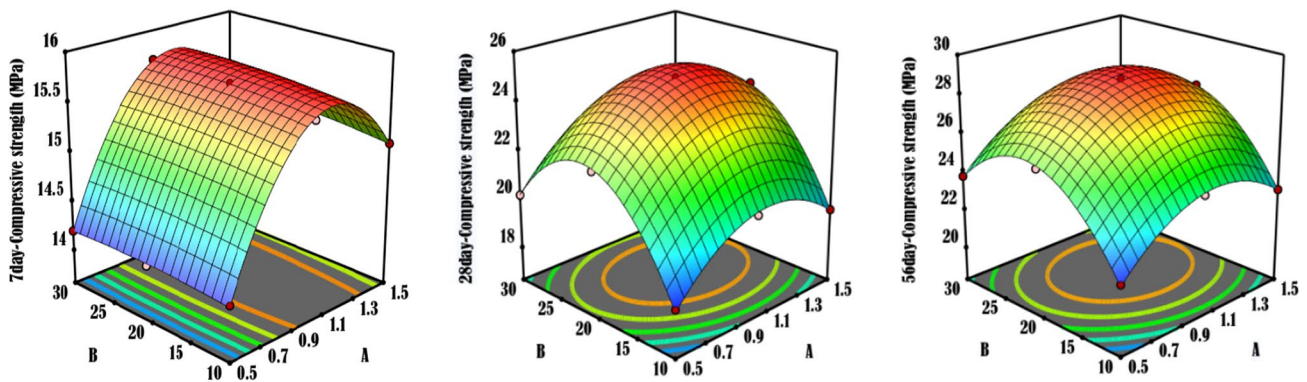


Fig. 1 Surface plot for compressive strength of concrete after curing periods of, a 7 days, b 28 days, and c 56 days

strength was seen when 1.0–1.5% of the fiber was replaced with 20–30% cement (Fig. 1b). Equally, the addition of 0.5 to 1.0% fibers to a concrete mixture containing 10 to 20% glass powder as a cement substitute provoked an increase in compressive strength after 28 days. In contrast, a decrease in 56-day compressive strength was seen when 1.0–1.5% of the fiber was replaced with 20–30% cement (Fig. 1c). The boost in strength with fiber proportions between 0.5% and 1.0% is attributable to the fiber's resistance to fracture propagation and the matrix's improved bond strength [46]. Cheng et al. [47] linked the increase in compressive strength of fiber-reinforced concrete to the fiber's capacity to bridge cracks owing to a reduction in lateral expansion during compressive deformation.

Several experiments involving the use of natural fibers into concrete and mortar formulations have produced contradictory results. In their experiment, Ademati et al. [40] noticed a gradual increase in compressive strength between 0.5 and 1.5% banana fiber intake. The inclusion of jute fibers in the range of 0.1 to 0.4% by weight was observed to increase the compressive strength of concrete mixes by Gupta et al. [48]. When applied between 0.1 and 0.3 wt%, the fiber displayed a 6.5–12.4% appreciation in compressive strength compared to the reference mixture. According to Syed et al. [49], a coir fiber content between 0.6 and 1.2% increases the compressive strength of the produced composite. Azevedo et al. [50], who added Curaua fiber in mortar at 1, 2, and 3 wt%, also mention the enhancement of the compressive strength of cement composites in the presence of natural fibers even as Islam and Ahmed [51] realized that inclusion of 0.25, 0.5, 0.75, and 1.00 wt% of jute fiber into a cement composite improved its strength.

In Fig. 1a and b stand for banana fiber and percentage glass powder replacement of cement respectively.

Bheel et al. [52] relate the decrease in strength between 0.5% and 1.5% fiber to the larger voids associated with natural fibers. Natural fibers are known to have surface porosity; consequently, when the quantity of natural fibers in a concrete mixture increases, the fiber micropores increase, resulting in a decrease in compaction and strength. In addition to fiber agglomeration leading to stress concentration [32], fiber agglomeration at a fiber content of 1.0–1.5 wt% in the concrete mix contributes to the loss of strength.

The increase in strength with 10–20% cement replacement by glass powder is attributed to the pozzolan capability of the powder. Glass powder consists mostly of silica and alumina and undergoes pozzolanic reaction with hydrated lime in the presence of water to produce calcium silicate hydrate and/or calcium aluminate hydrate, which considerably contributed to the enhancement of compressive strength.

In accordance with our findings, Sakale et al. [53] used glass powder as a partial cement replacement in the proportions of 10, 20, 30, and 40% in concrete, achieving a 20.9%

increase in compressive strength at 20% cement replacement. Similarly, Olofinnade et al. [54] proved that replacing 20% of the cement with glass powder increased the strength of the concrete to its maximum. Ayegbokiki et al. [55] and Zanwar and Patil [56] observed a probable increase in peak strength at 20% replacement. The accomplishment depends on the pozzolanic potential inherent in the glass powder used.

In Fig. 1b, c, cement substitution over 20% resulted in a decrease in strength owing to an increase in silica and alumina content (produced from glass powder). High levels of glass powder in concrete have been observed to reduce the workability of the mixture, leading to segregation [57]. In addition, the larger volume percentage of fiber and glass powder reduces the blend's workability, resulting in segregation. The result is nonuniformity and unequal dispersion of additives, resulting in weakened matrix bonds. According to Ahmad et al. [58], a greater fraction of glass powder results in a greater alkali–silicate reaction (ASR) based on the presence of excess silica content that did not undergo pozzolanic reaction. This increases the possibility that an alkali–silica reaction (ASR) will result in ASR expansion which is detrimental to the compressive strengths.

In the research, the 7-day, 28-day, and 56-day maximum compressive strengths are 15.7, 24.6, and 27.5 MPa, providing 8.3, 18.3, and 14.2% over the reference mixtures, respectively. The surface plots analyzed in the present report demonstrated that the compressive strength depends on the interplay of the two input factors.

Contour plot

Figure 2a, b, and c's contour plots for compressive strength of the concrete reveal that varied combinations of the input factors (banana fiber and glass powder) produced a range of compressive strength values [59]. In the majority of report on contour plots, the optimal response area and variable combination are the focal point [59, 60]. A, B, and C correspond to the zones in the figures for maximizing the compressive strength of the concrete after 7, 28, and 56 days of curing. Based on the graph, optimal 7-day compressive strength in the range of 15.5 to 16.0 MPa may be achieved by including 0.8 to 1.48% banana fiber and 10 to 30% glass powder into the concrete mix. Optimizing compressive strength at 28 days is in the range of 24 to 26 MPa with the addition of 0.7 to 1.47% banana fiber in the presence of glass powder at 15.6 to 27.4 percent cement replacement. Lastly, the range 26–30 MPa for 56-day compressive strength is achievable between 0.7% and 1.4% banana fiber in the presence of glass powder at 16.4% to 27.1% cement replacement.

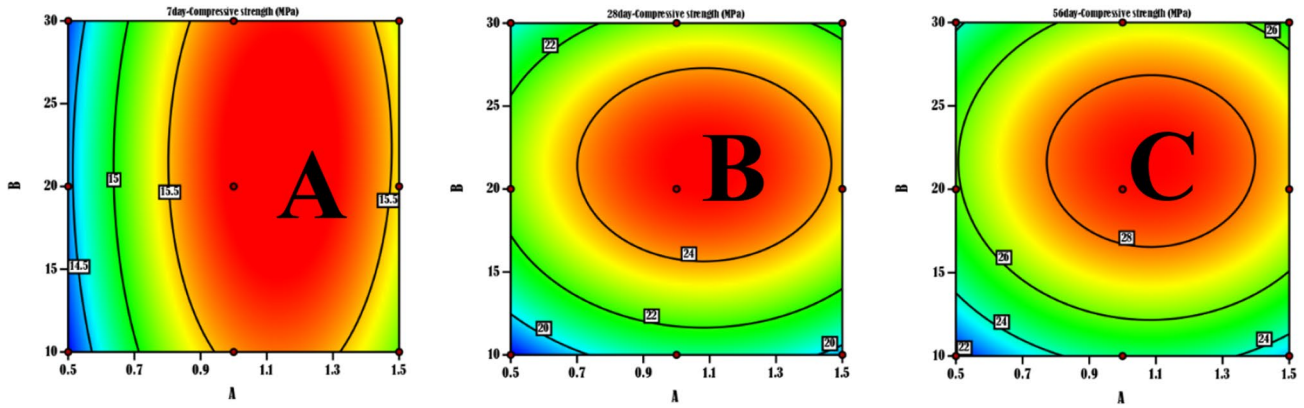


Fig. 2 Contour plot for the compressive strength at curing ages of, **a** 7 days, **b** 28 days, and **c** 56 days

Optimal values

In obtaining the optimum combination mix for strength optimization at 7-, 28-, and 56-day curing of the concrete, the responses were set at maximum in the numerical optimization, while the same level of importance was maintained as effected in [60]. The best combination predicted for optimum compressive strength for the respective curing periods is 1.01068% banana fiber and 17.3952% cement replacement for 7-day curing period, 1.0875% banana fiber and 20.75% cement replacement for 28-day curing period, and 1.0375% banana fiber and 21.75% cement replacement for 56-day curing period. The predicted strength values are 15.8599, 25.0703, and 28.8083 MPa for 7-, 28-, and 56-day curing periods, respectively (see optimization ramp in Fig. 3). In confirming the predicted combination and values, experimentation was carried out at proportions of 1.0% banana fiber and 17.4% cement replacement for 7-day curing period, 1.1% banana fiber and 20.8% cement replacement for 28-day curing period, and 1.0% banana fiber and 21.8% cement replacement for 56-day curing period. Three samples were prepared for each mix and tested for compressive strength. Values of 16.1, 25.4, and 29.9 MPa were obtained for the respective days, and the variation between the experimental values and the predicted values in each case is less than 5%. By this therefore, the best combination for optimum strength values is 1.0% banana fiber at 17.4% cement replacement, 1.1% banana fiber at 20.8% cement replacement, and 1.0% banana fiber at 21.8% cement replacement for 7-, 28-, and 56-day periods, respectively. Equally, the developed models are certified fit to predict the strength values at the respective days within the confine of the experimental conditions. In comparison with the reference concrete, the optimized concrete samples yielded 11.0, 22.1, and 27.0% over the reference mix at the respective curing periods.

Validation of models

The discrepancy between the anticipated values (by the model equations) and the actual values is shown in Table 6 (as obtained in experiment). The variance values are less than 5% for each run order and for all curing periods, indicating that the models are well suited for forecasting compressive strength for the various days (with a confidence level of 95%).

AV and PV are defined as actual and predicted values, respectively.

Conclusion

In this investigation, glass powder was used to partially replace cement at replacement rates of 10, 20, and 30%, while banana fiber was added at replacement rates of 0.5, 1.0, and 1.5% for fine aggregate. For modeling and optimization objectives, 7-day, 28-day, and 56-day compressive strength was evaluated, and experimental data were subjected to response surface analysis. The following conclusions were arrived at:

1. The analysis of variance revealed that fiber had a substantial impact on compressive strength for all curing durations, whereas the contribution of glass powder was negligible after 7 days of curing but significant after 28 and 56 days.
2. The constructed mathematical models were considered suitable for predicting compressive strength, while the surface plots illustrated the responses' dependence on the manner in which the two input variables interacted.
3. The optimal combination for optimal strength values is 1.0% banana fiber at 17.4% cement replacement, 1.1%

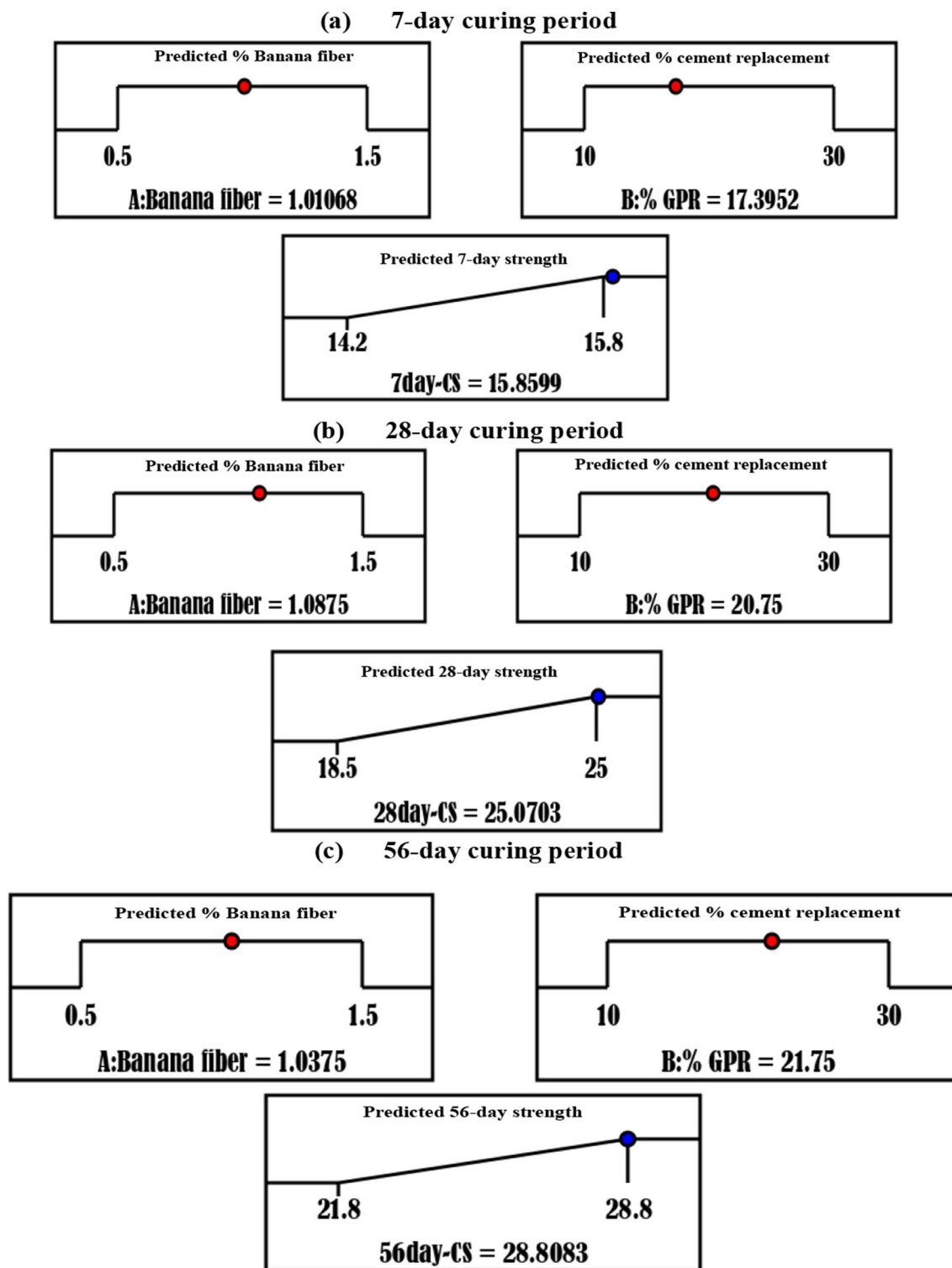


Fig. 3 Optimization plot for compressive strength at curing periods of, a 7 days, b 28 days, and c 56 days

banana fiber at 20.8% cement replacement, and 1.0% banana fiber at 21.0% cement replacement for 7-, 28-, and 56-day periods, respectively.

Conclusively, response surface method is capable of optimizing the process variables and modeling the responses for future prediction. Future research may involve the use of other forms of pozzolan and other natural fibers.

Table 6 Obtained errors between the predicted and actual values for the responses

Run order	7-day compressive strength (MPa)			28-day compressive strength (MPa)			56-day compressive strength (MPa)		
	AV	PV	Error (%)	AV	PV	Error (%)	AV	PV	Error (%)
1	14.20	14.19	0.07	18.50	18.39	0.60	21.80	21.70	0.46
2	15.60	15.57	0.19	20.70	20.83	- 0.62	24.40	24.51	- 0.45
3	15.10	15.14	- 0.26	19.60	19.57	0.15	23.10	23.09	0.04
4	14.40	14.43	- 0.21	22.40	22.50	- 0.44	25.70	25.84	- 0.54
5	15.80	15.83	- 0.19	25.00	24.97	0.12	28.80	28.68	0.42
6	15.50	15.43	0.45	23.80	23.73	0.29	27.30	27.28	0.07
7	14.30	14.27	0.21	20.20	20.21	- 0.05	23.80	23.75	0.21
8	15.70	15.70	0.00	22.80	22.70	0.44	26.60	26.61	- 0.04
9	15.30	15.32	- 0.13	21.40	21.49	- 0.42	25.20	25.24	- 0.16

Declarations

Conflict of interest The authors declare no competing interest that may affect the publication or readership of this work.

Ethical approval Not applicable.

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