Hindawi
Journal of Engineering
Volume 2023, Article ID 6237122, 13 pages
https://doi.org/10.1155/2023/6237122

Research Article

Optimization of Concrete Containing Polyethylene Terephthalate Powder and Rice Husk Ash Using Response Surface Methodology

Temitope F. Awolusi,[1] **Daniel O. Oguntayo**,[2,3] **Oluwasegun J. Aladegboye**,[2,3] **Marc Azab**,[4] **and Ahmed F. Deifalla**[5]

[1]*Department of Civil Engineering, Afe Babalola University, Ado Ekiti, Ekiti State, Nigeria*
[2]*Landmark University SDG 11 (Sustainable Cities and Communities Research Group), Omu-Aran, Nigeria*
[3]*Department of Civil Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria*
[4]*College of Engineering and Technology, American University of the Middle East, Egaila 54200, Kuwait*
[5]*Structural Engineering and Construction Management Department, Future University in Egypt, New Cairo 11835, Egypt*

Correspondence should be addressed to Temitope F. Awolusi; awolusitf@abuad.edu.ng

Received 14 December 2022; Revised 10 January 2023; Accepted 27 January 2023; Published 10 February 2023

Academic Editor: Claudio Mazzotti

The continuous increase in population, advancement in technology, and affluence have influenced the amount of biodegradable and nonbiodegradable waste generated. Studies have shown that the utilization of different wastes in concrete is imperative to reduce the long-term environmental problems associated with their handling and management. This study evaluates the performance of concrete incorporating polyethene terephthalate powder (PETp) and rice husk ash (RHA) as supplementary cementitious materials varied at 0%, 7.5%, and 15%. Results indicated that the presence of PETp reduces workability while increasing the content of both PETp and RHA decreased the compressive and flexural strengths. A few studies have demonstrated the prediction and optimization of PETp as a fine aggregate. This study explores the central composite design of response surface methodology in optimizing the fresh and hardened properties of concrete incorporating PETp and RHA. The results indicate that workable concrete can be achieved with an RHA content higher than the PETp content. The analysis of variance provided effective models with good prediction capabilities. The simulated values from the models were close to those obtained experimentally. An optimal percentage of 5.76% PETp and 9.45% RHA was obtained for predicted responses and validated with a good level of accuracy. An overview of the different combinations of RHA and PETp indicates that concrete incorporating only RHA had the tendency to absorb the least water and exhibit low voids. However, the combination of 7.5% RHA and 7.5% PETp had a reduced water absorption when compared with a concrete mix containing 15% of either supplementary cementitious material. In general, eco-friendly concrete with improved durability can be produced by incorporating PETp and RHA.

1. Introduction

The change in taste and fashion style occasioned by an improved standard of living is closely related to the change in technology. Industries are mandated to adapt to consumer demand as most processed goods are packaged in polyethene terephthalate (PET) bottles instead of glass bottles due to the fragile nature of glass. PET packaged products are cheaper and easy to handle, which presents an advantage to both producers and consumers. The growth in world population and urbanisation, driven by technological innovation, has resulted in an increased quantity of solid waste [1]. Millions of metric tons of PET are generated annually across the globe since PET bottles are widely accepted means of packaging. Generally, the use of plastic products presents the advantages of versatility, hardness, lightness, and resistance to water and chemical penetration [2]. The disposal of this product constitutes litter in urban and rural areas in developing countries such as Nigeria. The country currently does not have landfills to accommodate this nonbiodegradable waste which spread all over the streets. During rainy seasons, plastic products usually block most drainage channels, the majority of which are PET bottles. Recycling and reusing PET bottles is imperative to reduce long-term environmental problems associated with handling and management.

Numerous wastes are now incorporated into concrete due to the demand for sustainability in the construction industry [1, 3–7]. One such waste is PET bottle powder obtained from PET bottles. PET is a thermoplastic material used for food wrapping. This constitutes a significant fraction of household waste. Research in this area has found the material suitable for use as a partial replacement for fine and coarse aggregates or as shredded synthetic fibres in reinforcing concrete [4, 8–12]. As a reinforcement, PET bottles have been found to improve the mechanical and engineering properties of concrete [13]. The annual estimated usage of concrete is close to 11 billion metric tons [14]. This makes it the most commonly used construction material. The aggregates constitute about 60–80% of a concrete constituent, which is naturally sourced. PET bottle powder provides an alternative to reduce the fast depletion of natural resources. PET bottles as aggregates provide a lighter concrete when compared to conventional concrete.

Another waste found useful in concrete over time is rice husk ash obtained from rice husk. The rice husk, also known as rice hull, is a protective coating on rice grains. The husk plays a significant role in protecting rice seeds during the growing season. In the milling process, every kilogram of rice obtained results in approximately 0.28 kg of rice husk as a by-product. Rice husk is 74% organic and 26% inorganic. This material is usually hard, with silica and lignin as its major constituents. It is expected that rice production across the globe will continuously increase due to the ever-increasing population and the need to provide staple food for human survival. An increase in rice production invariably leads to an increase in the amount of rice husk produced. The estimated amount of rice produced globally is 700 million tons, of which rice husks constitute about 20% by weight of the total rice produced [15]. The rice husk is yellowish and slightly larger than the rice grain. It has a convex shape with a bulk density between 90 and 150 kg/m^3. Initially, the cheap availability and bulkiness of rice husk as an agricultural waste make the handling and management of rice husk problematic for rice producers. However, over time, rice husk as a raw material is applicable in several ways, which include the production of fertiliser, solid fuel, and insulating materials [16]. Another form of application is the incineration of rice husk to produce rice husk ash (RHA).

The incineration process of rice husk produces one-quarter of the initial quantity by weight of the husk. A ferrocement furnace can incinerate rice husk at a controlled temperature and time. Most evaporation compounds are gradually lost during incineration, leaving compounds rich in silicates. The properties of the ash produced are determined by the composition of the rice husk, the burning temperature, and the burning duration [17]. The recycled rice husk produces inorganic compounds such as silica, alumina, calcium oxide, magnesium oxide, sodium oxide, sulfur trioxide, iron oxide, silicon carbide, and potassium oxide. Silica, a significant constituent of RHA, is in two phases; one is known as amorphous silica, while the other is crystalline silica. The difference between both types of silica is the burning temperature. Controlled burning at a temperature between 500°C and 800°C produces amorphous silica, while higher burning temperatures produce crystalline silica [18]. The amorphous form of silica can be classified as pozzolana. Pozzolanas are mineral admixtures with essential compounds such as silica and alumina [19]. Pozzolanas can be used as a supplementary cementitious material in concrete; however, their finely divided form possesses no cementitious properties but produces compounds with cementitious properties in the presence of water. RHA is usually combined in suitable proportions as a supplementary cementitious material to produce eco-friendly concrete [20]. According to Sandhu and Siddique [19], RHA can positively influence the strength and durability properties of concrete at a percentage replacement of cement between 10 and 15%. Hainin et al. [20] have also reported excellent performance and strength by incorporating RHA as one of the mineral admixtures in producing concrete pavement.

In a recent report by Kim et al. [21]; milling PET into a powder has been found to display amorphous humps. The findings of this study will further broaden the applicability of PET in construction to promote eco-friendly concrete. The usage of PETp as a partial replacement for aggregate and RHA as a partial replacement for cement in concrete is widely known. However, there is a paucity of literature on the use of PETp as a supplementary cementitious material as well as the combined effect of PET powder and RHA on concrete performance. The study evaluates the combined effect of varying percentages of PETp and RHA as supplementary cementitious materials on concrete's fresh, mechanical, and durability properties. The study is aimed at obtaining the maximum utilization of RHA and PETp without compromising the strength of concrete. It is therefore essential to determine the percentage at which these materials can be incorporated into the concrete mix. Furthermore, there is a need to establish a relationship between both supplementary cementitious materials and the strength of the concrete. In order to achieve this, we use response surface methodology (RSM), which has been known to be an excellent tool for understanding the relationship between input variables and desired outputs [1, 22]. The relationship between the input factors (independent/input variables) and the desired outputs (dependent variables/response) can be achieved with a minimum number of experiments [23]. The multiresponse technique of RSM plays a significant role in optimizing the proportion of concrete constituents [25]. This tool, which employs both mathematical and statistical means of evaluating a system to improve and optimize the process, has been explored in this study. Previous researchers have studied the effects of RHA and PETp in concrete separately [19, 21]. The current study explores RSM in evaluating the combined effect of RHA and PETp on the fresh and hardened properties of concrete by obtaining predictive equations for the response and optimizing the percentage of both variables, which is unique when compared to earlier research.

2. Materials, Methods, and Testing

2.1. Materials. The grade 42.5 brand of portland limestone cement (PLC) manufactured by Danaoge Plc was purchased at a local market in Omu-Aran. The fine aggregate was river sand sourced from a nearby river close to the Landmark University campus, Omu-Aran. The coarse aggregate was crushed rock passing through a sieve with a size of 10 mm purchased from a local quarry in Omu-Aran town. Rice husk was obtained from Landmark University's farm. The rice husk was burned in an oven until it turned into ashes. The PETp powder were obtained from PET bottles, readily available in Landmark's waste bins and on the streets of Landmark University. The PET bottles were appropriately rinsed and sun-dried. After drying, the bottles were subjected to heat for conversion to liquid. The melted PETp was allowed to cool and afterwards milled to powder in the geotechnics laboratory, Landmark University, Omu-Aran, Kwara State, using a Los Angeles abrasion machine. The four stages involved in the conversion process of PET bottle to powder are presented in Figure 1. Lastly, Potable water available at the Landmark University concrete laboratory was used for mixing and curing of concrete.

2.2. Sample Preparation. The mixing was carried out manually with a shovel and a hand trowel. The required constituents for each experimental run is presented in Table 1. In the initial phase, fine aggregates, coarse aggregates, cementitious materials, and additives were first mixed in dry conditions to achieve a uniform blend. The water mixed with the superplasticizer was added to the mix to improve the workability. The mixture was manually blended again until a homogenous and workable mix was achieved. Following the completion of the mixing process, the slump was determined, and the freshly prepared concrete was filled in the appropriate mould. Figure 2 is a diagram illustrating the mixing process.

2.3. Laboratory Investigation

2.3.1. Workability. A slump cone with a bottom diameter of 200 mm, a top diameter of 100 mm, and a height of 300 mm was used to measure the workability. The test was conducted according to BS EN 12350-2, [26]. Three layers of concrete were added, and each layer was tamped with a tampering rod about twenty-five (25) times (the tampering rod is a steel of 16 mm diameter and 600 mm long). Using a hand trowel, extra concrete was removed after filling the third layer. Immediately, the mould was progressively lifted in a vertical direction. The mould height and the tested specimen's highest point were measured, and the slump was expressed in millimeters (mm).

2.3.2. Compressive Strength. According to [27], the compressive strength test was performed after 28 days. For cylindrical specimens measuring 100 mm by 200 mm, the strength was assessed using a control compression machine with a load capacity of 2000 kN. The average of three specimens per test run was used to calculate the results. Using equation (1), the compressive strength was estimated.

$$F_c = \frac{P}{A_c}, \tag{1}$$

where F_c = Compressive strength P = Maximum load at failure A_c = Cross sectional area.

2.3.3. Flexural Strength. At 28 days after casting, a three-point flexural strength test in accordance with [28] was conducted. The top of the (100 mm by 200 mm by 50 mm) prism specimens was marked on a centre line using a black felt-tip marker parallel to their length. The test subjects were supported over a 160 mm span as they were subjected to a central line load. A universal test device with a load capacity of 50 kN and a displacement rate of 0.10 mm/min was employed for this test. In order to calculate the flexural strength, equation (2) was employed.

$$F_s = \frac{3pl}{bd^2}, \tag{2}$$

where F_c = Flexural strength P = Maximum load at failure A_c = Cross sectional area.

2.3.4. Permeable Voids and Water Absorption. According to [29], the permeable voids and water absorption tests were performed to evaluate the concrete's water permeability properties. Three 100 by 200 by 50 mm prism specimens were cured in water for 28 days prior to this test. The saturated specimens' surfaces were dried by wiping away surface moisture with a towel, and the weight was calculated (W_{28}). In order to attain a constant weight, the surface-dried specimens were then further dried in an oven at a constant temperature of 105 ± 5°C (W_{od}). Equation (3) provides the fraction of the permeable void.

$$\text{Permeable voids} = \frac{W_{28} - W_{od}}{V} \times 100, \tag{3}$$

where V is the volume of the prism specimen.

Afterwards, the oven-dried specimens were fully submerged in water to conduct the initial surface absorption (ISA) and final water absorption (FWA) tests. At 30 minutes and 96 hours, the specimens were taken out of the water immersion and weighed to determine how much mass had been gained for the ISA and FWA, respectively. Equations (4) and (5) were used to calculate the values for the ISA and FWA.

$$\text{ISA} = \frac{W_{30\,\text{min}} - W_{od}}{W_{od}} \times 100, \tag{4}$$

$$\text{FWA} = \frac{W_{96\text{hours}} - W_{od}}{W_{od}} \times 100, \tag{5}$$

Figure 1: Conversion process of PET bottles to powder.

Table 1: Mix proportion for experimental run.

Run no	RHA (%)	PETp (%)	PLC (kg/m^3)	RHA (kg/m^3)	PET (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	Superplasticizer (kg/m^3)
1	0	0	750	0	0	990	660	188	12.75
2	7.5	0	694	56	0	990	660	188	12.75
3	15	0	638	113	0	990	660	188	12.75
4	0	7.5	694	0	56	990	660	188	12.75
5	7.5	7.5	638	56	56	990	660	188	12.75
6	15	7.5	581	113	56	990	660	188	12.75
7	0	15	638	0	113	990	660	188	12.75
8	7.5	15	581	56	113	990	660	188	12.75
9	15	15	525	113	113	990	660	188	12.75

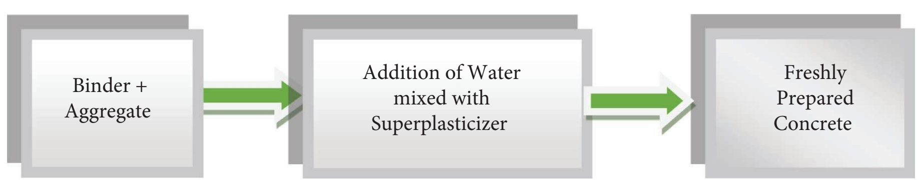

Figure 2: Mixing procedure for concrete.

where $W_{30\text{min}}$ is the weight of the surface-dried specimen after 30 min of immersion, and $W_{96\text{h}}$ is the weight of the surface-dried specimen after 96 h of immersion.

2.4. Response Surface Methodology. Over time, RSM has been a dependable tool for most prediction and optimization processes [23]. It comprises of mathematical and statistical tools that evaluate the influence of input variables on desired responses [1]. The central composite design (CCD) of RSM was used to analyze the experiment results. The different percentages of RHA and PETp simultaneously varied at 0% (low level), 7.5% (mid-level), and 15% (high level) were considered input variables. Details of the various combinations of RHA and PETp are presented in Table 1. The desired responses considered for analysis are slump, compressive, and flexural strengths.

3. Results and Discussions

3.1. Workability of Concrete. The workability of the concrete mix containing varying percentages of PETp and RHA was evaluated by a slump test. The results obtained are presented in Figure 3. From this figure, it was observed that run number 1 with neither PETp nor RHA had a lower slump value of 42 mm compared to the 48 mm obtained for run number 2 containing 7.5% RHA and 0% PETp. Moreover, as seen in Figure 4, there was an increase in the slump as RHA increased. This implies that the workability of the concrete can be enhanced by the presence of RHA. This agrees with Safiuddin et al. [18]. The study has reported an increase in slump flow with an increase in the percentage of RHA. Furthermore, run number 4, with 7.5% PETp and 0% RHA, had a slump value close to that obtained in run number 1. Figure 4 shows a slight increase in the slump as PETp increases to 7.5% and a further decrease as PETp increases. From the above-given results, it could be inferred that the presence of PET powder reduces the workability of the concrete. Umasabor and Daniel [4] also observed a decrease in slump value with an increase in PET content. The low workability could be attributed to the inability of PETp to absorb excess water. However, with an equal percentage of 7.5% for RHA and PETp, a slump value of 50 mm was observed for run number 5. A slight increase in slump was

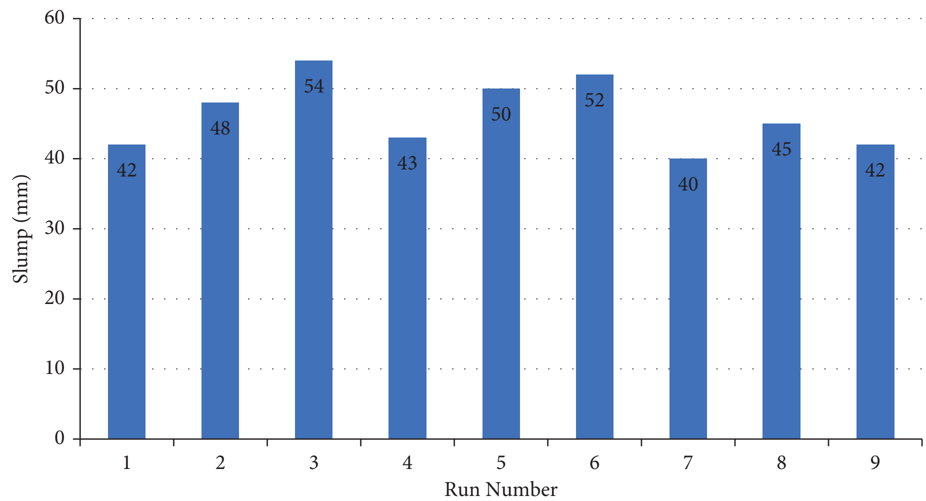

FIGURE 3: Slump properties of RHA and PETp-modified concrete.

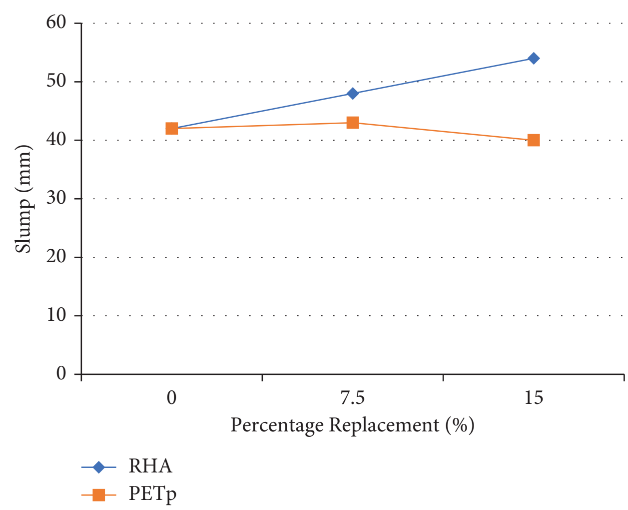

FIGURE 4: Effects of RHA and PETp on the slump.

also observed for run number 6, with RHA increased to 15% combined with a PETp of 7.5%. It was generally observed that the reduced workability experienced by incorporating PETp in the concrete mix could be reduced with the presence of RHA. This may be attributed to the ability of the RHA particle to absorb the excess water, which the PETp could not absorb.

3.2. Mechanical Properties. The mechanical properties were evaluated using compressive and flexural strengths. The compressive and flexural strength values obtained ranged from 15 to 24 N/mm^2 and 1.4 to 2.8 N/mm^2, respectively, as presented in Figure 5. The compressive and flexural strengths for run number 2 with a concrete mix containing 7.5% RHA were slightly lower than those for run number 1 (conventional mix). The strength values reduced further when the percentage of RHA was increased to 15%, as observed in run number 3. Figures 6 and 7 present the effects of PETp and RHA on the concrete strengths. It was observed that there was a strength decrease as the PETp and RHA increased, the strengths obtained for RHA were higher than that of PETp, indicating that incorporating RHA is preferable to PETp when strength is desired. However, a concrete mix containing a combination of RHA and PETp gave improved strength values over the mix with only 7.5% PETp. A similar trend was observed for other combinations of RHA and PETp. This could be attributed to the improved bonding of the PETp concrete mix with the incorporation of RHA. Previous research by Nadimalla et al. [10] attributed reduced compressive and flexural strengths to the weak bonding of PET bottles with other concrete constituents.

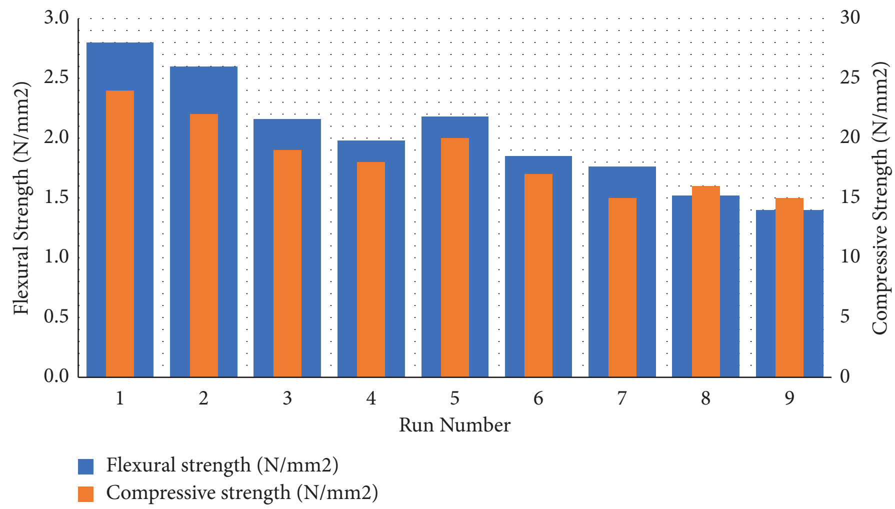

Figure 5: Flexural strength and compressive strength of RHA and PETp-modified concrete.

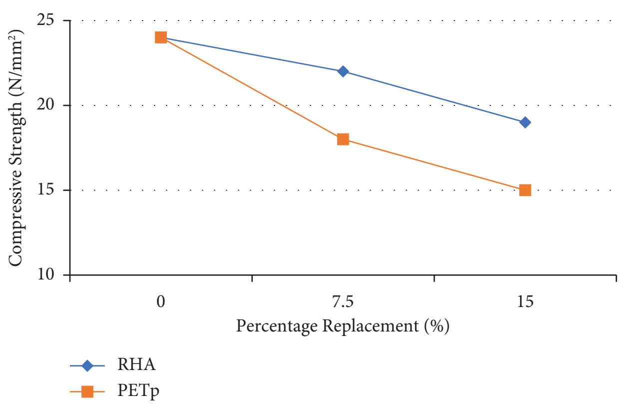

Figure 6: Effects of RHA and PETp on the compressive strength.

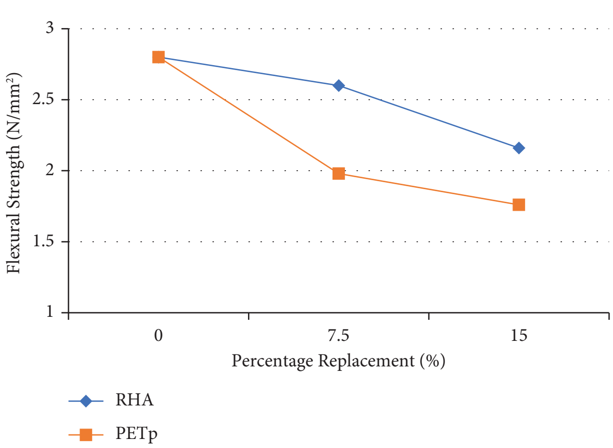

Figure 7: Effects of RHA and PETp on the flexural strength.

Generally, it was observed that the performance of concrete containing PETp could be enhanced by incorporating RHA in the concrete mix.

3.3. The Fresh and Mechanical Properties Analyzed Using Response Surface Methodology. The response surface methodology has proven to be a reliable tool for understanding the behaviour of composite materials [1, 23]. It has the capability of improving desired outputs by providing mathematical models and optimizing the required inputs and outputs. The input factors are regarded as the independent variables that influence the responses. The RHA and PETp were incorporated into the mix as independent variables in the combination presented in Table 1, while the slump, compressive, and flexural strengths are the dependent variables. The analysis of the variables was done using the CCD of RSM. The CCD evaluated the influence of RHA and PET over the responses as presented in Tables 2–5. The model equations obtained for each response in actual terms are presented in Table 2. The model predictions and the experimentally obtained results are presented in Table 3. The results obtained from the simulation were close to those obtained from the laboratory. This signifies the models ability to navigate the design space. The Analysis of Variance (ANOVA) is presented in Table 4. ANOVA was done to determine the level of significance of the model and model terms. Terms with p values less than 0.05 signify the influence of the model and model terms [1, 23]. The model p values of 0.020914, 0.015553, and 0.033172 were obtained for the slump, compressive strength, and flexural strength, respectively. As observed, these values were less than 0.05 which signifies a 95% confidence level. The f-values of 16.88852, 20.78734, and 12.15873 for the slump, compressive strength, and flexural strength, respectively, also reveal the significance of the model. The models for all responses were examined statistically, and the results are presented in Table 5. The coefficient of determination (R^2) is used to determine how perfectly the input variables can influence changes in the calculated response. According to Chaliha et al. [24], R squared is considered to determine the level of model accuracy. The R^2 values of 0.9657, 0.9719, and 0.9530 obtained for the slump, compressive strength, and flexural strength, respectively, were closer to 1. This high value shows

Table 2: Mathematical equations of the responses.

Response	Constant	A	B	AB	A^2	B^2
Slump (mm)	40.94	1.422	+0.800	−0.044	−0.039	−0.056
Compressive strength (N/mm^2)	+23.472	+0.0555	−0.6333	+0.0222	−0.0237	+0.00296
Flexural strength (N/mm^2)	+2.7422	−0.00556	−0.08311	+0.00124	−0.00193	+0.00065

Table 3: Real and simulated values for response.

Run	Slump (mm)		Compressive strength (N/mm^2)		Flexural strength (N/mm^2)	
	Real	Simulated	Real	Simulated	Real	Simulated
1	42	40.94	24	23.47	2.8	2.74
2	48	49.44	22	22.56	2.6	2.59
3	54	53.61	19	18.97	2.16	2.23
4	43	43.78	18	18.89	1.98	2.16
5	50	49.78	20	19.22	2.18	2.07
6	52	51.44	17	16.89	1.85	1.78
7	40	40.28	15	14.64	1.76	1.64
8	45	43.78	16	16.22	1.52	1.63
9	42	42.94	15	15.14	1.40	1.40

Table 4: Results of ANOVA.

Source	DF	Slump (mm)			Compressive strength (N/mm^2)			Flexural strength (N/mm^2)		
		SS	F value	p value	SS	F value	p value	SS	F value	p value
Model	5	190.778	16.88852	0.020914	76.02778	20.78734	0.015553	1.640978	12.15873	0.033172
A	1	88.166	39.02459	0.008275	6	8.202532	0.064365	0.212817	7.884262	0.06741
B	1	48.167	21.31967	0.019117	60.16667	82.25316	0.002832	1.3824	51.21405	0.005619
AB	1	25	11.06557	0.044836	6.25	8.544304	0.061344	0.0196	0.726125	0.456764
A^2	1	9.388	4.155738	0.134232	3.555556	4.860759	0.114666	0.023472	0.86958	0.41986
B^2	1	20.055	8.877049	0.058623	0.055556	0.075949	0.800756	0.002689	0.099616	0.772974
Residual	3	6.77778			2.194444			0.080978		

A-RHA; B-PET; SS: sum of squares; DF: degrees of freedom.

Table 5: Summary of ANOVA results of responses.

Response	Slump (mm)	Compressive strength (N/mm^2)	Flexural strength (N/mm^2)
R^2	0.9657	0.9719	0.9530
Adjusted R^2	0.9085	0.9252	0.8746
SD	1.50	0.8553	0.1643
Mean	46.22	18.44	2.03
CV (%)	3.25	4.64	8.10
Adequate precision	10.8643	12.649	9.9643

that the obtained models are in good agreement with the experimental results [25]. It could be inferred from the above values that at least 97% of the estimated data can be interpreted by the obtained model. This signifies the applicability of the RSM approach in effectively predicting the response considered in this study. For the model's suitability to be examined, Figures 8–10 display the plot of predicted versus actual values. The distribution of data indicates that the majority of the points were located close to the 45-degree linear line [30]. The plot also suggests that the normally distributed residuals in the models and the degree of random errors are similar for the fitted values [23]. The adequate precision is a statistical tool that estimates the signal-to-noise, which determines the magnitude of simulated outcomes compared to the average simulation of the residual at design points. The adequate precision values observed for the slump, compressive strength, and flexural strength were 10.86, 12.65, and 9.96, respectively. According to Aldahdooh et al. [25], adequate precision values greater than 4 indicate that the predicted models are desirable and can be optimized. Furthermore, it validates the applicability of the model and the credibility of the ANOVA [31].

The relationships between the independent variables and the responses are presented by the response surface plot

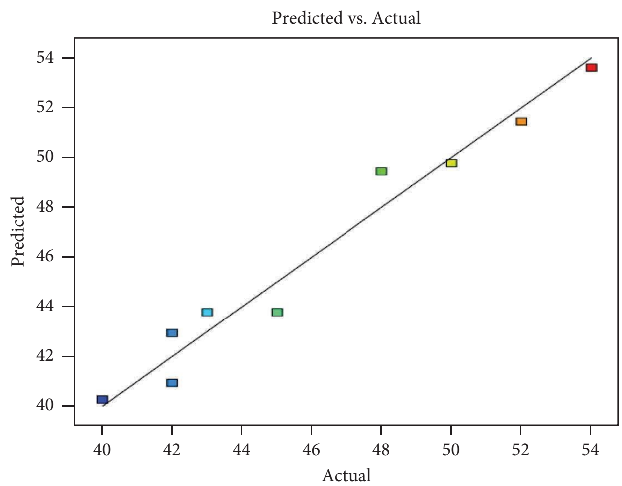

Figure 8: Simulated and actual outcome for slump.

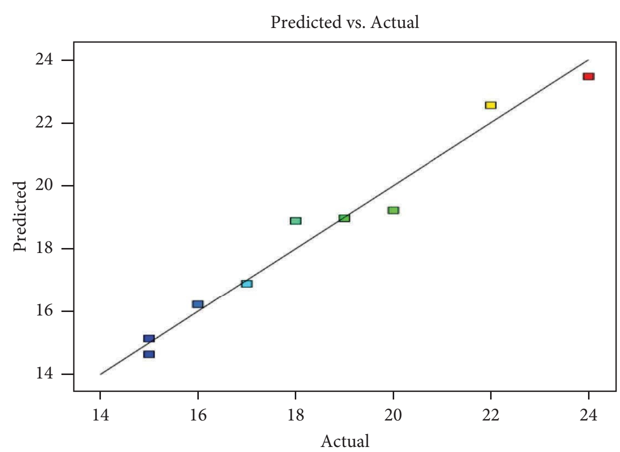

Figure 9: Simulated and actual outcome for compressive strength.

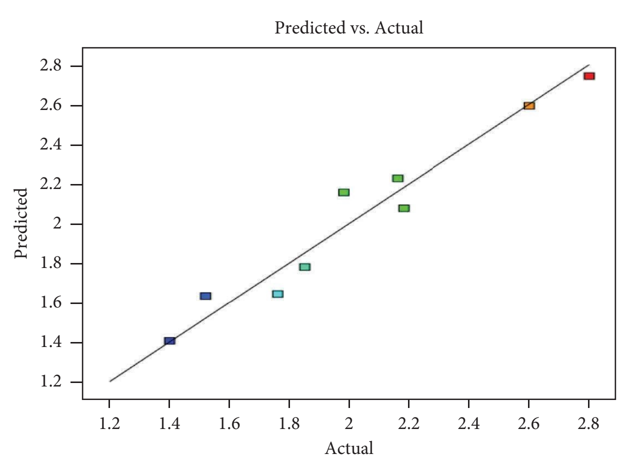

Figure 10: Simulated and actual outcome for flexural strength.

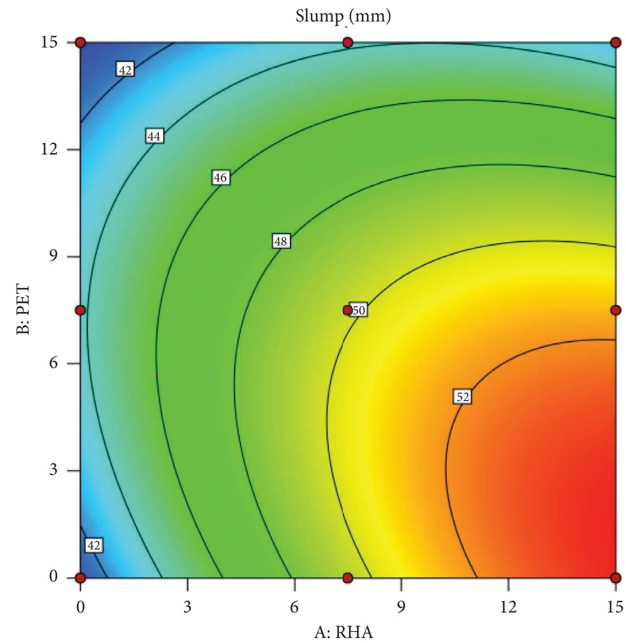

Figure 11: Response surface plot for slump.

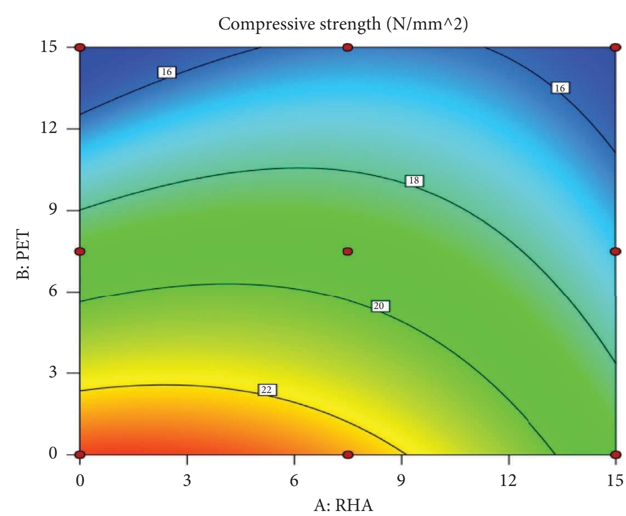

Figure 12: Response surface plot for compressive strength.

figures. These two-dimensional (2D) plots are displayed in Figures 11–13. The 2D plot for slump (Figure 11) shows that the slump value increases with the addition of PETp until a maximum value is observed between 6% and 9%, and further additions demonstrate a decrease in a slump. Likewise, the study of Umasabor and Daniel [4] observed decreasing slump value for increasing the content of PETp from 0 to 15%. On the other hand, increased slump values were observed with increased RHA from 0% to 15%. Safiuddin et al. [18] noticed an increase in a slump with the incorporation of 15% RHA when compared to the control. This implies that the presence of PETp reduces the concrete workability. From Figure 12, the compressive strength values were observed to be high at reduced percentages of PETp and RHA. The plot demonstrates that a minimum compressive strength value of 20 N/mm^2 can be achieved with a PETp content below 3% and a RHA of about 9%. A previous study on the use of PETp in concrete by Ramadevi and Maniu [32] indicates an increase in compressive strength up to 2% of PETp addition, while another study by Umasabor and Daniel [4] indicates a maximum of 5% addition of PETp. A study of the effect of RHA in high-performance concrete by Salas et al. The study of [33] has also reported an increase in compressive strength with the incorporation of RHA between 5% and 10% when compared with the control specimens. According to Ahmed et al. [23], concrete containing supplementary cementitious materials that are pozzolanic leads to the formation of calcium silicate hydrate (CSH) gel, which contributes to

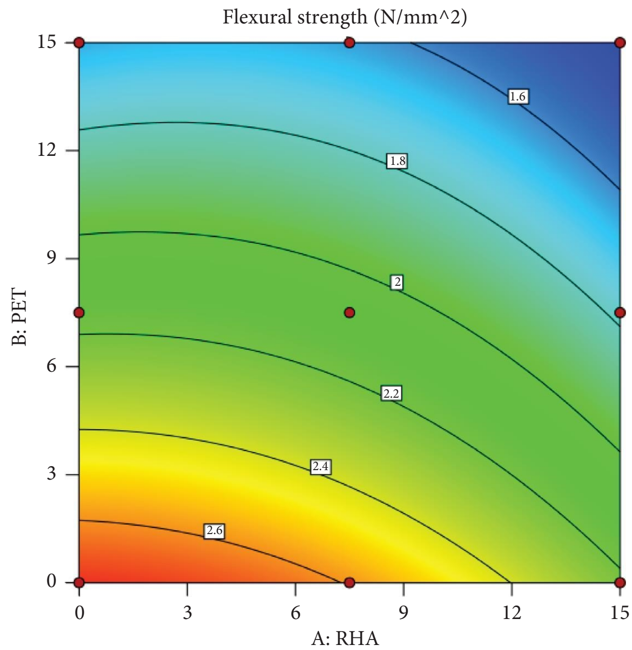

Figure 13: Response surface plot for flexural strength.

Table 6: Optimization criteria of responses and variables.

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: RHA	Maximize	0	15	1	1	3
B: PET	Maximize	0	15	1	1	3
Slump	Is in range	40	54	1	1	3
Compressive strength	Maximize	15	24	1	1	3
Flexural strength	Maximize	1.4	2.8	1	1	3

concrete strength. The plot for flexural strength (Figure 13) follows a similar trend as observed with the plot for compressive strength. The plot demonstrates that a maximum flexural strength value can be achieved with PETp content below 3% and RHA below 9%. It has been most often observed that in the absence of fiber, the flexural strength of concrete can be expressed as a fraction of the compressive strength. The present study has observed that the flexural strength is slightly less than 12% of the compressive strength at a similar combination of PETp and RHA. El-Nadourry [34] has also observed that the flexural strength of concrete containing 5% of PETp are comparable to conventional concrete. The current study has observed that a further increase in either PETp or RHA beyond 3% and 9%, respectively, reduces the mechanical properties of concrete, which may be attributed to poor adhesion between the cement and the supplementary cementitious materials [35].

3.4. Optimization and Validation of the Responses. The optimization of variables and responses was expressed in mathematical equations. The CCD of RSM was used to obtain the optimal combination of input parameters (PETp and RHA) for enhanced fresh and hardened properties of concrete. The criteria used for the optimization are presented in Table 6. RHA and PETp were set at maximum to promote maximum incorporation of both waste materials in concrete. The slump was set in range to ensure a workable concrete while the compressive and flexural strengths were set at maximum for enhanced concrete performance. From the optimization results, 5.76% PETp with 9.45% RHA were found to be the optimum percentage of input parameters. In this study, the same importance was set for both input parameters and responses. The highest desirability was observed at this condition and the predicted results were validated by experimental carry out using 5.76% PETp with 9.45% RHA. The results obtained and those of the simulated values are presented in Table 7. The closeness of both values confirms the validity of both models.

3.5. Durability Properties. The durability properties were evaluated using the initial surface absorption, final water absorption, and permeable void, as presented in Figure 14. According to Kosmatka et al. [36], concrete is of good quality when water absorption is less than 5%. This is achieved through reduced pore size, which inhibits connectivity and decreases porosity. The least and highest initial surface absorption of 0.42 and 2.09 were, respectively, observed for runs 2 and 8. A similar trend of 0.47 and 2.18 was

Table 7: Validation of the response surface model (9.45% RHA and 5.76% PET).

Response	Predicted result	Experimental result
Slump (mm)	51.26	50.0
Compressive strength (N/mm^2)	19.54	20.32
Flexural strength (N/mm^2)	2.128	2.05

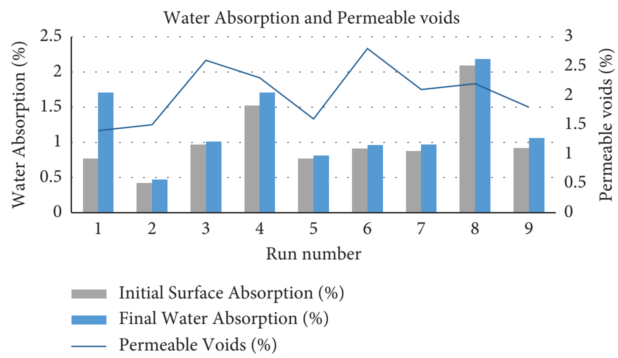

Figure 14: Effects of RHA and PETp on the permeable void and water absorption properties of concrete.

observed for the final water absorption. It was observed that the final water absorption for the conventional mix was higher than those containing SCMs with the exception of run number 8. A comparison between run number 2 with 7.5% of RHA and 0% of PETp and run number 4 with 7.5% of PETp and 0% of RHA powder indicates that the concrete mixed with RHA displayed the tendency to absorb less water and exhibit low voids. Sandhu and Siddique [19] have earlier observed that the inclusion of RHA reduces the water absorption capacity of concrete. A comparison between run number 9 incorporating a combination of 15% RHA and 15% PETp, and run number 3 with only 15% RHA, revealed a reduction in water absorption. However, the combination of 7.5% RHA and 7.5% PETp (run number 5) had a reduced water absorption when compared with a concrete mix containing either 15% of RHA or PETp (run number 3 or 7). This observation indicates a positive synergy between RHA and PETp in resisting water penetration in concrete. The least and highest permeable voids of 1.4 and 2.8 were, respectively, observed for runs 1 and 6. In general, it can be concluded that the water absorption properties and porosity are closely related. This observation agrees with Ling and Poon [37]. Choropa and Siddique [35] have attributed the reduced porosity to the pozzolanic reaction of the supplementary cementitious material.

4. Conclusions

The properties of concrete containing polyethene terephthalate powder (PETp) and rice husk ash (RHA) as supplementary cementitious materials were evaluated. The conclusions drawn are as follows:

(i) The presence of PETp reduces the workability of the concrete. The reduced workability experienced by incorporating PETp in the concrete mix can be minimized with the presence of RHA in the mix.

(ii) RSM models were promising based on the ANOVA results and model summary statistics.

(iii) The strengths obtained for the concrete mix incorporating only RHA were higher than those for PETp. However, the concrete mixes containing a combination of RHA and PETp gave improved strength values.

(iv) The slump value increases with the addition of PETp until a maximum value is observed between 6% and 9%, and further additions demonstrated a decrease in a slump. However, the slump values increased with the increase in RHA from 0% to 15%.

(v) The maximum compressive strength values of 20 N/mm^2 can be achieved with PETp content below 6% and RHA of about 9%.

(vi) The maximum flexural strength values can be achieved with a PETp content below 3% and an RHA below 9%.

(vii) The optimum condition obtained for input variables gave 5.76% PETp and 9.45% RHA to achieve a slump of 50 mm, a compressive strength of 20 N/mm^2, and flexural strength of 2 N/mm^2.

(viii) Concrete mix with RHA tends to absorb less water and exhibit low voids. However, the combination of 7.5% RHA and 7.5% PETp had a reduced water absorption when compared with a concrete mix containing 15% of either supplementary cementitious material.

Data Availability

All data generated or analysed during this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] T. F. Awolusi, O. L. Oke, O. O. Akinkurolere, and A. O. Sojobi, "Application of response surface methodology: predicting and optimizing the properties of concrete containing steel fibre extracted from waste tires with limestone powder as filler," *Case Studies in Construction Materials*, vol. 10, Article ID e00212, 2019.

[2] M. Jalaludddin, "Use of plastic waste in civil constructions and innovative decorative materials (eco-friendly)," *MOJ Civil Engineering*, vol. 3, no. 5, pp. 359–369, 2017.

[3] T. Awolusi, A. Taiwo, O. Aladegboye, D. Oguntayo, and O. Akinkurolere, "Optimisation of quinary blended supplementary cementitious material for eco-friendly paving unit using Taguchi orthogonal array design," *Materials Today Proceedings*, vol. 65, 2022.

[4] R. I. Umasabor and S. C. Daniel, "The effect of using polyethylene terephthalate as an additive on the flexural and compressive strength of concrete," *Heliyon*, vol. 6, Article ID e04700, 2020.

[5] J. K. Prusty and S. K. Patro, "Properties of fresh and hardened concrete using agro-waste as partial replacement of coarse aggregate – a review," *Construction and Building Materials*, vol. 82, pp. 101–113, 2015.

[6] B. S. Thomas, R. C. Gupta, P. Kalla, and L. Cseteneyi, "Strength, abrasion and permeation characteristics of cement concrete containing discarded rubber fine aggregates," *Construction and Building Materials*, vol. 59, pp. 204–212, 2014.

[7] M. Carsana, M. Frassoni, and L. Bertolini, "Comparison of ground waste glass with other supplementary cementitious materials," *Cement and Concrete Composites*, vol. 45, pp. 39–45, 2014.

[8] V. N. Mastan and S. S. Asadi, "PET bottle waste as a supplement to concrete fine aggregate," *International Journal of Civil Engineering & Technology*, vol. 8, no. 1, pp. 558–568, 2017.

[9] E. M. Bachtiar, M. Mustaan, F. Jumawan et al., "Examining polyethylene terephthalate (pet) as artificial coarse aggregates in concrete," *Civil Engineering Journal*, vol. 6, no. 12, pp. 2416–2424, 2020.

[10] A. Nadimalla, S. A. B. Masjuki, A. B. S. Kamsiah, B. M. Ismail, and M. B. Ali, "Polyethylene terephthalate (pet) bottles waste as fine aggregate in concrete," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, pp. 1177–1180, 2019.

[11] D. Wilinskia, P. Łukowskia, and G. Rokicki, "Application of fibres from recycled PET bottles for concrete reinforcement," *Journal of Building Chemistry*, vol. 10, no. 1, pp. 1–8, 2018.

[12] S. Shahidan, S. S. MohdZuki, F. Sheikh Khalid, A. R. M. Ridzuan, and F. M. Nazri, "Concrete incorporated with optimum percentages of recycled polyethylene terephthalate (pet) bottle fiber," *International Journal of Integrated Engineering*, vol. 10, no. 1, pp. 1–8, 2018.

[13] J. Wang, Q. Dai, R. Si, and S. Guo, "Mechanical, durability, and microstructural properties of marcro synthetic polypropylene (PP) fiber-reinforced rubber concrete," *Journal of Cleaner Production*, vol. 234, pp. 1351–1364, 2019.

[14] M. Praveen, V. Shibi, P. Thomas, and V. Eldho, "Recycled plastic as coarse aggregate for structural concrete," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 2, no. 3, 2013.

[15] M. K. Uddin and P. F. Rahaman, "A study on the potential application or rice husk derivatives as useful adsorptive material. Materials Science and Engineering," *Chapter*, vol. 4, pp. 147–186, 2017.

[16] R. Sekifuji and M. Tateda, "Study of the feasibility of rice husk recycling scheme in Japan to produce silica fertiliser for rice plant," *Sustainable Environment research*, vol. 29, no. 11, pp. 1–9, 2019.

[17] G. A. Habeeb and H. B. Mahmud, "Study on properties of rice ash and its use as cement replacement material," *Materials Research*, vol. 13, no. 2, 2010.

[18] M. Safiuddin, J. S. West, and K. A. Soudki, "Properties of freshly mixed self-consolidating concretes incorporating rice husk ash as a supplementary cementing material," *Construction and Building Materials*, vol. 30, pp. 833–842, 2012.

[19] R. K. Sandhu and R. Siddique, "Influence of rice husk ash (RHA) on the properties of self-compacting concrete: a review," *Construction and Building Materials*, vol. 153, pp. 751–764, 2017.

[20] M. R. Hainin, R. P. Jaya, T. H. Chan, N. A. Hassan, and F. M. Narri, "Strength and properties of concrete pavement incorporating multiple blended binders," *Materials Science*, vol. 889, pp. 265–269, 2017.

[21] M. O. Kim, J. K. Park, T. H. Han, J. Seo, and S. Park, "Influence of polyethylene terephthalate powder on hydration of portland cement," *Polymers*, vol. 13, no. 15, p. 2551, 2021.

[22] B. W. Chong, E. R Othman, P. R Jaya, X. Li, M. R. M. Hasan, and M. M. Abdullah, "Mata- analysis of studies on eggshell concrete using maixed regression and response surface methodology," *Journal of King Saud University - Engineering Sciences*, 2021.

[23] T. Ahmed, S. Ray, M. Haque, T. Tasnim Nahin, and M. Ferdous, "Optimization of properties of concrete prepared with waste glass aggregate and condensed milk can fber using response surface methodology," *Cleaner Engineering and Technology*, vol. 8, p. 100478, 2022.

[24] C. Chaliha, E. Kalita, and P. K. Verma, "Optimizing in vitro culture conditions for the biotrophic fungi exobasidium vexans through response surface methodology," *Indian Journal of Microbiology*, vol. 60, pp. 167–174, 2020.

[25] M. Aldahdooh, N. Muhamad Bunnori, and M. Megat Johari, "Evaluation of ultra-high-performance-fiber reinforced concrete binder content using the response surface method," *Materials and Design*, vol. 52, pp. 957–965, 2013.

[26] British Standard Institution, Bs En 12350-2, *Testing fresh concrete, Slump test*, 2009.

[27] Astm C, "Standard test method for compressive strength of hydraulic cement mortars (using portions of prisms broken in flexure)," *American Society of Testing Materials*, vol. 349, 2008.

[28] Astm C, "Standard test method for flexural strength of hydraulic-cement mortars," *American Society of Testing Materials*, vol. 348, 2008.

[29] Astm C, "Standard test method for density, absorption, and voids in hardened concrete," *American Society of Testing Materials*, vol. 642, 2006.

[30] B. S. Mohammed, L. W. Xian, S. Haruna, M. S. Liew, I. Abdulkadir, and N. A. W. A. Zawawi, "Deformation properties of rubberized engineered cementitious composites using response surface methodology," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 45, no. 2, pp. 729–740, 2021.

[31] L. Zhang and J. Zhai, "Application of response surface methodology to optimize alkaliactivated slag mortar with limestone powder and glass powder," *Structural Concrete*, vol. 22, pp. E430–E441, 2021.

[32] K. Ramadevi and R. Manju, "Experimental investigation on the properties of concrete with plastic PET fibers as fine aggregates," *International Journal of Emerging Technology Advanced Engineering*, vol. 2, no. 6, pp. 42–46, 2012.

[33] A. Salas, S. Delvasto, R. M. de Gutierrez, and D. Lange, "Comparison of two processes for treating rice husk ash for use in high performance concrete," *Cement and Concrete Research*, vol. 39, no. 9, pp. 773–778, 2009.

[34] W. El- Nadoury, "Chemically treated plastic replacing fine aggregate in structural concrete," *Frontiers*, vol. 9, 2022.

[35] I. Mallum, A. R. Abdul, N. H. A. S. Lim, and N. Omolayo, "Sustainable utilization of waste glass in concrete: a review," *Silicon*, vol. 14, 2021.

[36] S. H. Kosmatka, B Kerkhoff, W. C. Panarese, N. F. MacLeod, and R. J. McGrath, *Design and Control of Concrete Mixtures*, Cement Association of Canada Ottawa, Ontario, Canada, 2002.

[37] T. Ling and C. Poon, "Properties of architectural mortar prepared with recycled glass," *Materials and Design*, vol. 32, pp. 2675–2684, 2011.

[38] D. Chopra and R. Siddique, "Strength, permeability and microstructure of self-compacting concrete containing rice husk ash," *Biosystems Engineering*, vol. 130, pp. 72–80, 2015.