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Response surface methodology approach for optimized compressive strength of some mix design concrete aggregates from waste cockle shells and glass powder

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A B S T R A C T

Nowadays, with increased demand for aggregates for concrete and an awareness of the need of protecting natural resources, experts are becoming increasingly interested in waste material as a building material substitute. However, the compressive strength is influenced by the composition of concrete. In this study, the compressive strength of concrete under substitution using waste from cockle shells and glass was investigated using Response Surface Methodology (RSM). Central Composite Design (CCD) based on RSM was used to assess the influence of epoxy resin, cockle shells powder, and glass powder on compressive strength responses. RSM developed first-order and second-order mathematical models with findings from experimental design. Analysis of variance was used to determine the correctness of CCD's mathematical models. Desirability analysis was then employed to optimize epoxy resin, cockle shells powder, and glass powder yielding maximum compressive strength. The RSM analysis revealed that the empirical results fit well into linear and quadratic models of concrete compressive strength. The mixing components will produce cement with compressive strength in each formulation of 54.71 MPa (4.88% epoxy resin and 4.0% cockle shells powder), 47.82 MPa (6.85% epoxy resin and 8.0% glass powder), 147.0 MPa, (4% cockle shells powder and 8% glass powder), and 56.08 MPa (4.4% epoxy resin, 4.0% cockle shells powder, and 8.0% glass powder). The results confirmed that a reasonable compressive strength of concrete could be achieved using epoxy resin, cockle shells powder, and glass powder.

1. Introduction

Today, eco-friendly construction approaches are growing rapidly. Utilizing materials derived from natural sources is one method of implementing the green construction idea. Regarding this approach, a study was conducted to investigate the potential of waste from cockle shells and glass as a material for partial cement replacement or filler material (Raseela and George, 2019). However, using this material in a concrete mix must still consider its compressive strength to maintain its safety.

Compressive strength should be optimized to maximize material waste from cockle shells and glass into concrete (Mohamad et al., 2021). This is frequently accomplished through single-factor optimization, in which all possible combinations of variables are tried. Thus it requires a long time involving a large number of experiments. Planning to optimize the compressive strength of concrete mixed with waste from cockle shells and glass is important to be done properly to avoid over or under design (Jayanti et al., 2021; Sitorus et al., 2018). Nevertheless, response surface methodology (RSM) is employed as an option to optimize the compressive strength of concrete. The key objective of RSM is to uncover and detect

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the interplay between optimal parameters and statistical model development. RSM in optimization reduces the number of experiments and saves time, space, and raw materials.

RSM has been widely used for concrete optimization compressive strength of different products from various material including waste from cockle shells (Murugan et al., 2020), palm shells (Basri et al., 1999), coconut shells (Gupta et al., 2020), walnut shells (Hilal et al., 2021), plastic waste and periwinkle shells (Ede et al., 2021). Moreover, many studies have used RSM to optimize the compressive strength of concrete aggregates from much substitution material (Habibi et al., 2021; Hammoudi et al., 2019; Nematzadeh et al., 2020). This indicated that optimization of compressive strength using RSM should be employed from substitution material.

RSM is becoming prominent in research for the optimality of various procedures, including the manufacture of concrete. Software tools used in the design of experiments using RSM include Design Expert and Minitab (Habibi et al., 2021; Hammoudi et al., 2019; Nematzadeh et al., 2020). These software tools provide optimal experimental designs, regression analyses, and suitable statistical tests. RSM as a partial factorial design has been shown to minimize the number of trials required compared to the use of complete factorial design. Additionally, it is well recognized that experimenters often lack the resources and time necessary to perform complete factorial studies and hence resort to frequently utilized partial factorial designs. One may conclude that RSM results in significant cost reductions in effort, time, and money.

This research captures the compressive strength of concrete containing waste from cockle shells and glass. The unique contribution of this research is on optimization of cockle shells powder and glass powder contents establishing maximum compressive strength of concrete. The applicability of this research is demonstrated through increased compressive strength due to the inclusion of cockle shells powder and glass powder in concrete. Hence, it highlights the potential compressive strength benefits of concrete incorporated with waste from cockle shells and glass, which can encourage corporations to adopt these sustainable construction materials.

2. Materials and method

2.1 Experimental results

This study utilized the class 3 design developed by the British Research Establishment (BRE). CCD of the response surface approach was used to generate 28 experimental runs. This number of runs reflects precise optimal values and illustrative experimental data. Three designs with different levels of epoxy resin, waste cockle shells, waste glass. Waste cockle shells and waste glass are crushed into powder before mixed with cement. The physical properties of cockle shells powder and glass powder are shown in Table 1. The epoxy resin has two-level including 0 and 13%. Cockle shell powder is made with levels of 0, 0.75, 1, 1.5, 2, 2.5 3 and 4%. Glass powder is made with levels of 0.75, 1, 1.5, 2, 2.5, 3, 3.5, 4, 6, and 8%. The independent variables consisting of epoxy resin, cockle shells powder, and glass powder were introduced in the design and were represented in a coded form as A (epoxy resin), B (cockle shells powder), and C (glass powder). Responses indicated as R1 defined the compressive strength of concrete.

Table 1. Properties material of fine aggregate for concrete

Properties	Material type		Unit
	Cockle shells powder	Glass powder	
Bulk specific gravity	2.83 ± 0.0375	2.48 ± 0.0028	-
Bulk SSD specific gravity	2.84 ± 0.0255	2.50 ± 0.0007	-
Apparent specific gravity	2.86 ± 0.0028	2.54 ± 0.0064	-
Absorption	0.30 ± 0.4271	0.91 ± 0.1442	%

2.2 Experimental procedure

The experimental design for all runs was rendered using Design Expert v.12 (Trial Version). The concrete casting including waste materials (cockle shells and glass), was conducted using manual mixing. A mixing procedure has been undertaken for about 8 minutes to ensure the concrete matrix's homogeneity. Fresh concrete was placed in lubricated molds following the blending of all the constituent materials. After that, fresh concrete was compacted utilizing a poker vibrator until uniform compaction was achieved. The specimens were then left for 24 h before demolding with cylindrical molded concrete (diameter of 80 mm and height of 160 mm). After demolding, all specimens were measured using UTM.

2.3 Measurement of compressive strength

Compressive strengths measurements were conducted on 80 × 160 mm (diameter × height) cylindrical specimens following ASTM C109-11. After 7 days of cure, testing was undertaken. The compressive strength test was conducted using a 250 kN UTM RTF 1350, 0.5 kN/s. The specimens are placed between the lower plates of the UTM centrically (Fig. 1). Loading is carried out at a speed of 4-6 kg/cm^2 per second.

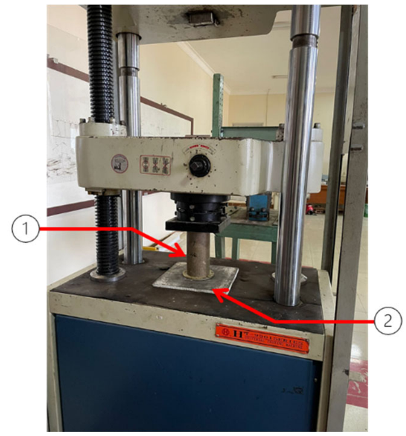


Fig. 1. Set-up for compressive strength tests (1-specimens, 2-lower plates)

2.4 Optimization by RSM

Response surface methodology (RSM) forecasted the impact, cockle shells powder, and glass powder as independent variables on compressive strength responses. It covered the optimization aspect by obtaining the optimum of compressive strength. RSM analysis may be used to determine the linear interaction and quadratic effect of independent factors on the concrete characteristics. The study optimized the combined effects of these variables in order to reduce or maximize desired results.

Data analysis will be carried out using statistical Analysis of variance (ANOVA). Data analysis was performed on compressive strength response. The reading results using ANOVA analysis include the significance of the P-value on the model, lack of fit, the difference between the R-squared adj value and the R-squared pred value, and adequate precision. After the overall response is analyzed, the compressive strength is optimized based on the factors and responses determined. Optimization is done by determining the priority scale of each factor and response. The optimization obtained is then re-verified whether it follows what has been predicted by the software so that it can be applied and increase the compressive strength of concrete.

The optimization approach was designed to find the optimal values for three independent factors that provide desirable response variables. Response models visualization using graphical optimization led to understanding the influence of epoxy resin, cockle shells powder, and glass powder on concrete compressive strength. Numerical optimization's overall objective was to maximize compressive strength. Multiple optimization approaches, such as desirability analysis, were used to integrate these objectives. This method aimed to optimize compressive strength to get feasible parameters of epoxy resin, cockle shells powder, and glass powder.

3. Results and discussion

3.1. Regression and establishment

The influence of independent parameters (epoxy resin, waste of cockle shells, waste of glass) on the compressive strength performance of concrete was evaluated. Both response variables were predicted using polynomial coefficient computations using experimental data. The ANOVA results indicated that linear and quadratic models might represent compressive strength. Eq. (1) to Eq. (4) depict the regression equations created for each response using the response surface approach.

$$Cs1 = 53.74 + 24.43A + 7.05B, \quad (1)$$
$$Cs2 = 49.85 + 24.98A - 3.37C, \quad (2)$$
$$Cs3 = 84.86 + 26.16B + 33.47C + 14.51BC + 14.87B^2 - 26.87C^2, \quad (3)$$
$$Cs4 = 54.73 + 24.18A + 7.58B + 1.57C, \quad (4)$$

where A, B, and C are epoxy resin (%, w/w), cockle shells powder (%, w/w), and glass powder (%, w/w), respectively, and Cs1, Cs2, Cs3, Cs4 predict compressive strength for each mixing of concrete. A positive variable in a regression equation suggests a synergistic effect, in which the outcome increases as the independent variables' inputs increase. On another side, a negative sign indicates an antagonistic impact, in which the response rises as the input variables are decreased. A total of 28 experiments were completed to optimize the three parameters (epoxy resin, waste of cockle shells, waste of glass), and more 4 replicated each combination parameter using RSM. The load-displacement data from UTM is shown in Fig. 2. The results show that the maximum compressive strength of concrete obtained was 87.11 MPa (at load 437.82 KN) using the epoxy resin of 13% (w/w), cockle shells powder of 3% (w/w), and glass powder of 2% (w/w), while the minimum compressive strength of concrete obtained was 24.17 MPa (at load 121.80 KN) using the epoxy resin of 0% (w/w), cockle shells powder of 1% (w/w), and glass powder of 3% (w/w). A quadratic model (Eq. (1) to Eq. (4)) was developed via multiple nonlinear regression of the empirical data to forecast the compressive strength of concrete.

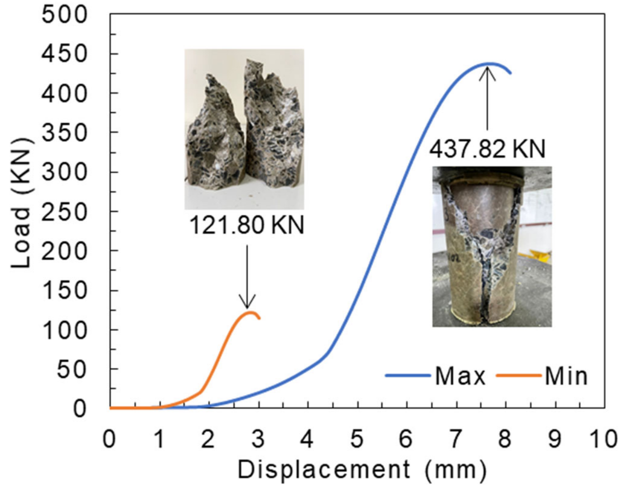


Fig. 2. Load-displacement data from UTM on min and max compressive strength of concrete

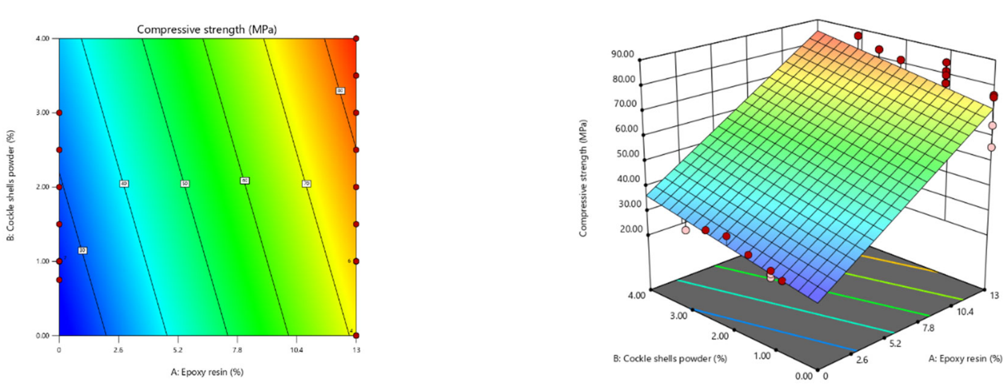
3.2 Analysis of compressive strength of concrete response

3.2.1 Effect of factors epoxy resin and cockle shells powder

Table 2 establishes the model of compressive strength of concrete by ANOVA under the effect of epoxy resin and cockle shells powder. The interaction influence of epoxy resin and cockle shells powder on the compressive strength of concrete is shown in Fig. 3. The three-dimensional surface graph relates to the linear model compressive strength response. The normal probability and residual vs. predicted (fits) plots are shown in Fig. 4. The result of the compressive strength of the concrete response is displayed in Table 3. According to Table 3, despite a small difference for one DFFITS value, the model is usually regarded as acceptable.

Table 2. ANOVA for compressive strength of concrete response surface model under the effect of epoxy resin and cockle shells powder

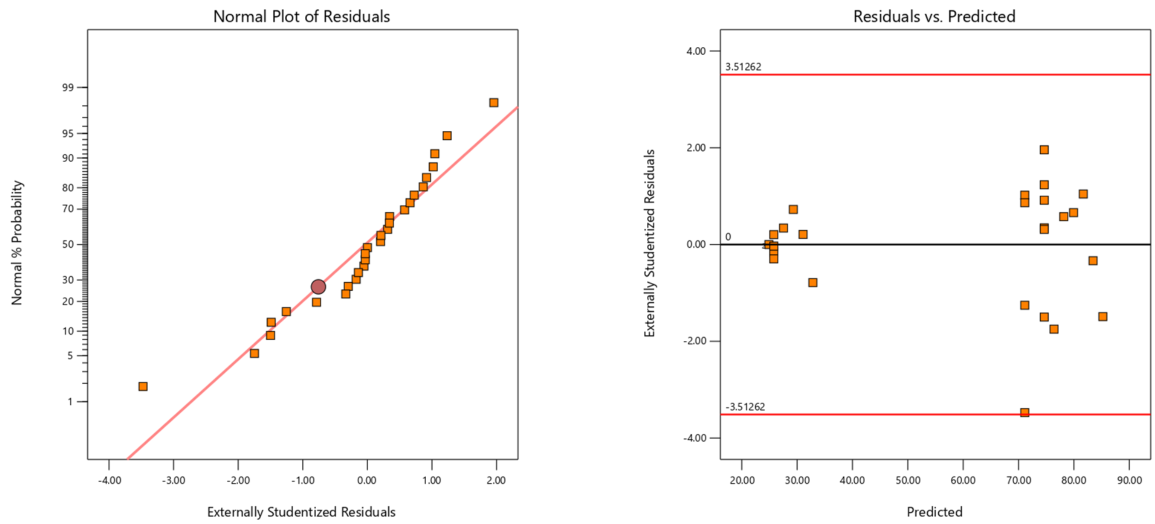
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	16764.17	2	8382.09	265.14	<0.0001	Significant
A-Epoxy resin	16368.58	1	16368.58	517.77	<0.0001	
B-Rotational speed	370.56	1	370.56	11.72	0.0021	
Residual	790.34	25	31.61			
Lack of fit	308.89	11	28.08	0.8166	0.6270	Not significant
Pure error	481.45	14	34.39			
Total	17554.51	27				



(a) Contour plot (b) 3-D response surface plot

Fig. 3. Contour plot and response surface plot of concrete compressive strength under the effect of epoxy resin and cockle shells powder

A statistical test was run on the regression model and individual model variables to determine the effect of epoxy resin and cockle shells powder on the compressive strength of concrete. Table 2 shows the ANOVA for the data yielded by Equation 1 for compressive strength of concrete under the effect of epoxy resin and cockle shells powder. A high F-value and a low P-value demonstrate the significance of the developed model (Hamouda et al., 2015; Yirgu et al., 2021). The F-value of 265.14 and P-value of 0.0001 in this study showed that the model was significant. All linear models had significant impacts on the compressive strength of concrete. The F-value and P-value for lack of fit were 0.8166 and 0.6270, respectively, indicating that the lack of fit was not statistically significant compared to the error and that the model fit is satisfactory (Karri et al., 2021).



(a) Normal probability plot (b) Residual vs predicted (fits) plot

Fig. 4. Diagnostic plots for compressive strength of concrete under the effect of epoxy resin and cockle shells powder

Table 3. Report of diagnostic case for compressive strength of concrete under the effect of epoxy resin and cockle shells powder

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	24.84	25.79	-0.9488	0.089	-0.177	-0.173	0.001	-0.054	1
2	25.49	25.79	-0.2928	0.089	-0.055	-0.053	0.000	-0.017	2
3	26.91	25.79	1.12	0.089	0.209	0.205	0.001	0.064	3
4	25.61	25.79	-0.1790	0.089	-0.033	-0.033	0.000	-0.010	4
5	25.03	25.79	-0.7595	0.089	-0.142	-0.139	0.001	-0.043	5
6	24.17	25.79	-1.62	0.089	-0.301	-0.296	0.003	-0.092	6
7	55.94	71.12	-15.18	0.129	-2.892	-3.473	0.412	-1.336(1)	7
8	76.47	71.12	5.35	0.129	1.019	1.020	0.051	0.392	8
9	75.68	71.12	4.56	0.129	0.870	0.865	0.037	0.333	9
10	64.61	71.12	-6.51	0.129	-1.241	-1.255	0.076	-0.483	10
11	67.26	76.41	-9.15	0.063	-1.680	-1.748	0.063	-0.453	11
12	81.33	78.17	3.16	0.074	0.584	0.576	0.009	0.163	12
13	83.49	79.94	3.56	0.103	0.668	0.660	0.017	0.223	13
14	87.11	81.70	5.41	0.148	1.043	1.045	0.063	0.435	14
15	81.76	83.46	-1.70	0.210	-0.340	-0.334	0.010	-0.172	15
16	78.33	85.23	-6.90	0.288(2)	-1.454	-1.489	0.285	-0.948	16
17	66.71	74.65	-7.94	0.068	-1.463	-1.499	0.052	-0.405	17
18	76.55	74.65	1.90	0.068	0.351	0.344	0.003	0.093	18
19	81.28	74.65	6.63	0.068	1.222	1.235	0.036	0.334	19
20	84.72	74.65	10.07	0.068	1.856	1.958	0.084	0.529	20
21	79.63	74.65	4.99	0.068	0.919	0.916	0.021	0.248	21
22	76.37	74.65	1.73	0.068	0.319	0.313	0.002	0.085	22
23	24.91	24.91	0.0035	0.097	0.001	0.001	0.000	0.000	23
24	25.61	25.79	-0.1790	0.089	-0.033	-0.033	0.000	-0.010	24
25	29.42	27.55	1.87	0.084	0.347	0.341	0.004	0.103	25
26	33.23	29.31	3.92	0.096	0.733	0.726	0.019	0.236	26
27	32.20	31.08	1.12	0.124	0.214	0.209	0.002	0.079	27
28	28.78	32.84	-4.06	0.170	-0.793	-0.787	0.043	-0.356	28

(1) Exceeds limits.
(2) Observation with leverage > 2.00 × (average leverage).

ANOVA was used to determine the model's satisfactoriness under the effect of epoxy resin and cockle shells powder. R^2 and adjusted R^2 values of 0.955 and 0.9514 indicate a high degree of congruence between experimental results and fitted regression models. The greater R^2 indicated that the model was very reliable in predicting the compressive strength of concrete; the adjusted R^2 indicated the amount of variation around the mean explained by the model. The high adjusted R^2 value indicated an acceptable agreement between observed and anticipated compressive strength values for concrete, implying that the proposed linear model equation produces satisfactory and accurate results. The lack of fit is also significant under the effect of epoxy resin and cockle shells powder, which is expected because an appropriate model is required (Sinkhonde *et al.*, 2021). The distribution of points compatible with the regression line demonstrates the applied regression model's increased adequacy (Salarian *et al.*, 2016). Also, random bouncing of residuals presents that the implied relationship is good. Simultaneously, the model's low coefficient of variance (10.20%) suggested a high degree of accuracy and a high degree of dependability for the observed data (Ren *et al.*, 2017). Hence, the generated model was satisfactory for estimating the compressive strength of concrete in the range of experimental variables under the effect of epoxy resin and cockle shells powder.

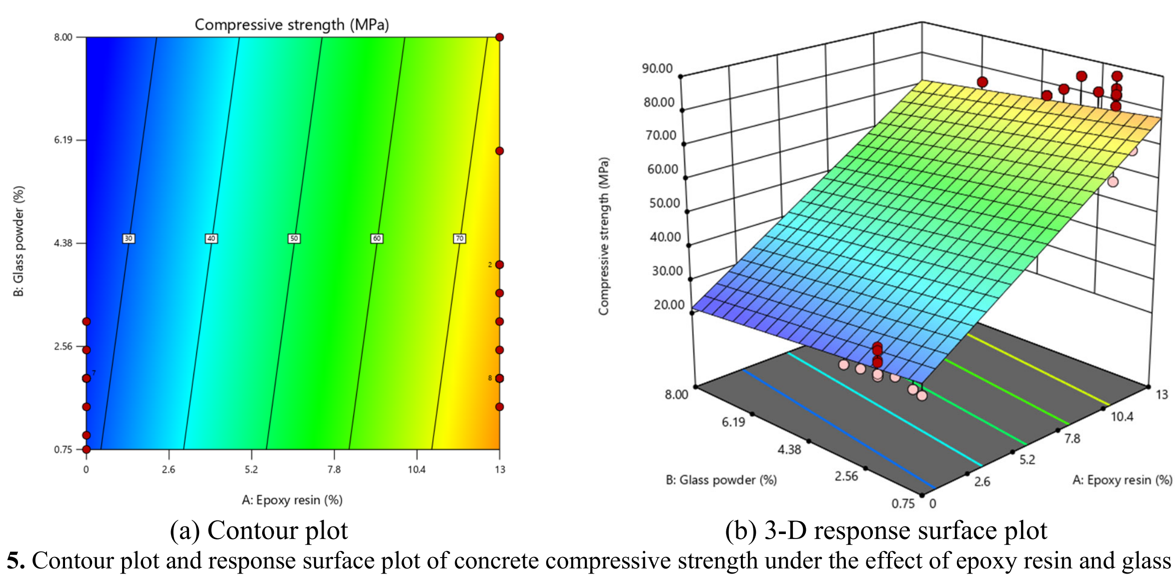
3.2.2 Effect of factors epoxy resin and glass powder

Table 4 establishes the model of compressive strength of concrete by ANOVA under the effect of epoxy resin and glass powder. The interaction influence of epoxy resin and glass powder on the compressive strength of concrete is shown in Fig. 5. The three-dimensional surface graph relates to the linear model compressive strength response. The normal probability and residual vs. predicted (fits) plots are shown in Fig. 6. The result of the compressive strength of the concrete response is displayed in Table 5. According to Table 5, despite a small difference for one Cook's Distance values and two DFFITS values, the model is usually regarded as acceptable.

Table 4. ANOVA for compressive strength of concrete response surface model under the effect of epoxy resin and glass powder

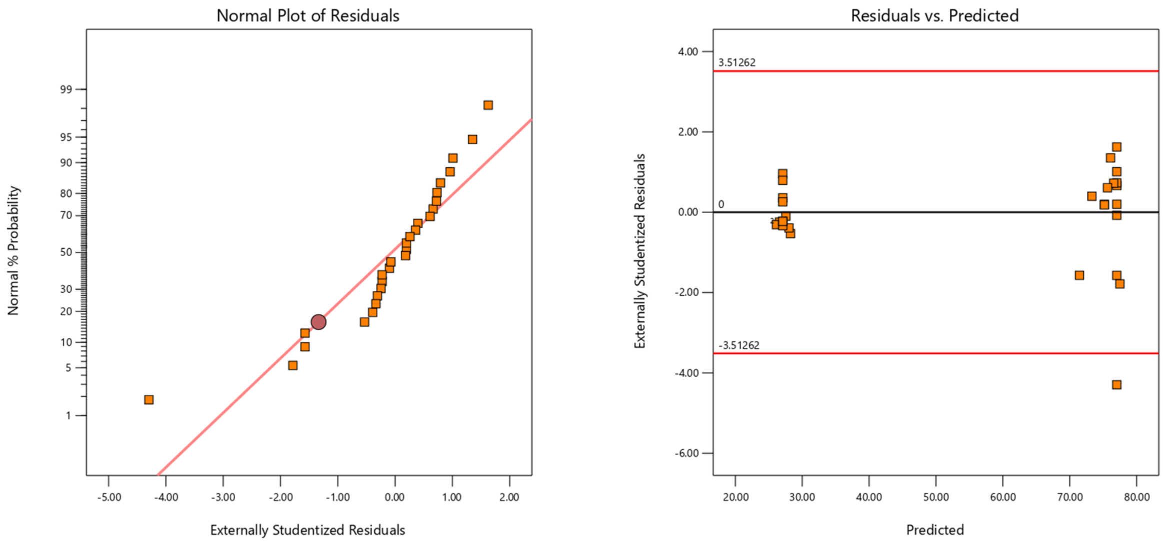
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	16437.42	2	8218.71	183.93	< 0.0001	significant
A-Epoxy resin	14567.55	1	14567.55	326.01	< 0.0001	
C-Glass powder	43.81	1	43.81	0.9804	0.3316	
Residual	1117.09	25	44.68			
Lack of fit	326.60	11	29.69	0.5258	0.8554	not significant
Pure error	790.49	14	56.46			
Total	17554.51	27				

A statistical test was run on the regression model and individual model variables to determine the effect of epoxy resin and glass powder on the compressive strength of concrete. Table 4 presents the ANOVA for the data yielded by Eq. (2) for the compressive strength of concrete under the effect of epoxy resin and glass powder. F-value of 183.93 and P-value of 0.0001 in this study showed that the model was significant. All linear models had significant impacts on the compressive strength of concrete. The F-value and the P-value for lack of fit were 0.5258 and 0.8554, indicating that the lack of fit was not statistically significant compared to the error and that the model fit is satisfactory.



(a) Contour plot (b) 3-D response surface plot

Fig. 5. Contour plot and response surface plot of concrete compressive strength under the effect of epoxy resin and glass powder



(a) Normal probability plot (b) Residual vs predicted (fits) plot

Fig. 6. Diagnostic plots response for compressive strength of concrete under the effect of epoxy resin and glass powder

Table 5. Report of diagnostic case for compressive strength of concrete under the effect of epoxy resin and glass powder

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	24.84	28.25	-3.41	0.109	-0.541	-0.533	0.012	-0.187	1
2	25.49	28.02	-2.52	0.099	-0.397	-0.391	0.006	-0.130	2
3	26.91	27.55	-0.6427	0.086	-0.101	-0.099	0.000	-0.030	3
4	25.61	27.09	-1.48	0.084	-0.231	-0.227	0.002	-0.068	4
5	25.03	26.62	-1.59	0.091	-0.250	-0.245	0.002	-0.077	5
6	24.17	26.16	-1.99	0.107	-0.314	-0.309	0.004	-0.107	6
7	55.94	77.04	-21.09	0.083	-3.296	-4.295(1)	0.330	-1.296(2)	7
8	76.47	75.18	1.29	0.081	0.201	0.198	0.001	0.059	8
9	75.68	73.32	2.36	0.236(3)	0.405	0.398	0.017	0.221	9
10	64.61	71.46	-6.85	0.550(3)	-1.527	-1.572	0.950(2)	-1.737(2)	10
11	67.26	77.04	-9.78	0.083	-1.528	-1.572	0.071	-0.474	11
12	81.33	77.04	4.30	0.083	0.671	0.664	0.014	0.200	12
13	83.49	77.04	6.46	0.083	1.009	1.009	0.031	0.305	13
14	87.11	77.04	10.08	0.083	1.575	1.625	0.075	0.491	14
15	81.76	77.04	4.72	0.083	0.738	0.731	0.017	0.221	15
16	78.33	77.04	1.29	0.083	0.202	0.198	0.001	0.060	16
17	66.71	77.50	-10.80	0.109	-1.711	-1.784	0.119	-0.623	17
18	76.55	77.04	-0.4886	0.083	-0.076	-0.075	0.000	-0.023	18
19	81.28	76.57	4.71	0.068	0.729	0.722	0.013	0.195	19
20	84.72	76.11	8.61	0.063	1.331	1.353	0.039	0.349	20
21	79.63	75.64	3.99	0.067	0.618	0.610	0.009	0.163	21
22	76.37	75.18	1.20	0.081	0.187	0.183	0.001	0.054	22
23	24.91	27.09	-2.18	0.084	-0.340	-0.334	0.004	-0.101	23
24	25.61	27.09	-1.48	0.084	-0.231	-0.227	0.002	-0.068	24
25	29.42	27.09	2.33	0.084	0.365	0.358	0.004	0.108	25
26	33.23	27.09	6.15	0.084	0.960	0.959	0.028	0.290	26
27	32.20	27.09	5.11	0.084	0.799	0.793	0.019	0.240	27
28	28.78	27.09	1.69	0.084	0.265	0.260	0.002	0.078	28

(1) Observation with External Stud. Residuals > 3.51
(2) Exceeds limits.
(3) Observation with leverage > 2.00 × (average leverage).

The greater R^2 value indicated that the model was very reliable in predicting the compressive strength of concrete; the adjusted R^2 value indicated the amount of variation around the mean explained by the model. The R^2-value showed 93.64% of the variability in compressive strength of concrete defined by the linear model in this investigation. The high adjusted R2 value indicated an acceptable agreement between observed and forecasted compressive strength values for concrete, indicating that the proposed linear model equation produces satisfactory and accurate results. The Adj R^2 (0.9313) and pred R^2 (0.9364) in this treatment have a difference of less than 0.2, indicating that they are in proper agreement with each other. Simultaneously, the model's low coefficient of variance (12.13%) suggested a high degree of accuracy and a high degree of dependability for the observed data. Hence, the generated model was satisfactory for estimating the compressive strength of concrete in the range of experimental variables under the effect of epoxy resin and glass powder.

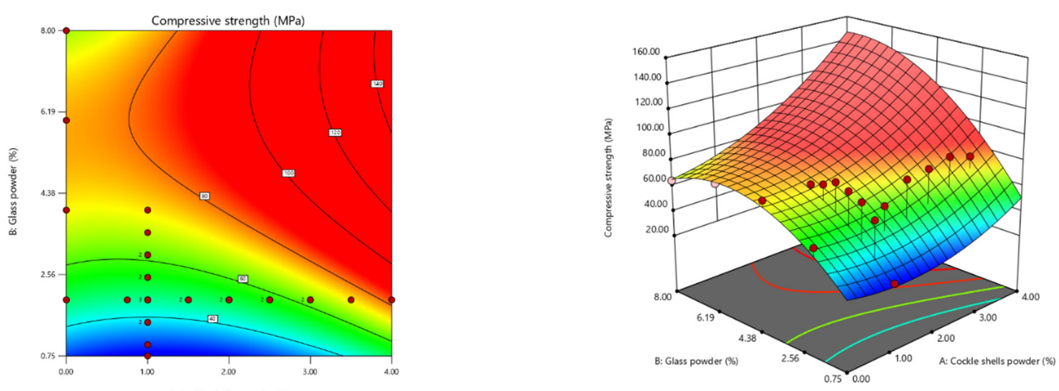
3.2.3 Effect of factors cockle shells powder and glass powder

Table 6 establishes the model of compressive strength of concrete by ANOVA under the effect of cockle shells powder and glass powder. The interaction influence of cockle shells powder and glass powder on the compressive strength of concrete is shown in Fig. 7. The three-dimensional surface graph relates to the quadratic model compressive strength response. The normal probability and residual vs. predicted (fits) plots are shown in Figure 8. The result of the compressive strength of the concrete response is displayed in Table 7.

Table 6. ANOVA for compressive strength of concrete response surface model under the effect of cockle shells powder and glass powder

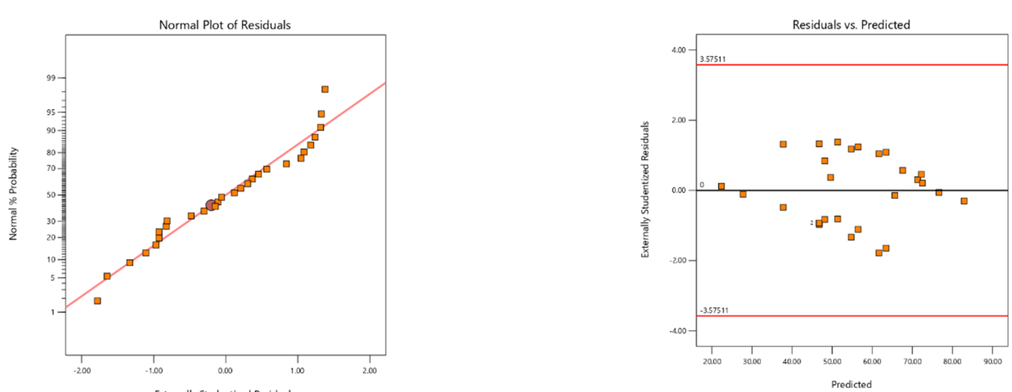
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	5439.24	5	1087.85	1.98	0.1224	Not significant
B-Cockle shells powder	85.17	1	85.17	0.1547	0.6979	
C-Glass powder	71.60	1	71.60	0.1300	0.7218	
AB	11.03	1	11.03	0.0200	0.8887	
A^2	335.20	1	335.20	0.6087	0.4436	
B^2	383.80	1	383.80	0.6969	0.4128	
Residual	12115.28	22	550.69			
Lack of fit	1288.60	13	99.12	0.0824	0.9999	Not significant
Pure error	10826.68	9	1202.96			
Total	17554.51	27				

A statistical test was run on the regression model and individual model variables to determine the effect of cockle shells powder and glass powder on the compressive strength of concrete. Table 6 shows the ANOVA for the data yielded by Eq. (3) for the compressive strength of concrete under the effect of cockle shells powder and glass powder. The F-value of 1.98 and P-value of 0.1224 in this study showed that the model was not significant. All linear terms, two quadratic terms (A2, and B2), and interactive terms (AB) had no significant effects on the compressive strength of concrete. The F-value and P-value for lack of fit were 0.0824 and 0.9999, respectively, indicating that the lack of fit was not statistically significant in relation to the error and that the model fit is satisfactory.



(a) Contour plot (b) 3-D response surface plot

Fig. 7. Contour plot and response surface plot of concrete compressive strength under the effect of cockle shells powder and glass powder



(a) Normal probability plot (b) Residual vs predicted (fits) plot

Fig. 8. Diagnostic plots response for compressive strength of concrete under the effect of cockle shells powder and glass powder

Table 7. Report of diagnostic case for compressive strength of concrete under the effect of cockle shells powder and glass powder

Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	24.84	22.42	2.42	0.298	0.123	0.120	0.001	0.078	1
2	25.49	27.80	-2.31	0.205	-0.110	-0.108	0.001	-0.055	2
3	26.91	37.81	-10.90	0.095	-0.488	-0.480	0.004	-0.156	3
4	25.61	46.79	-21.18	0.055	-0.929	-0.926	0.008	-0.224	4
5	25.03	54.75	-29.72	0.063	-1.309	-1.331	0.019	-0.345	5
6	24.17	61.69	-37.52	0.114	-1.698	-1.780	0.062	-0.637	6
7	55.94	49.62	6.33	0.485(1)	0.376	0.368	0.022	0.357	7
8	76.47	71.32	5.15	0.505(1)	0.312	0.305	0.017	0.308	8
9	75.68	76.67	-0.9886	0.495(1)	-0.059	-0.058	0.001	-0.057	9
10	64.61	65.66	-1.06	0.907(1)	-0.148	-0.144	0.036	-0.451	10
11	67.26	48.17	19.10	0.077	0.847	0.841	0.010	0.244	11
12	81.33	51.40	29.93	0.109	1.352	1.379	0.037	0.483	12
13	83.49	56.49	27.00	0.118	1.225	1.240	0.033	0.453	13
14	87.11	63.45	23.67	0.131	1.082	1.086	0.029	0.421	14
15	81.76	72.26	9.50	0.238	0.464	0.456	0.011	0.255	15
16	78.33	82.93	-4.60	0.593(1)	-0.307	-0.301	0.023	-0.362	16
17	66.71	37.81	28.90	0.095	1.295	1.316	0.029	0.427	17
18	76.55	46.79	29.76	0.055	1.305	1.327	0.017	0.321	18
19	81.28	54.75	26.53	0.063	1.168	1.178	0.015	0.306	19
20	84.72	61.69	23.03	0.114	1.042	1.045	0.023	0.374	20
21	79.63	67.60	12.03	0.217	0.579	0.570	0.016	0.300	21
22	76.37	72.50	3.88	0.401	0.214	0.209	0.005	0.171	22
23	24.91	46.80	-21.89	0.075	-0.970	-0.969	0.013	-0.276	23
24	25.61	46.79	-21.18	0.055	-0.929	-0.926	0.008	-0.224	24
25	29.42	48.17	-18.75	0.077	-0.832	-0.826	0.010	-0.239	25
26	33.23	51.40	-18.17	0.109	-0.820	-0.814	0.014	-0.285	26
27	32.20	56.49	-24.29	0.118	-1.102	-1.108	0.027	-0.405	27

(1) Observation with leverage > 2.00 × (average leverage).

ANOVA evaluated the satisfactoriness of the model under the effect of cockle shells powder and glass powder. R^2 and adjusted R^2 values of 0.3098 and 0.1530 indicated weak relativity of experimental findings with the fitted regression model. The small of R^2 indicated low reliability of the model in predicting compressive strength of concrete; the adjusted R^2 measured the amount of variation about a mean explained by the model. The R^2-value indicated 30.98% of the variability in compressive strength of concrete explained by the quadratic model in this study. The model's high coefficient of variance (42.57%) suggested a low degree of accuracy and a high degree of dependability for the observed data. Hence, the developed model was fair for predicting the compressive strength of concrete in the range of experimental variables under the effect of cockle shells powder and glass powder.

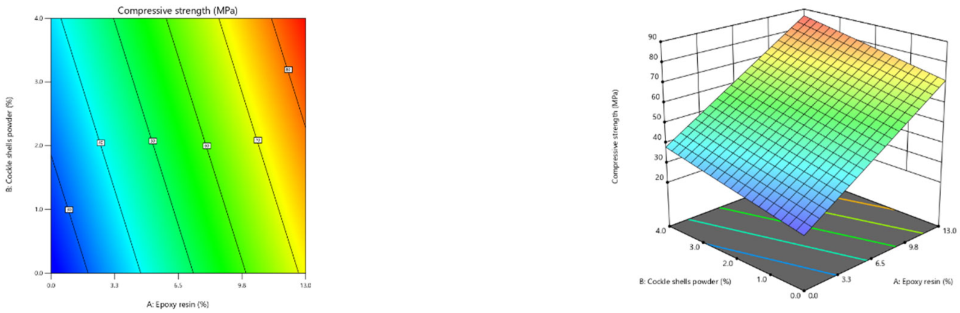
3.2.4 Effect of factors epoxy resin, cockle shells powder and glass powder

Table 8 establishes the model of compressive strength of concrete by ANOVA under the effect of epoxy resin, cockle shells powder and glass powder. The interaction influence of epoxy resin, cockle shells powder, and glass powder on the compressive strength of concrete is shown in Fig. 9. The three-dimensional surface graph relates to the linear model compressive strength response. The normal probability and residual vs. predicted (fits) plots are shown in Fig. 10. The result of the compressive strength of the concrete response is displayed in Table 9. According to Table 9, despite a small difference for one Cook's Distance values and two DFFITS values, the model is usually regarded as acceptable.

Table 8. ANOVA for compressive strength of concrete response surface model under the effect of epoxy resin, cockle shells powder and glass powder

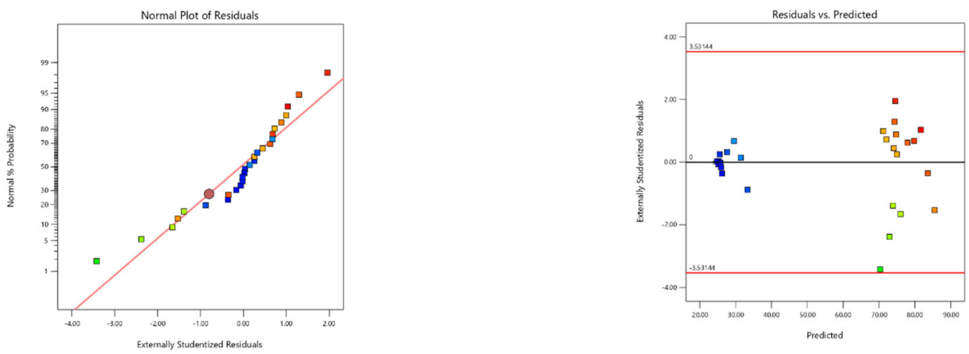
Source	Sum of squares	df	Mean square	F-value	p-value	
Model	16771.57	3	5590.52	171.37	< 0.0001	Significant
A-Epoxy resin	13081.63	1	13081.63	401.00	< 0.0001	
B-cockle shells powder	334.15	1	334.15	10.24	0.0038	
C-Glass powder	7.40	1	7.40	0.2268	0.6382	
Residual	782.94	24	32.62			
Lack of fit	782.94	23	34.04			
Pure error	0.0000	1	0.0000			
Total	17554.51	27				

A statistical test was run on the regression model and individual model variables to determine the effect of epoxy resin, cockle shells powder and glass powder on the compressive strength of concrete. Table 8 shows the ANOVA for the data yielded by Eq. (4) for compressive strength of concrete under the effect of epoxy resin, cockle shells powder, and glass powder. The model F-value of 171.37 and P-value of 0.0001 in this study showed that the model was significant. All linear terms had significant effects on the compressive strength of concrete.



(a) Contour plot (b) 3-D response surface plot

Fig. 9. Contour plot and response surface plot of concrete compressive strength under the effect of epoxy resin, cockle shells powder and glass powder



(a) Normal probability plot (b) Residual vs predicted (fits) plot

Fig. 10. Diagnostic plots for compressive strength of concrete under the effect of epoxy resin, cockle shells powder and glass powder

Table 9. Report of diagnostic case for compressive strength of concrete under the effect of epoxy resin, cockle shells powder and glass powder

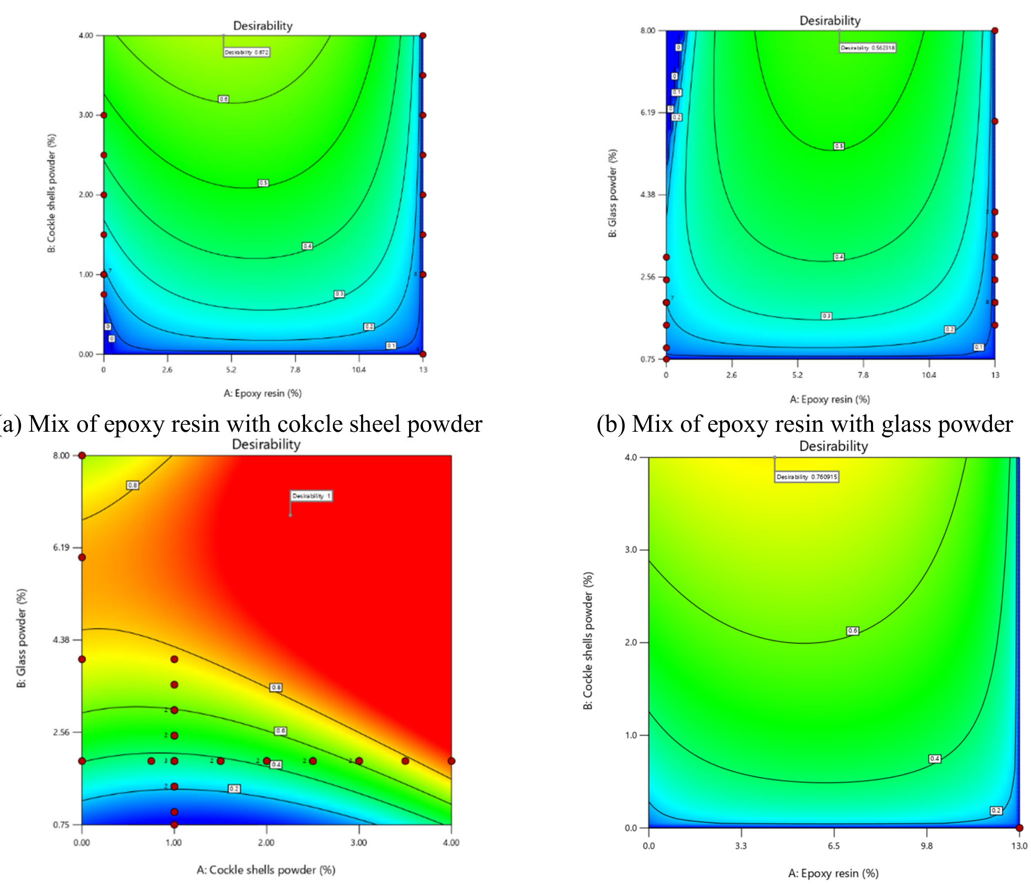
Run Order	Actual Value	Predicted Value	Residual	Leverage	Internally Studentized Residuals	Externally Studentized Residuals	Cook's Distance	Influence on Fitted Value DFFITS	Standard Order
1	24.84	25.19	-0.3485	0.137	-0.066	-0.064	0.000	-0.026	1
2	25.49	25.29	0.1995	0.121	0.037	0.036	0.000	0.014	2
3	26.91	25.51	1.40	0.099	0.258	0.253	0.002	0.084	3
4	25.61	25.73	-0.1194	0.089	-0.022	-0.021	0.000	-0.007	4
5	25.03	25.94	-0.9163	0.092	-0.168	-0.165	0.001	-0.052	5
6	24.17	26.16	-1.99	0.107	-0.369	-0.362	0.004	-0.126	6
7	55.94	70.30	-14.36	0.219	-2.845	-3.421	0.568	-1.813(1)	7
8	76.47	71.17	5.30	0.129	0.995	0.995	0.037	0.383	8
9	75.68	72.03	3.65	0.241	0.734	0.727	0.043	0.410	9
10	64.61	72.90	-8.29	0.556(2)	-2.178	-2.380	1.485(1)	-2.663(1)	10
11	67.26	75.99	-8.73	0.087	-1.599	-1.656	0.061	-0.510	11
12	81.33	77.88	3.45	0.086	0.632	0.623	0.009	0.191	12
13	83.49	79.78	3.71	0.106	0.688	0.680	0.014	0.234	13
14	87.11	81.67	5.44	0.148	1.032	1.033	0.046	0.430	14
15	81.76	83.57	-1.81	0.211	-0.357	-0.350	0.009	-0.181	15
16	78.33	85.47	-7.14	0.296(2)	-1.489	-1.530	0.233	-0.992	16
17	66.71	73.88	-7.17	0.148	-1.360	-1.386	0.080	-0.578	17
18	76.55	74.09	2.46	0.109	0.456	0.448	0.006	0.157	18
19	81.28	74.31	6.97	0.083	1.275	1.293	0.037	0.390	19
20	84.72	74.52	10.19	0.070	1.851	1.957	0.064	0.537	20
21	79.63	74.74	4.89	0.069	0.888	0.884	0.015	0.241	21
22	76.37	74.96	1.42	0.081	0.259	0.254	0.001	0.075	22
23	24.91	24.78	0.1292	0.099	0.024	0.023	0.000	0.008	23
24	25.61	25.73	-0.1194	0.089	-0.022	-0.021	0.000	-0.007	24
25	29.42	27.62	1.80	0.084	0.329	0.323	0.002	0.098	25
26	33.23	29.52	3.71	0.101	0.686	0.678	0.013	0.228	26
27	32.20	31.41	0.7868	0.140	0.149	0.145	0.001	0.059	27
28	28.78	33.31	-4.53	0.199	-0.887	-0.882	0.049	-0.440	28

(1) Exceeds limits.
(2) Observation with leverage > 2.00 × (average leverage).

ANOVA was used to determine the model's satisfactoriness for compressive strength of concrete under the effect of epoxy resin, cockle shells powder and glass powder. R^2 and adjusted R^2 values of 0.99554 and 0.9498 indicate strong relativity of experimental findings with the fitted regression model. The high value of adjusted R^2 showed a reasonable agreement between the observed and predicted values of the compressive strength of concrete and suggested that the proposed linear model equation offers satisfactory and accurate results. The lack of fit is also insignificant for compressive strength of concrete under the effect of epoxy resin, cockle shells powder and glass powder, which is expected because an appropriate model is required. The distribution of points compatible with the regression line demonstrates the applied regression model's increased adequacy. Also, random bouncing of residuals presents that the implied relationship is good. Simultaneously, the model's low coefficient of variance (10.36%) suggested a high degree of accuracy and a high degree of dependability for the observed data. Hence, the generated model was satisfactory for estimating the compressive strength of concrete in the range of experimental variables under the effect of epoxy resin, cockle shells powder, and glass powder.

3.3 Optimization of compressive strength of some combination mix aggregate of concrete

The desirability close to one is the most desirable because it increasingly shows the value of optimization accuracy. The desirability is to indicate the level of fulfillment of the specified criteria. The prediction of optimal conditions in the cement mixing process between the epoxy resin and cockle shells powder (Fig. 11a) is 4.88%, 4.0%, respectively, with the desirability of 0.672. The most optimal formula solutions in the cement mixing process between the epoxy resin and glass powder are 6.85%, 8.0%, or equivalent to the desirability of 56.2% (Fig. 11b). Optimal conditions in the cement mixing process between cockle shells powder and glass powder (Fig. 11c) are 4.0%, 8.0%, respectively, with the desirability of 1.0. The optimal formulation in the cement mixing process between epoxy resin, cockle shells powder, and glass powder is 4.40%, 4.0, 8.0%, respectively, equivalent to the desirability of 76.1% (Fig. 11d). Under these conditions, the mixing components will produce cement with compressive strength in each formulation of 54.71 MPa, 47.82 MPa, 147.0 MPa, and 56.08 MPa. These results are in line with the research of Murugan et al. (2020), who reported that cockle shell substitution (5 – 30%) would provide compressive strength in concrete in the range of 42.46 MPa to 52.64 MPa. The formulations in each of these can be used according to the availability of raw materials for cockle shells waste and glass waste and the level of compressive strength required by the user.



(a) Mix of epoxy resin with cokcle sheel powder (b) Mix of epoxy resin with glass powder

(c) Mix of cokcle sheel powder with glass powder (d) Mix of epoxy resin, cokcle sheel powder and glass powder

Fig. 11. Optimization of epoxy resin, cockle shell powder, and glass powder using desirability analysis

4. Conclusion

In this study, the compressive strength of mixed concrete aggregates was optimized from waste cockle shells and waste glass. The compressive strength of concrete incorporated with epoxy resin, cockle shells powder, and glass powder is identified to be higher than that of normal concrete. It is appropriate to evaluate such sustainable buildings based on the findings. The linear and quadratic polynomial models utilized in this study demonstrated that they could accurately predict compressive strength responses. It was found that 4.88% epoxy resin and 4.0% cockle shells powder improved the compressive strength at two types of combination aggregate. Another type of concrete mix aggregate, 6.85% epoxy resin and 8.0% glass powder improved the compressive strength. Concrete mix aggregate with cockle shells powder and glass powder respectively at 4.0% and 8.0% provides optimization of compressive strength. Finally, the combination of epoxy resin, cockle shells powder, and glass powder of 4.40%, 4.0, 8.0%, respectively, will also optimize the compressive strength of the concrete. In addition, only mixing of 4.0% cockle shells powder and 8.0% glass were noticed to yield maximum compressive strength on concrete. Optimized values are a good way to build with waste material in a way that is environmentally friendly. RSM was discovered to provide a substantial quantity of information in a short time and with the fewest possible experiments.

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