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Optimization of Self-Compacting Concrete Incorporating Granite Dust and Rice Husk Ash Using Response Surface Methodology

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Abstract
Concrete that can flow under its own weight, fully fill a space or formwork, and create a dense, suitably homogenous material without the requirement for compaction is known as self-compacting concrete, or SCC for short. Rice husk ash and granite dust were added to self-compacting concrete, which was optimized using response surface approach. At 3, 7, 28, and 90 days at an unchanged water-binder ratio of 0.46, the effectiveness of the granite dust and rice husk ash in self-compacting mixes of concrete was evaluated in terms of compressive strength and workability using the V-funnel, J-ring, and slump flow tests. The findings suggest that discarded granite dust and rice husk ash can be effectively used to make self-compacting concrete. The best percentage replacement values were found to be 10% for rice husk ash and 20% for granite dust in place of fine aggregate and cement. This approach allows for the production of self-compacting concrete compositions that are highly sustainable and efficient by optimizing the proportions of these two components.

1.0 Introduction

The use of self-compacting concrete (SCC) has dramatically increased in recent years (Jawad *et al*., 2023; Liu, 2010; Leemann and Munch, 2010; Kou and Poon, 2009; Adetoye *et al*., 2023)). In 1988, self-compacting concrete (SCC) was created in Japan to increase the homogeneity and reliability of concrete; it requires no consolidation or compaction activity at the site (Okamura and Ouchi, 1999). The addition of mineral admixtures is one of the key distinctions between SCC and conventional concrete. As a result, numerous investigations on how mineral admixtures affect SCC's characteristics have been carried out. These investigations demonstrate the benefits of using mineral admixtures in SCC, including better workability at lower cement concentrations (Ye *et al.*, 2007; Poppe and Schutter, 2005). Reducing the cement content in concrete is a cost-effective approach because cement is the most expensive component. Furthermore, the mineral admixtures have the capacity to enhance particle packing and reduce concrete's permeability. Therefore, the durability of concrete is also increased (Assie *et al.*, 2007). Industrial by-products or agricultural waste materials such as granite powder and rice husk ash are generally used as mineral admixtures in SCC (Ravinda and Rafat, 2017, Gzegorz *et al*., 2019). As a result, SCC is more workable and more waste or by-products can be utilized.

Large volumes of granite dust (GD) granules are created in granite quarries as a byproduct of the stone crushers. There is an accumulation of these powders in large quantities, and it is difficult to suggest using these byproducts in terms of disposal, environmental contamination, and health risks. (Prokopski *et al*., 2020, Adetoye et al., 2023). Due to their detrimental effects on the water requirement and toughness of the hardened concrete, substantial quantities of mineral admixtures are not often used to concrete mixtures in conventional concrete. These mineral admixtures, however, are effective at enhancing viscosity, especially in powder-type SCC. Moreover, granite dust has been shown to significantly improve the workability and density of concrete, as well as the compressive strength beyond 28days. (Prokopski et al., 2020).

An estimated 148 million tons of rice husks are generated annually, along with 742 million tons of rice produced worldwide (FAO study, 2015). About 0.19 tons of ashes are produced for every ton of husk. Rice husks are burned to create rice husk ash (RHA). Generally, every ton of husk produces about 0.19 ton of ash (Prasad et al., 2000, Bouzoubaa and Fournier, (2001). Rice husk has a high calorific value (Asavapisit and Ruengrit, 2005; RHA market study, 2003). The concentration of amorphous silica is primarily found on the surface of the rice husk. (Jauberthie *et al.*, 2000). The use of RHA in SCC results in more affordable and environmental friendly concrete. RHA, a by-product of agricultural activities, is a valuable mineral admixture (MA) because of its high surface area, quantity, and pozzolanic character, and its utilization in SCC reduces building time and energy consumption. Self-compacting concrete mixes have unique characteristics not seen in ordinary concrete because of the changed aggregate concentration and the inclusion of chemical and mineral admixtures (Neville, 2003).

This work's primary goal is to create self-compacting concrete (SCC) with varying amounts of superplasticizer (SP), rice husk ash (RHA), and granite dust (GD) while maintaining a steady water-to-binder (w/b) ratio. The specific objectives are to assess the workability, filling capacity, and passing ability of SCC in its fresh form. The study also intends to evaluate the effects on the compressive strength of SCC by replacing fine aggregate with granite dust (GD) and cement with RHA.

2.0 Materials and Methods

2.1 Materials

- Cement: Ordinary Portland cement (Grade 42.5) was used. The physical and chemical properties of the Portland cement comply with the requirements of NIS 444-14.
- Aggregates: Coarse aggregate used was crushed stone of nominal maximum size of 20 mm, and fine aggregate was natural river sand of maximum size less than 4.75mm, and both are graded in accordance with EN 12620.
- Superplasticizer: Conmix SP – high-range superplasticizer based on polycarboxylic ethers was used.
- Granite dust: The granite dust used for the study was obtained from a granite processing industry.

2.1.2 Concrete Mix Design

The concrete mix design of M30 MPa was carried out according to ACI-211, 2003.

Table 1: Mix design

Component	Value
Minimum strength (N/mm^2)	30
Target strength (N/mm^2)	38
Cement type	OPC 42.5
Maximum size of aggregate	20mm
Water/cement ratio	0.46
Cement content (kg/m^3)	435
Fine aggregate (kg/m^3)	980
Coarse aggregate (kg/m^3)	795
Water content (kg/m^3)	200
Superplasticizer (kg/m^3)	8.7
Mix ratio	1:2.85:1.53:0.46

2.2.2 Experimental Design

Box Behnken response surface methodology was adopted in the design of experimental combinations. Experimental runs were created by Design-Expert software 13 for M30 grade concrete. It was also used to quantify the relationship between the controllable input parameters and the obtained response surfaces. The Box–Behnken experimental design was used to analyze, model and optimize the results of compressive strength of SCC.

Table 2: Factor and Factor Levels of Mixture.

	Factor level	
Factor	Low	High
GD (%)	20	60
RHA (%)	5	20
Superplasticizer	1	3

Table 3: Factor Combinations for BBD.

Run	Factor 1 A:G.D %	Factor 2 B:RHA %	Factor 3 C:S.P %
1	60	20	2
2	20	12.5	1
3	40	20	3
4	60	5	2
5	20	12.5	3
6	40	5	1
7	20	20	2
8	40	12.5	2
9	40	12.5	2
10	60	12.5	1
11	40	20	1
12	40	12.5	2
13	40	5	3
14	20	5	2
15	60	12.5	3
16	40	12.5	2
17	40	12.5	2

3.0 Results and Discussion

3.1 Fresh Properties

Table 4 and Figures 1, 2, and 3 present the results of slump flow, V-funnel, and J-ring tests carried out on the SCC. The slump flow and V-funnel tests indicate the filling ability of SCC, whereas the J-ring test indicates its passing ability. All the SCC mixtures had slump flows between 612 and 812 mm, which suggest reasonable deformability (Divya *et al.*, 2015). Mixtures containing 20% RHA, 40% GD at SP dose of 3% had the lowest workability, whereas mixtures containing 5% RHA, 40% GD with an SP dose of 3% had the highest workability. As generally observed for the mixtures, the workability decreased with an increase in the contents of RHA and GD. For the V-funnel test, mixtures containing 5% RHA and 40% GD had the least flow time, whereas mixtures containing 12.5% RHA and 20% GD had the highest flow time. The J-ring results indicated SCC mixtures containing 12.5% RHA and 60% GD had the lowest passing ability, whereas SCC mixtures with 12.5% RHA and 40% GD had the highest passing ability. Patil *et al*. (2024) and Divya et al. (2015) had achieved similar results. The results are in accordance with the requirements of EFNARC (2002).

Table 4: Results of Fresh Properties of SCC

Run	RHA (%)	GD (%)	Slump flow (mm) 550-850	V-funnel (sec) 6-12s	J-ring (mm) 0-10mm
C	0	0	620	8.9	7.6
1	5	20	632	7.8	7.2
2	5	60	712	6.6	6.8
3	12.5	20	646	7.5	7.5
4	12.5	60	765	6.3	6.4
5	20	20	702	7.1	7.3
6	20	60	788	6.3	5.1

*EFNARC(2002) range

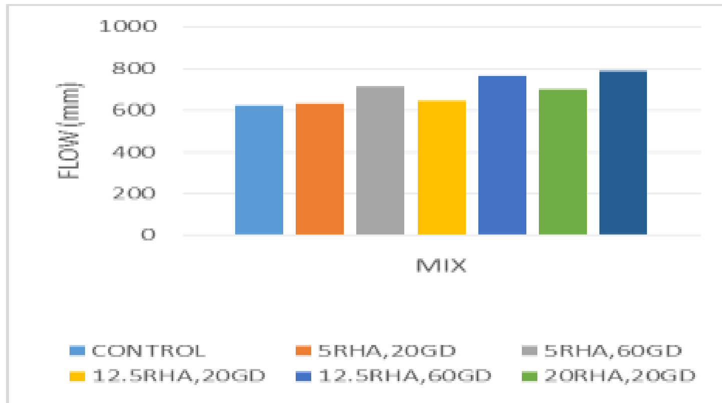

Figure 1: Results of slump flow test.

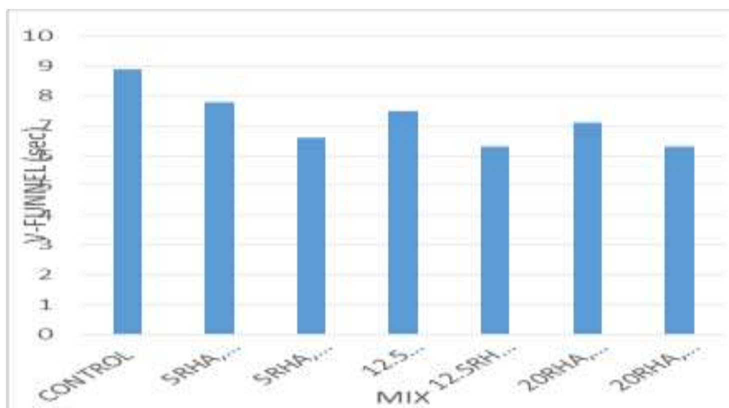

Figure 2: Results of V-funnel test

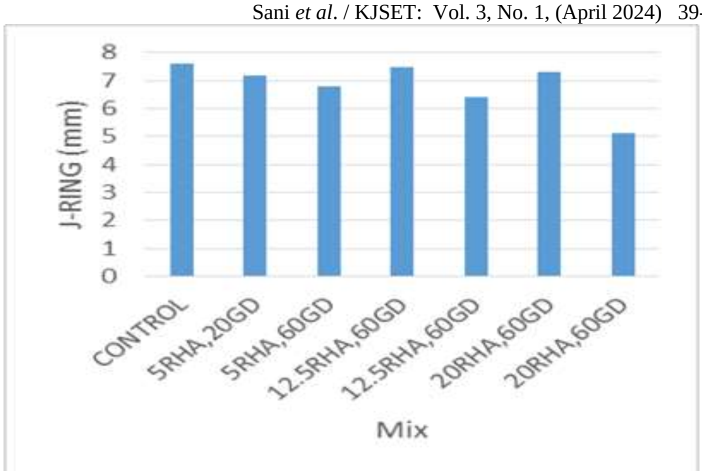

Figure 3: Result of J-ring test.

3.2 Compressive strength

Compressive strength test was carried out on SCC cubic specimens of size 100 mm x 100 mm x 100 mm, in accordance to ASTM C109. The strength was recorded at 3, 7, 28, and 90 days, respectively. The average reading of three cubes was recorded as the compressive strength at the respective age. The compression test was conducted with a compression testing machine of 3000 kN capacity at a loading rate of 0.3 kN/min. The ultimate strength was recorded after the specimens fail to resist any more loads. The compressive strength was calculated using Equation 1:

$$\text{Compressive Strength} = \frac{Failure\ Load\ (P)}{Cross\ Sectional\ Area\ (A)} \quad \text{... (1).}$$

The compressive strength at various ages is shown in Table 5 and the 3D reaction exterior plots in Figures 4–8. Increasing the number of mineral admixtures usually results in a decrease in strength at early ages if compared to the control combination. Since GD and RHA solely function as inert mineral admixtures in this situation, their roles are also better understood because they lower the SCC's compressive strength. In comparison to the control values of 9.1 N/mm2 and 18.9 N/mm2, respectively, the compressive strength of the SCC mixes at three and seven days after application ranged from 4 to 7 N/mm2 and 11 to 15 N/mm2, respectively. The "dilution effect" (Sani, 2019) refers to the early-age reduction in the compressive strength of SCC mixtures caused by the removal of cement out of the reacting system. This reduction will cause a decrease in the rate of heat development and strength gain corresponding to the amount of cement replaced. The range of compressive strength at 28 days was 25 to 32.3 N/mm2, which is similar to the control value. When compared to the control strength, the compressive strength at 90 days showed higher values, ranging from 20.5 to 36.1 N/mm2. The metallic and micro-filling impact of RHA and GD on the cellular and pore structure of the concrete are responsible for the later age increase in compressive strength. The response surface plots show that the influence of RHA is greater than the impacts of GD and SP on the compressible strength of SCC at all ages. The response spectrum models reach extremely substantial significance ($p < 0.0001$) at all ages, according to the analysis of variance (ANOVA) shown in Tables 6, 7, 8, and 9. The Model F values also show significant models. The model terms' significance is further supported by the P-values. The R2 values show that there is a strong correlation amongst the actual and expected outcomes and that the regression model matches the test data. The adjusted R^2 values have shown that the generated models can explain response value change of 87.5%, 98.95%, 98.56%, and 98.98% at 3, 7, 28, and 90 days respectively. The relationship between the forecast and the experimental values (Predicted and Actual) as presented in Tables 10 and 11 show that the values are distributed comparatively on a straight line. The experimental results are in good agreement with the predicted. The compressive strength models are given by the following equations:

$$3\ days\ compressive\ strength = 8.42 - 0.04 * GD - 0.112\ RHA + 0.163 * SP \quad \text{.. (2)}$$

$$7\ days\ compressive\ strength = 11.96 + 0.0031 * GD + 0.521 * RHA + 0.4208\ SP + -0.0035\ GD\ (RHA) + 0.0025\ GDC(SP) - 0.0166667\ RHA\ (SP) - 0.00013\ (GD)^2 + -0.0164\ (RHA)^2 - 0.1\ (SP)^2 \quad \text{.. (3)}$$

$$\text{28-days compressive strength} = 25.803 + 0.01083\ GD + 0.9472\ RHA + 1.4958\ SP - 0.0067\ GD\ (RHA) - 0.005\ GD\ (SP) - 0.0367\ RHA(SP) - 9.375e-05(GD)^2 - 0.0295556\ (RHA)^2 - 0.3125\ (SP)^2 \quad \text{.. (4)}$$

$$\text{90 days compressive strength} = 26.34 + 0.037GD + 1.041RHA + 4.612SP - 0.007GD(RHA) - 0.006GD(SP) - 0.08RHA\ (SP) - 0.00053(GD)^2 - 0.0291(RHA)^2 - 1.013\ (SP)^2 \quad \text{...(5)}$$

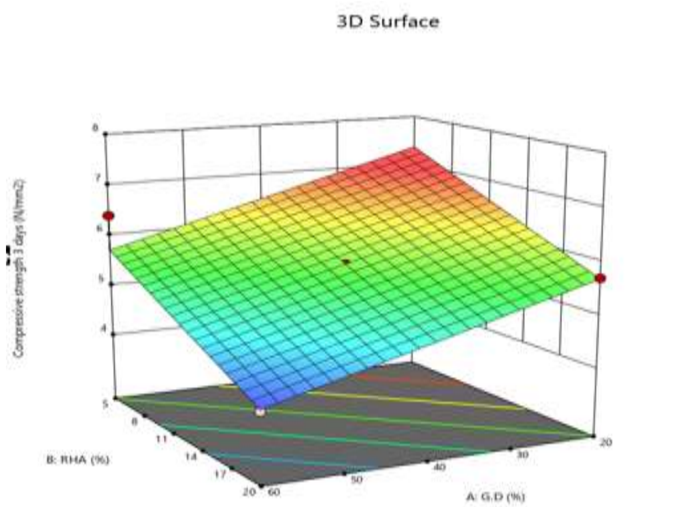

Figure: 43D Reaction Surface for compressive strength after three days

Table 5: Results of compressive strength

Run	Response 1 Compressive strength 3 days (N/mm^2)	Response 2 7 days Compressive strength (N/mm^2)	Response 3 28 days Compressive strength (N/mm^2)	Response 4 90 days Compressive strength (N/mm^2)
C	9.1	18.9	28.1	32.5
1	4	11.5	25	28.9
2	6.5	15.1	32	36.1
3	5.5	12.4	26.5	29.5
4	6.4	13.3	28.6	32.6
5	6.7	15	31.5	35.1
6	6.5	13.9	29.8	33.2
7	5.7	14.4	30.8	35
8	5.7	14.3	30.4	34.6
9	5.7	14.3	30.4	34.6
10	4.4	13.2	28.8	31.9
11	4.6	13	28	32.2
12	5.7	14.3	30.4	34.6
13	6.6	13.8	29.4	32.9
14	7	14.1	30.4	34.5
15	4.5	13.3	27.9	30.4
16	5.7	14.3	30.4	34.6
17	5.7	14.3	30.4	34.6

C* is Control.

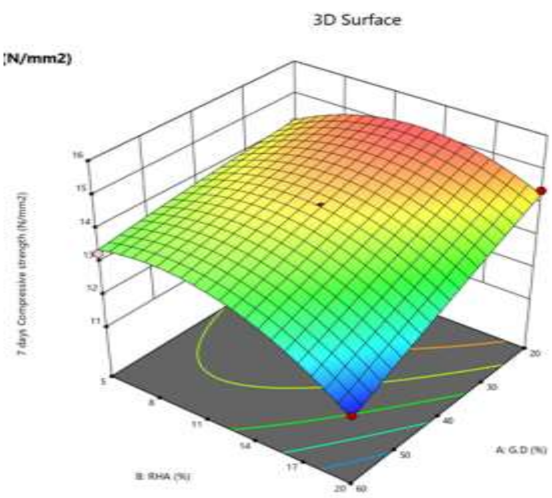

Figure5: The 7-day compressive strength response surface in three dimensions.

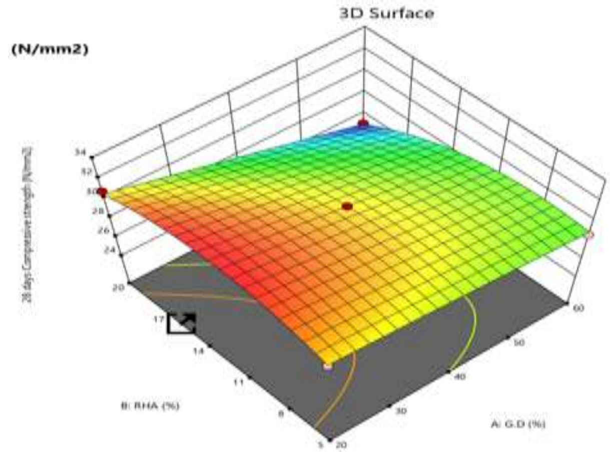

Figure 6: 3D response surface for 28-day compressive strength

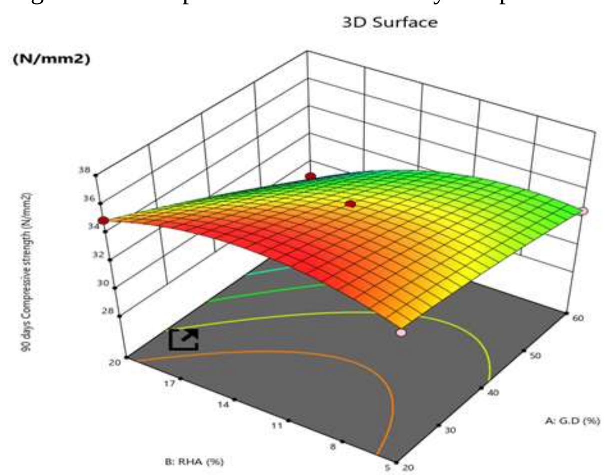

Figure 7: 3D Response surface for 90 day compressive strength

Table 6: Analysis of variance for 3 days comprehensive strength of GD/RHA concrete.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	11.27	3	3.76	38.37	< 0.0001
A-G.D	5.44	1	5.44	55.63	< 0.0001
B-RHA	5.61	1	5.61	57.33	< 0.0001
C-S.P	0.2112	1	0.2112	2.16	0.1656
Residual	1.27	13	0.0979		
Lack of Fit	1.27	9	0.1414		
Pure Error	0.0000	4	0.0000		
Cor Total	12.54	16			

Table 7: Analysis of variance for 7-days comprehensive strength of GD/RHA concrete.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	13.45	9	1.49	73.39	< 0.0001
A-G.D	6.66	1	6.66	327.22	< 0.0001
B-RHA	1.80	1	1.80	88.67	< 0.0001
C-S.P	0.0612	1	0.0612	3.01	0.1264
AB	1.10	1	1.10	54.16	0.0002
B^2	3.60	1	3.60	176.97	< 0.0001
Residual	0.1425	7	0.0204		
Lack of Fit	0.1425	3	0.0475		
Pure Error	0.0000	4	0.0000		
Cor Total	13.59	16			

Table 8: Analysis of variance for 28-days comprehensive strength of GD/RHA concrete.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	51.83	9	5.76	102.71	< 0.0001
A-G.D	25.92	1	25.92	462.27	< 0.0001
B-RHA	7.80	1	7.80	139.13	< 0.0001
C-S.P	1.36	1	1.36	24.28	0.0017
AB	4.00	1	4.00	71.34	< 0.0001
B^2	11.64	1	11.64	207.55	< 0.0001
C^2	0.4112	1	0.4112	7.33	0.0303
Residual	0.3925	7	0.0561		
Lack of Fit	0.3925	3	0.1308		
Pure Error	0.0000	4	0.0000		
Cor Total	52.22	16			

Table 9: Analysis of variance for 90-days comprehensive strength of GD/RHA concrete.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	69.55	9	7.73	173.10	< 0.0001
A-G.D	35.70	1	35.70	799.71	< 0.0001
B-RHA	7.22	1	7.22	161.73	< 0.0001
C-S.P	3.78	1	3.78	84.70	< 0.0001
AB	4.41	1	4.41	98.78	< 0.0001
BC	1.44	1	1.44	32.26	0.0008
B^2	11.29	1	11.29	252.90	< 0.0001
C^2	4.32	1	4.32	96.69	< 0.0001
Residual	0.3125	7	0.0446		
Lack of Fit	0.3125	3	0.1042		
Pure Error	0.0000	4	0.0000		
Cor Total	69.86	16			

Table 10: Table showing actual and predicted values of 3-day and 7-day compressive strength.

Run Order	Actual Value	Predicted Value	Actual Value	Predicted Value
1	4.00	4.04	11.50	11.41
2	6.50	6.36	15.10	15.20
3	5.50	5.02	12.40	12.59
4	6.40	5.71	13.30	13.41
5	6.70	6.69	15.00	14.92
6	6.50	6.37	13.90	13.71
7	5.70	5.69	14.40	14.29
8	5.70	5.70	14.30	14.30
9	5.70	5.70	14.30	14.30
10	4.40	4.71	13.20	13.27
11	4.60	4.70	13.00	13.01
12	5.70	5.70	14.30	14.30
13	6.60	6.70	13.80	13.79
14	7.00	7.36	14.10	14.19
15	4.50	5.04	13.30	13.20
16	5.70	5.70	14.30	14.30
17	5.70	5.70	14.30	14.30

Table 11: Table showing actual and predicted values of 28-day and 90-day compressive strength.

Run Order	Actual Value	Predicted Value	Actual Value	Predicted Value
1	25.00	24.91	28.90	28.64
2	32.00	32.16	36.10	36.05
3	26.50	26.75	29.50	29.71
4	28.60	28.89	32.60	32.64
5	31.50	31.54	35.10	34.92
6	29.80	29.55	33.20	32.99
7	30.80	30.51	35.00	34.96
8	30.40	30.40	34.60	34.60
9	30.40	30.40	34.60	34.60
10	28.80	28.76	31.90	32.08
11	28.00	28.13	32.20	32.29
12	30.40	30.40	34.60	34.60
13	29.40	29.27	32.90	32.81
14	30.40	30.49	34.50	34.76
15	27.90	27.74	30.40	30.45
16	30.40	30.40	34.60	34.60
17	30.40	30.40	34.60	34.60

3.3 Optimization of Self-Compacting Concrete Mixtures

The goals that were set for each response are presented in table 12.

Table 12: Goals used for numerical optimization of SCC.

Compressive strength	Goal
3 days	Maximize
7 days	Maximize
28 days	Maximize
90 days	Maximize

According to the Design-Expert software version 13's optimization function, Figure 8 presents the ideal values of the factors for the maximum concrete strength for RHA-GD SCC. 10% replacement of RHA content and 20% replacement of GD. SP 2% substitution. The compressive strengths after 3, 7, 28, and 90 days are 6.8 N/mm^2, 15.1 N/mm^2, 32.N/mm^2, and 36.3 N/mm^2.

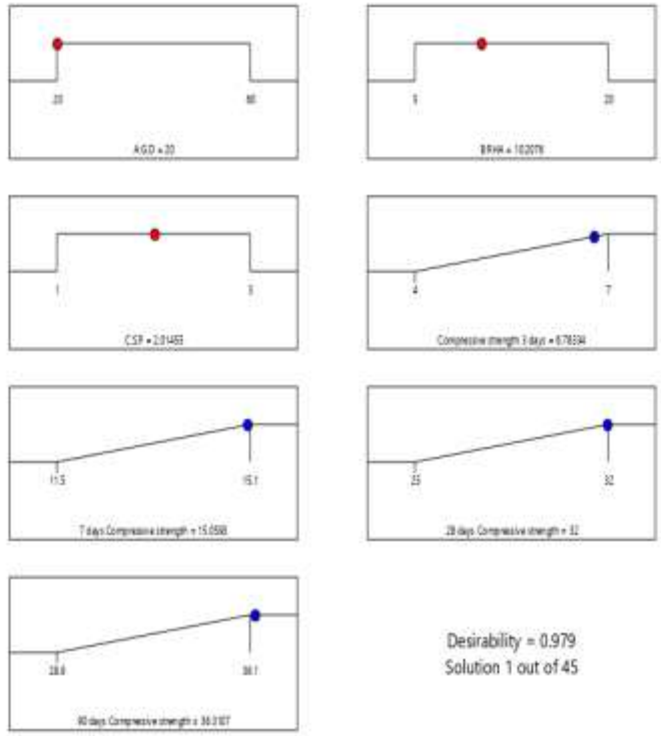

Figure 8: Contour graph showing the optimal values for responses.

4.0 Conclusions

The findings suggest that self-compacting concrete can be effectively made from waste GD and RHA. The investigation leads to the following conclusions:

1. In their fresh form, all of the mixes exhibited good self-compacting capabilities.
2. The results of the slump flow, V-funnel, and J-ring tests showed that the inclusion of GD and RHA improved the workability.
3. RHA is an appropriate pozzolanic building material for long-term growth in strength in SCC due to its high silica concentration.
4. Compressive strength development at 3 and 7 days decreased as dosage of GD and RHA increases.
5. At 28 days, the compressive strength is similar to the control value; however, by 90 days, it surpasses the control value.
6. The optimal percentage replacement levels are 20% GD replacing fine aggregate and 10% RHA replacing cement.

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Declaration of conflict of interest

The authors have collectively contributed to the conceptualization, design, and execution of this study. They have worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the authors do not have any affiliation with any organization that has a direct or indirect financial stake in the subject matter discussed in this manuscript

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