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Original Research Article

Compressive Strength and Optimization of Concrete Produced by Replacing Cement with Coconut Shell Ash (CSA) and Groundnut Shell Ash (GSA)

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Abstract

The compressive strength and optimization of concrete produced by replacing cement with CSA and GSA was conducted in this study. The materials used were cement, water, fine aggregate, coarse aggregate, CSA, and GSA. The CSA and GSA replaced cement at 5, 10, 15, 20, and 25% in combination, with a total of seventy two (72) cubes cast, while the concrete compressive strength was determined after curing by complete immersion in water at 7, 14, 21, and 28 days. The modeling and optimization was done with the aid of design expert (version 13) software, while the Analysis of Variance (ANOVA) was done using SPSS (Statistical Package for Social Sciences) version 23 and adopting the Least Square Difference (LSD) method. Results from the findings showed that the CSA used in the study is a good reactive pozzolana, and the GSA is not a reactive pozzolana. Also, the increase in CSA and GSA content in concrete reduces its workability, and concrete compressive strength. However, cement replaced with 5%CSA-0%GSA gave the optimum 28 days compressive strength which is not statistically significantly from the control concrete and can be used to produce concrete of compressive strength close to the control. Further findings from the regression model showed that CSA-GSA concrete compressive strength significantly fits a linear model and can be used to predict the 7, 14, 21, and 28 days compressive strength of CSA-GSA concrete, while the optimized result showed that CSA and GSA replacement of cement at 3.29% and 4.45% respectively yielded an optimum compressive strength of approximately 22.31N/mm^2.

Keywords: Groundnut shell ash (GSA), Coconut shell ash (CSA), Concrete, Compressive-strength, Optimization, Modeling.

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1.0 INTRODUCTION

Concrete is a construction material that comprises of coarse aggregates commonly gravel, fine aggregates usually sand, cement, water, and any other essential additives (McCormac & Brown, 2015). Concrete possesses many favorable properties as a structural material, among which are its high compressive strength and durability properties. However, the conventional concrete technology uses the ordinary Portland cement (OPC) as the main binder, which is a key contributor to global CO_2 emissions (Shoaei *et al*., 2020). This and several factors have led to quest of alternative materials for replacement of cement in concrete.

The recycling of agricultural waste materials for use as partial replacement material of cement in concrete production has proven to be an effective way of disposing of them (Zareei *et al*., 2019). Products like coconut shell ash (CSA), groundnut shell ash (GSA), egg shell ash (ESA), and rice husk etc., which are agricultural byproducts, have mainly been used and integrating these industrial by-products to partially substitute the use of cement in concrete has become common (Hanif *et al*., 2017; Kwan & Chen, 2013).

In developing countries like Nigeria and most African countries, the constant rise in the price of cement has motivated researchers to explore the viability of some pozzolanic materials as replacement materials, which would be used as partial replacement for cement and reduce the cost of cement, such that more people can afford to build their houses (Mujedu & Adebara, 2016). One of those materials includes

Coconut Shell Ash (CSA) and Groundnut Shell Ash (GSA) which is considered in this study.

Coconut is grown in more than 92 countries in the world. Presently the world production of coconuts stands at 62,450,192 metric tons and Nigeria as the 19th producer in the world and 5th in Africa, which translate to a total of 295,000 metric tons to the total world production (FAOSTAT, 2015). Groundnut shell on the other hand is an agricultural waste gotten from milling of groundnut. Nigeria contributes about 7 percent of world groundnut production which makes Nigeria the 3rd largest producer of groundnut in the world. In Nigeria, the foremost producing states include Niger, Kano, Jigawa, Zamfara, Kebbi, Sokoto, Katsina, Kaduna, Yobe, Adamawa, Borno, Taraba, Plateau, Nasarawa, Bauchi, Gombe and Kwara. It is projected that over 2million hectares are planted to groundnut in Nigeria (NAERLS, 2011).

However, CSA and GSA have been reported to cause environmental hazard in several studies. Bamgboye and Jekayinfa (2006) reported that about 90% coconut (empty fruit bunches, fibers, fronds, trunks, shells) was thrown away as a waste and either burnt in the open air or left to settle in wastes ponds. Also, Elinwa and Mahmood (2002) reported that groundnut shell is found in both the urban and rural areas of Nigeria as a waste after been consumed.

Therefore, the use of agricultural by-products such as CSA and GSA can help to reduce the need for Portland cement in addition to creating more durable concrete and reducing greenhouse gas emissions (Malhotra, 2004; Mehta, 2002). Mujedu and Adebara (2016) reported the use of groundnut shell ash (GSA) up to 15% replacement of ordinary Portland cement in concrete. They also added that the strength of OPC/GSA concrete was lower than that of 100% cement, but it can still be used for constructing of light load bearing structures. Kumar *et al*., (2017) concluded that the partial replacement of cement with CSA gives an average optimum compressive strength of 21.7 MPa at 28 days, and they added that the use of coconut shell ash as a partial replacement of cement produced a cheaper structural light weight concrete. Kumar and Kumar (2014) concluded that the OPC – CSA mix gives an average optimum compressive strength of 31.78MPa at 28 days.

From the foregoing, due to waste management problem of CSA-GSA and the high cost of conventional cement in concrete production coupled with its environmental impact of CO_2 emissions, this research seeks to investigates the use of Coconut Shell Ash (CSA) and Groundnut Shell Ash (GSA) to partially replace cement without negatively affecting the performance of the final product.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Cement

Cement was obtained from the open market at Zaria-Kaduna State, Nigeria and used for the experiment.

2.1.2 Water

Water from department of Building Laboratory of Ahmadu Bello University (ABU) Zaria was used in producing the concrete mixture for this study.

2.1.3 Fine Aggregate

The fine aggregate used was sieved through a BS 4.75mm sieve to remove some of the contained coarse aggregates.

2.1.4 Coarse Aggregates

Crushed granite was used in this research. It was obtained from a local dealer within Zaria city.

2.1.5 Coconut shell ash

The coconut shell was obtained from Sabon Gari local government of Kaduna state, Nigeria. It was cleaned from impurities, sun-dried for 48 hours to remove moisture and possible debris, after which it was burnt to ash (control burning) and further heated at a temperature of 600^oC for 2 hours, and sieved through 75µm.

2.1.6 Groundnut shell ash

The Groundnut shell was also obtained from Sabon Gari local government of Kaduna state, Nigeria. It was also cleaned from impurities, sun-dried for 1 week to remove moisture and debris, after which it was burnt to ash (control burning) and further heated at a temperature of 650^oC for 3 hours, and sieved through 75µm.

2.2 Methods

2.2.1 Tests on Cement

2.2.1.1 Consistency of Cement

This test was conducted in accordance to BS-EN-196-3 (2016). The test was conducted in the concrete laboratory of Building Department in Ahmadu Bello University Zaria, Nigeria.

2.2.1.2 Setting Time of Cement

The test was conducted as described in BS-EN-196-3 (2016).

2.2.1.3 Soundness of Cement

The test was conducted on cement using the Le Chaterlie's mould as described in BS-EN-196-3 (2016). The specimens were prepared using the water-cement ratio as determined from the consistency test. The expansion of each of the specimen was measured.

2.2.1.4 Specific Gravity of Cement
This test was carried out according to BS-EN-196-3 (2016).

2.2.2 Tests on Aggregate
2.2.2.1 Sieve analysis of materials
Sieve analysis was conducted on fine and coarse aggregate (NA, RAP, and RCA) using various sieve sizes in accordance with BS-882:2 (1992).

2.2.2.2 Water absorption tests
The test was conducted in accordance with BS-812:2 (1995).

2.2.2.3 Specific gravity test
The specific gravity tests for coarse and fine aggregates were conducted in accordance with BS-812:2 (1995).

2.2.2.4 Bulk density test
The test was performed to determine the weight that would fill a unit volume and was conducted in accordance with BS-812:2 (1995).

2.2.2.5 Aggregate Impact Value Test
The test was conducted in accordance to British standard BS-812-110 (1990) which specified maximum value of 25 percent when the aggregate is to be used in heavy duty floors, 30 percent when the aggregate is to be used in concrete for wearing surfaces and 45 percent when it is to be used in the other concrete.

2.2.2.6 Aggregate Crushing Value
Aggregate crushing value gives a relative measure of the resistance of an aggregate sample to crushing under gradually applied compressive load. This test was performed with a single size aggregate passing 12.7mm sieve and retained in 9.52mm sieve. The aggregate crushing value test was carried out in accordance with BS-812-110 (1990).

2.2.3 Oxide composition test
The chemical composition of the cement, CSA, and GSA used in this research was carried out using XRF test in accordance with ASTM-C618 (2008).

2.2.4 Workability of Concrete (Slump Test)
The test is used as a measure of workability of concrete. Slump test was conducted in accordance with BS-EN-12350 (2009)

2.2.5 Compressive Strength Test
The compressive strength test of the hardened concrete was determined using the compressive testing machine at the concrete laboratory of Department of Building, Ahmadu Bello University Zaria.

2.3 Concrete Mix Proportion
The batching was carried out by substituting the cement partially with coconut shell ash (CSA) and groundnut shell ash (GSA). A total number of six (6) experiments were prepared with mix proportions by weight, mix ratios of 1:2:4 and a water cement ratio of 0.55 was adopted. Twelve (12) numbers of cubes were produced for each experiment in triplicates and crushed at 7, 14, 21, and 28, curing periods respectively making it a total of seventy two (cubes) as shown in Table 1.

Table 1: Materials Schedule

S/No	Cement replacement	CSA (%)	GSA (%)	Concrete Cubes
1	Control (100%)	0	0	12
2	5%	5	0	12
3	10%	5	5	12
4	15%	5	10	12
5	20%	5	15	12
6	25%	5	20	12
Total				**72 cubes**

2.5 Model of CSA-GSA Concrete
Regression models were formulated to predict the 3, 7, 14, 21, and 28 days compressive strength of RAP and RCA concrete, while Analysis of Variance (ANOVA) on the concrete compressive strength was done using SPSS (Statistical Package for Social Sciences) version 23 and adopting the Least Square Difference (LSD) method of ANOVA. In the analysis of the data, a 95% confidence level was adopted and values less than 0.05 were considered to be statistically significant while values that are greater than 0.05 were considered not statistically significant.

3.0 RESULTS AND DISCUSSION
3.1 RESULTS
3.1.1 Preliminary Test on Materials
Preliminary tests were conducted on the materials used in this study to determine its conformity to relevant code; tests were conducted on cement, aggregates, CSA, and GSA and are presented in Table 2.

Table 2: Preliminary Tests Result

Description of Test	Results	Standard	Code
Cement			
Consistency (%)	29.3	26-33%	BS-EN-196-3 (2016)
Initial setting time (mins)	88	≥45	BS-EN-196-3 (2016)
Final setting time (mins)	149	≤ 600	BS-EN-196-3 (2016)
Soundness (mm)	1.0	≤ 10mm	BS-EN-196-3 (2016)
Specific gravity	3.13	3.1 – 3.16	BS-EN-196-3 (2016)
Aggregates			
Bulk density	**(kg/m^3)**		
Fine aggregate	1498	<1520	BS-812:2 (1995)
Coarse aggregate	1788	<1520	
Specific Gravity			
Fine aggregate	2.59	2.5 – 2.8	BS-812:2 (1995)
Coarse aggregate	2.77		
CSA	2.38		
GSA	2.35		
Aggregate Crushing Value	(%)		
Coarse aggregate	17.02	< 25%	BS-812-110 (1990)
Aggregate Impact Value	(%)		
Coarse aggregate	21.3	< 25%	BS-812-110 (1990)
Water Absorption	(%)		
Coarse aggregate	0.22	< 3%	BS-812:2 (1995)
Cement	0.55		
CSA	1.42		
GSA	1.39		

The results from Table 2 shows that the cement used in this study is adequate for concrete production since the consistency (29.3%), initial setting time (88 minutes), final setting time (149 minutes), soundness (1mm), and specific gravity (3.13) all met code requirements.

Also, from the table, the fine and coarse aggregate used in this study were found to be adequate for concrete production since the specific gravity, bulk density, aggregate crushing value, and aggregate impact value all met code requirements. The specific gravity of the CSA (2.38) and GSA (2.35) is lower than that of the coarse and fine aggregate (2.57-2.77) which can be attributed to the lightweight of the materials (CSA-GSA). Hence makes is less dense.

Finally, from the table, the water absorption value of the CSA (1.42%) and GSA (1.39%) is higher than that of the coarse aggregate (0.22%) and cement (0.55%). This is an indication that higher amount of CSA-GSA in concrete mix will absorb more water.

Table 3: Oxide Composition of Cement, CSA and GSA

Oxides Composition	OPC (%)	CSA (%)	GSA (%)
Na_2O	0.710	0.986	0.844
MgO	1.690	1.792	3.090
Al_2O_3	5.700	25.575	4.099
SiO_2	14.980	44.548	27.625
P_2O_5	-	2.891	5.232
SO_3	2.670	3.270	2.741
Cl	-	0.330	0.660
K_2O	0.100	7.035	38.574
CaO	68.300	4.254	15.563
TiO_2	0.220	0.985	1.444
Cr_2O_3	0.010	0.007	0.005
Mn_2O_3	-	0.129	0.163
Fe_2O_3	4.100	11.042	5.668
ZnO	-	0.077	0.225
SrO	-	0.063	0.135

The results from Table 3 shows that the combination of SiO_2, Al_2O_3 and Fe_2O_3 is approximately 81.16% and 37.39% for CSA and GSA respectively which is an indication that the CSA is a good reactive pozzolana, while the GSA is a low reactive pozzolana since the presence of siliceous and aluminous material in coconut shell ash and groundnut shell ash indicates that in finely grounded form, it can react with calcium hydroxide to form calcium silicates hydrate (CSH) which is a strength forming product in cement (ASTM-C618, 2008). Also, the values of SO_3 of 3.270% for CSA, and 2.741% for GSA are lower than the 4% specified by ASTM-C618 (2008) which indicate the possibility of improved durability and of soundness when use in concrete.

3.1.2 Gradation of Fine Aggregate

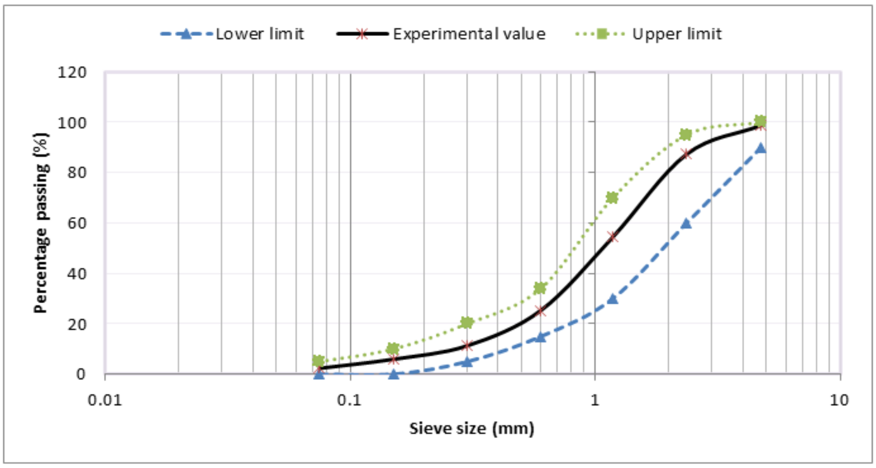

Figure 1: Particle Size Analysis of Fine aggregate

Figure 1 shows the particle size results of the fine aggregate used in this research. BS-882:2 (1992) was used to grade the fine aggregate which showed that the fine aggregates were of grading zone 1 (15% finer than 600µm and 35% coarser than 600µm). This shows that the fine aggregate is suitable for use in concrete.

3.1.3 Gradation of Coarse Aggregate

The coefficient of uniformity indicates that the fine aggregate is well graded i.e. Cu > 4.0, for fine aggregates. Hence good concrete/mortar can be made with this fine aggregate.

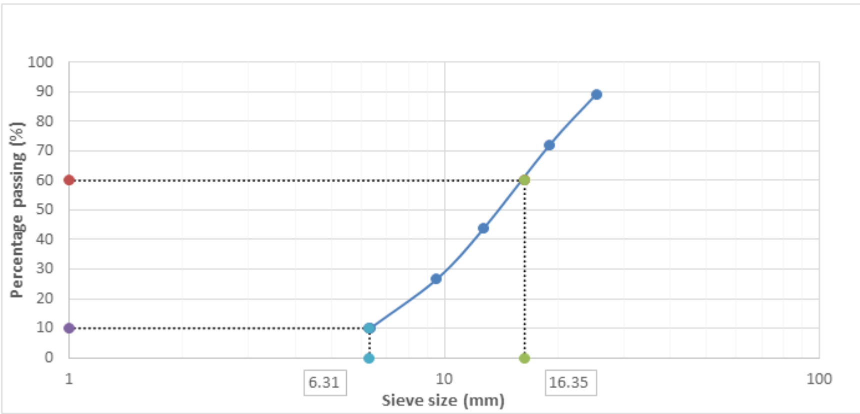

Figure 2: Sieve Analysis of Coarse Aggregate

From the curves, the coefficient of uniformity (C_u) of the fine aggregate is given as;

D_{10} = 6.31 mm, D_{60} = 16.35 mm

Hence

$$C_u = \frac{D_{60}}{D_{10}} = \frac{16.35}{6.31} = 2.59$$

The coefficient of uniformity indicates that the coarse aggregate is well graded i.e. Cu > 2.0, for coarse aggregates. Hence good concrete can be made with this aggregate.

3.2 CSA-GSA Concrete Slump

The test was conducted to determine the workability of control concrete and CSA-GSA concrete, and the result is presented in Figure 3.

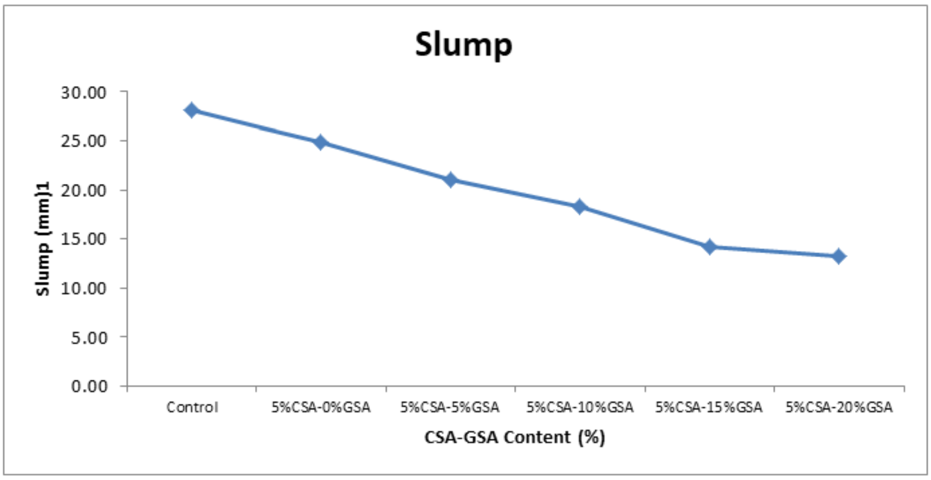

Figure 3: Workability of CSA-GSA Concrete

The result from Figure 3 shows that the slump decreased as replacement of CSA-GSA content increases as partial replacement of ordinary Portland cement which can be attributed to the high absorption ability of CSA and GSA as reported in Table 2. Thus, it can be inferred that to attain the require workability, mixes containing CSA-GSA will required higher water than the conventional mix (control).

3.3 Compressive Strength

The compressive strength of CSA and GSA concrete was determined at days 7, 14, 21, and 28 days which was compared to the control, and the results are presented below.

a = values that are not statistically significant from the control

b = values that are statistically significant from the control

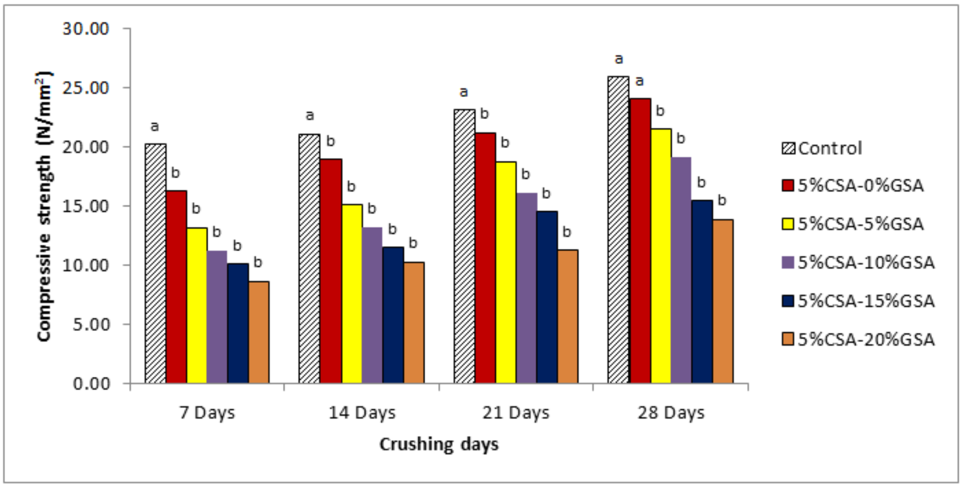

Figure 4: Compressive Strength of CSA-GSA Concrete

The result from Figure 4 shows that cement replacement of 5% CSA have the optimum compressive strength at day 3, 7, 14, 21, and 28 days respectively, followed by replacement of 5%CSA-5%GSA. Also from the result, as the control concrete increases, the experimental concrete decreases as CSA- GSA content increases, this can be attributed to dilution effect of Portland cement and weaker formation of C-S-H gel as a result of pozzolanic reaction of CSA-GSA. Also from the results in Figure 4, the mean compressive strength of the control concrete is significantly higher that all CSA-GSA concrete at 7, 14, and 21, days. However, the mean compressive strength of the control concrete is not significantly higher that 5% (5%CSA-0%GSA) replacement at 28 days but higher than the rest CSA-GSA concrete at 28 days (i.e. p-values < 0.05). This is an indication that the CSA-GSA concrete of 5%CSA-0%GSA replacement of cement can produce concrete of compressive strength close to the control.

3.4 Regression Model of CSA-GSA Concrete

The regression analysis was conducted in order to predict the 7, 14, 21, and 28 days compressive strength of CSA-GSA concrete as shown in Table 4.

Table 4: Model for Compressive Strength of RAP and RCA Concrete

Days	Model	R^2 Value	Adjusted R^2	Predicted R^2	p-value
7 days	20.173 – 0.936A -0.364B	0.9741	0.9707	0.9584	0.000
14 days	21.025 – 0.618A -0.417B	0.9645	0.9598	0.9510	0.000
21 days	23.013– 0.376A -0.482B	0.9678	0.9635	0.9529	0.000
28 days	25.872– 0.370A -0.526B	0.9771	0.9740	0.9702	0.000

Note: A = %CSA; and B = %GSA;

The result from Table 4 shows that the 7, 14, 21, and 28 days CSA-GSA concrete compressive strength significantly fits a linear model with p-values less than 0.05. Also, the predicted R^2 values are in reasonable agreement with the Adjusted R^2 values with a difference less than 0.2. However, the R^2 value of the 28 days compressive strength is the highest (0.9740) compared to the 7, 14, and 21 days compressive strength. Hence, the model can significantly predict the 28 days compressive strength of CSA-GSA concrete.

3.5 Optimization of CSA-GSA Concrete

Optimization was also done such that the dependent variable (28 days compressive strength) was maximized, and the independent variables (%CSA and %GSA) were also maximized and the result is presented in Figure 4.

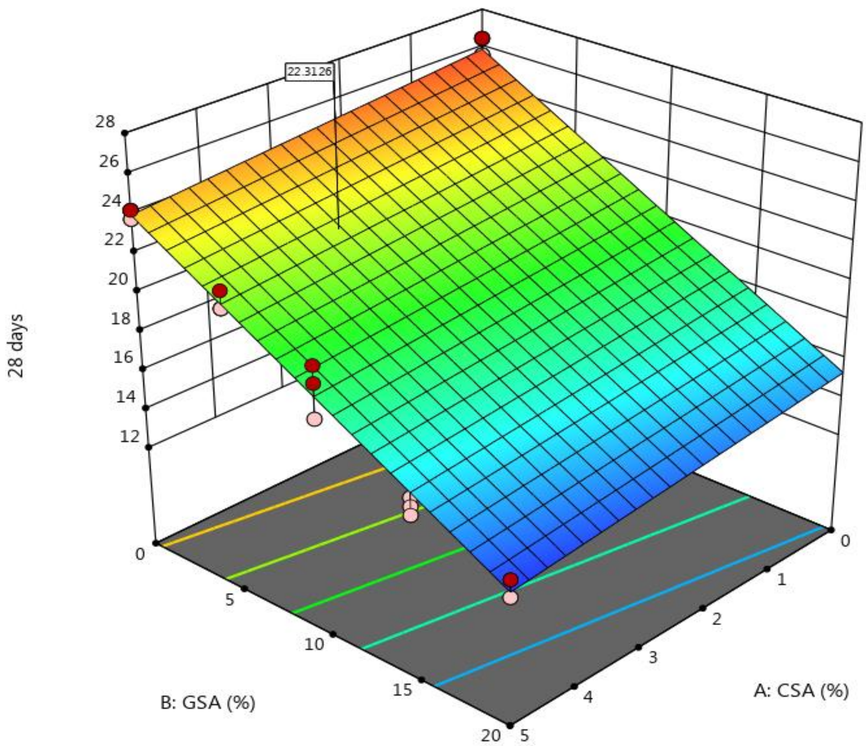

Figure 5: Optimized 28 Days CSA-GSA Concrete Compressive Strength

In the optimization, 3 runs were analyzed out of the 50 number of design points, while the optimized parameters with a desirability value of 0.531 was selected among the 3 runs since it is closest to 1. However, the result from Figure 5 shows that the optimized CSA-GSA concrete compressive strength is approximately 22.31N/mm^2 when concrete is produced by replacing CSA and GSA at approximately 3.29% and 4.45% respectively.

To validate the optimized result, the percentage replacement of CSA (3.29%) and GSA (4.45%) was substituted in the 28 days predictive model of concrete compressive strength from Table 4 given as;

25.872– 0.370A -0.526B
Where,
A = CSA = 3.29%
B = GSA = 4.45%

Therefore;
25.872 – 0.370 (3.29) - 0.526 (4.45) = 22.314 N/mm^2.

Hence, the value of the optimized (22.313 N/mm^2) 28 days compressive strength is close to the predictive model (22.314 N/mm^2) 28 day's compressive strength of CSA-GSA concrete.

4.0 CONCLUSION

This study was conducted to determine the compressive strength and optimization of concrete produced by replacing cement with CSA and GSA. At the end of the findings, it was concluded that the CSA used in this study is a good reactive pozzolana, while the GSA is a low reactive pozzolana. Also, the increment of CSA-GSA in concrete reduces workability due to its high absorption ability, while concrete compressive strength also reduces as CSA- GSA content increases. However, cement replacement of 5% CSA have the optimum 28 days compressive strength which is not statistically significantly from the control concrete, followed by replacement of 5%CSA-5%GSA. The result from the regression model showed that CSA-GSA concrete compressive strength significantly fits a linear model and can be used to predict the 7, 14, 21, and 28 days compressive strength of CSA-GSA concrete. The optimized result showed that CSA and GSA replacement of cement at 3.29% and 4.45% respectively, will give an optimum compressive strength of approximately 22.31N/mm^2.

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