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Development of Optimum Mix Design for Local Metakaolin Based Geopolymer Concrete

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Abstract- Researchers all over the globe are still working to arrive at an intentionally standard mix design for geopolymer concrete (Singh and Kapoor, 2022). To enhance the compressive strength of geopolymer concrete, this study investigates the impact of the metakaolin content, liquid-to-solid (L/S) ratio and the sodium silicate-to-sodium hydroxide (SS/SH) ratio. 20 sets of experiments were designed and tested for the compressive strength based on the response surface methodology technique. The optimal parameters were obtained via modeling of the 3 factors (metakaolin content, L/S ratio and SS/SH ratio) and 3 levels of compressive strength (3 day, 7 day and 28 day). The optimized results showed that the highest compressive strengths of the geopolymer concrete are 16.9N/mm^2 for 3 day, 30.3N/mm^2 for 7 day and 44.1N/mm^2 for 28 day curing when the three optimized factors are 420 grams for metakaolin content, 0.8 for L/S ratio and 1.7 for SS/SH ratio. Finally, the optimized factors (A) of 420 grams and factor C of 1.7 are higher by 5% and 13% than the actual test data of 400 grams and 1.5 for factors A and C respectively. It can then be concluded that the optimized factors setting influences the responses more than the actual test data.

Key Words: Optimum, Mix Design, Metakaolin and Geopolymer

I. INTRODUCTION

Geopolymer that is produced by mixing reactive aluminosilicate material with an adhesive usually alkaline solution is an inorganic aluminosilicate material. Geopolymer resource consumption, energy consumption, and CO2 emissions are significantly lower than those of Ordinary Portland Cement. According to Chen et al. (2021), the carbon dioxide emission into the air is one of the side effects of producing Portland cement. Parathi et al. (2021) and Kumar D. R. (2020) reported that the production of one ton of Portland cement produces one ton of carbon dioxide to the air which contributes much to the global warming. According to Hardjito et al., (2014), the search for environmentally friendly construction materials is imperative as the world is facing serious problems due to environmental degradation. Therefore, now geopolymer concrete becomes popular material because it does not need Portland cement as a binder, but uses natural materials such as Metakaolin, Fly Ash and Rice Husk Ash (Sharati et al. 2022).

Davidovits (1994) stated that natural material for replacing Portland cement in geopolymer concrete must contain high percent of silica and alumina. These elements react with alkaline liquids to develop a polymerization process that results in producing geopolymer binder. The metakaolin, which has high content of silica and alumina, reacts with alkaline solution like sodium hydroxide NaOH or potassium hydroxide KOH, and sodium silicate Na2SiO3 or potassium silicate K2SiO3, to form a gel that binds the fine and coarse aggregates. NaOH and KOH have been used as the alkalis for metakaolin geopolymer production. To produce geopolymer, the proportion of Na2SiO3 to NaOH in the alkaline solution is paramount. It determines the rate and extent of geopolymerization reaction (Pelisser et al., 2013). NaOH acts as an aluminosilicate dissolvent while Na2SiO3 acts as a binder in the geopolymerization process. The importance of solid/Liquid (S/L) ratio cannot be overemphasized as it governs the solid-liquid mass needed for homogeneous mixing which in turn could affect the geopolymer formation process, and the ultimate strength of the final geopolymer product (Ming et al., 2016). According to research conducted by Xiao et al., (2019) on geopolymerization process of alkali-metakaolin, S/L ratios above 2.0 were observed to result in metakaolin geopolymer with low workability while at low values of (0.4) S/L ratio, geopolymerization reaction seemed to be delayed. An S/L ratio of 0.8 was recommended by Kong et al. (2017) as the optimum for metakaolin-based geopolymer. The quest for development of fully pozzolanic binder for sustainable construction, having the same mechanical properties as Portland cement is still a major issue, as the mix design for geopolymer concrete is yet to evolve. Despite geopolymer concrete being a promising alternative to Portland/lime cement concrete, it has no code or mix specification to guide the choice of material mix proportion for specific grades of concrete (Shi et al. 2022) The recent modified types of Civil Engineering Software could offer sustainable solutions in addressing the problem of not having a standard code or mix specifications to guiding the choice of materials mix proportion for specific grade of concrete (Sharati et al. 2022). An experiment designed by central composite design in response surface methodology was used to produce an optimized geopolymer concrete mix design by varying the mix proportions, in order to achieving a grade 25 geopolymer concrete (Sun et al. 2018). This investigative work is limited to geopolymer of metakaolin based from Alkaleri kaolin clay in Bauchi state, Nigeria. The best performing mix ratio was evaluated through 3day, 7day and 28day Compressive Strength determination. The majority of the guidelines available on concrete are based on the pool of experimental data. Here, this study would contribute for the same and, in the process, understands the parameters governing the fresh and hardened properties of geopolymer concrete.

II. MATERIALS

The Alkaleri metakaolin (AMK) used in this study had a specific gravity of 2.28 and a bulk density of 215 Kg/m3 with a fineness (Blaine's) of 1488 (m2 /kg). The loss on ignition is 0.27%. The oxide composition of the metakaolin obtained from XRF analysis is listed in Table 1. Commercial grade Sodium Hydroxide (SH) flakes has a purity of 99%. The sodium silicate solution exhibited a SiO_2/Na_2O modulus of 2, which is ideal for promoting effective geopolymerization, were used. The composition and properties of the SS provided are given in Table 2. Bayara river sand in Bauchi state used, had a specific gravity of 2.55, bulk density of 1581 kg/m3, and fineness modulus of 2.73. Broken angular granite aggregates of 20mm size with a specific gravity of 2.69, and a bulk density of 1450 kg/m3 was used in making the concrete. The raw materials and the particle size distribution analysis for the AMK powder are depicted in figures 1 and 2 respectively.

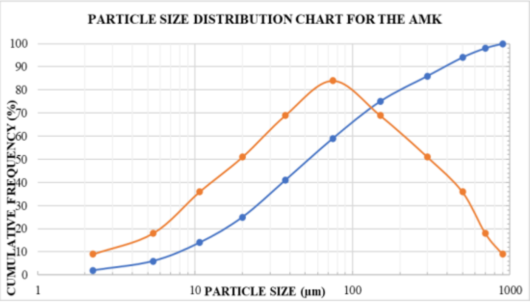
Table 1: Chemical Composition of the AMK

Oxides	Mass (%)
AL_2O_3	35.02
SiO_2	61.61
Fe_2O_3	1.89
Cao	0.15
SO_3	0.18
MgO	0.16
Na_2O	0.11
K_2O	0.50
MnO	0.11
L.O. I	0.27
Total	100.00

Table 2: Oxide Composition and Properties of Sodium Silicate

Na_2O (%)	SiO_2 (%)	Water (%)	Total Solid (%)	Specific Gravity
15.00	30.00	55	45	1.5

Figure 1: Raw Materials Used in this Study



D10------------2.3µm   Mean-------------- 246µm
D50-----------54µm   Mode-------------- 75µm
D90-----------380µm   Median------------ 38µm

Figure 2: Particle Size Distribution Curve for the Metakaolin Powder.

III. THE EXPERIMENT DESIGNED FOR THIS STUDY

Response Surface Methodology (RSM) through central composite design (CCD) was used in designing the experiment for this study and this is depicted in table 3. The independent variables (factors) used in this work include metakaolin content, liquid/solid ratio and sodium silicate/sodium hydroxide ratio and denoted by the letters A, B, and C respectively. While the dependable variables (responses) for the study are compressive strengths at 3day, 7day and 28day curing.

Table 3: Design of Experiment

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
Run	A:MK Content	B:L/S Ratio	C:SS/SH Ratio	3day C/S	7day C/S	28day C/S
	grams	------	------	N/mm2	N/mm2	N/mm2
1	315.91	0.8	1.5			
2	400	0.968179	1.5			
3	400	0.8	1.5			
4	400	0.631821	1.5			
5	400	0.8	1.5			
6	450	0.7	1			
7	400	0.8	1.5			
8	400	0.8	1.5			
9	400	0.8	1.5			
10	350	0.9	2			
11	400	0.8	1.5			
12	350	0.9	1			
13	450	0.9	2			
14	400	0.8	0.659104			
15	450	0.9	1			
16	450	0.7	2			
17	350	0.7	2			
18	350	0.7	1			
19	484.09	0.8	1.5			
20	400	0.8	2.3409			

IV. CONCRETE WORK AND LABORATORY TESTS

The sodium hydroxide solution of concentration 10M was prepared by dissolving the measured required quantity of solid sodium hydroxide in water and the solution was left to stay for 24 hours. Then, the metakaolin powder was mixed with the solution and stirred for 1 minute. The sodium silicate solution was added, and the mixture was heated for 45 minutes at interval of 15 minutes stirring at temperature of 60^{oc} until it was well mixed. Plates 1 and 2 depicted the preparation procedure of the alkaline solution. The measured aggregates (sand & gravel) weights were added to the heated mixture and thoroughly mixed for 5 minutes. After the mixing procedure was done, the fresh geopolymer concrete was cast into 100 mm X 100 mm X 100 mm cube mold. The specimens were obtained after compacting and pounding. In this work the concrete works carried out include preparations of sodium hydroxide solution and alkaline solution, dry and wet mixing of the geopolymer concrete ingredients, compaction and placing of the prepared concrete into the cube moulds, ambient curing of the geopolymer concrete specimens and compressive strength determination of the geopolymer concrete specimens at 3rd, 7th and 28th days of curing and all these procedures/processes are depicted in plates 1 to 6.

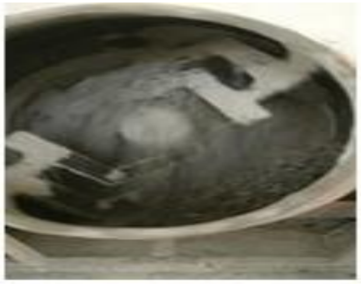
Plate 1: NaOH Flakes

NaOH Solution

Plate 2: Na_2SiO_3 Solution

Mixture of NaOH and Na_2SiO_3 Solutions

Plate 3: Dry Mixing of Materials



Wet Mixing of Materials

Plate 4: Final Geopolymer Concrete

Final Geopolymer Concrete

Plate 5: Ambient Curing of Metakaolin Based Geopolymer Concrete

Plate 6: Compressive strength test procedure of MK Based Geopolymer

V. RESULTS AND DISCUSSIONS

5.1. Analysis of Experimental Results

Compressive strength determination were performed on 60 cubes of geopolymer concrete. The measured compressive strengths for the Alkaleri metakaolin based geopolymer concrete is presented in Table 4. Out of the average 20 test data recorded, 6 of them are the center points of the design area to estimate the test error. The results were obtained after analyzing the relationship between the compressive strength values of the specimens cured for 3day, 7day and 28day and the three variables metakaolin content (A), liquid/solid ratio (B), and sodium silicate/sodium hydroxide (C) as shown in Table 4. The findings indicate a distinct trend in which MK content, L/S and SS/SH ratios substantially affect the compressive strength of the geopolymer concrete. The compressive strength at 3day, 7day and 28day of the MK750-based geopolymer consistently rises across all the L/S and SS/SH ratios. As the Mk content increases from 350 grams to 400 grams, L/S ratio from 0.7 to 0.8 and SS/SH ratio from 1.0 to 1.5, the compressive strength at 3day, 7day and 28day rises by 16.0%, 16.0% and 15.0% respectively, with the compressive strength increasing from 14.6 N/mm^2 to 16.9 N/mm^2, 26.1N/mm^2 to 30.2N/mm^2 and 38.3N/mm^2 to 44.1N/mm^{2}respectively. Also, as the MK content increases from 400 grams to 450 grams, L/S ratio from 0.8 to 0.9 and SS/SH ratio from 1.5 to 2.0, the compressive strength at 3day, 7day and 28day rises by 10.0%, 11.0% and 11.0% respectively, with the compressive strength dropping from 16.9 N/mm^2 to 15.2 N/mm^2, 30.2N/mm^2 to 26.8N/mm^2 and 44.1N/mm^2 to 39.4N/mm2 respectively. From this trend of increase and decrease by the factors and responses, it can be observed that beyond L/S ratio of 0.8, the compressive strength decreases all across the independent and dependent variables levels. This suggested that at MK content of 400 grams, L/S ratio of 0.8 and SS/SH of 1.5 is the optimum mix, with the highest compressive strength at 3day, 7day and 28 days of 16.9N/mm^2, 30.2N/mm^2 and 44.1N/mm^2 respectively. However, at very high L/S ratios such as 0.9, compressive strength starts to stabilize or slightly decrease for some SS/SH ratios such as 2.5, likely due to excessive liquid content causing the reduction in cohesion (Liew Y. M. et al., 2011). This decrease in compressive strength can be attributed to rise in water content in mix with liquid/solid ratio beyond 0.8. An oversaturated geopolymer system may result from an excessively high L/S ratio, which could potentially impair the formed structure. This oversaturation can be ascribed to the surplus Na content in the geopolymer system (Mohammed ASSK and Geber R., 2024). The geopolymerization process may be impeded and the resultant geopolymer concrete may be compromised as the SS/SH ratio rises. Conclusively, the selection of geopolymer concrete material is contingent upon the particular application, necessitating a balance among performance, cost, and environmental impact.

Table 4: Measured Compressive Strengths for the 20 Mixes

	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
Run	A:MK Content	B:L/S Ratio	C:SS/SH Ratio	3day C/S	7day C/S	28day C/S
	grams	------	------	N/mm2	N/mm2	N/mm2
1	315.91	0.8	1.5	15.3	27.3	40.2
2	400	0.968179	1.5	14.5	26.0	38.2
3	400	0.8	1.5	16.9	30.2	44.1
4	400	0.631821	1.5	13.6	24.3	35.7
5	400	0.8	1.5	16.8	30.0	44
6	450	0.7	1	14.7	26.4	38.8
7	400	0.8	1.5	16.7	29.9	43.9
8	400	0.8	1.5	16.8	30.3	44.1
9	400	0.8	1.5	16.7	30.0	43.9
10	350	0.9	2	15.3	27.2	40.2
11	400	0.8	1.5	16.7	30.1	44
12	350	0.9	1	15.0	26.8	39.4
13	450	0.9	2	15.2	27.2	40
14	400	0.8	0.659104	14.2	25.4	37.3
15	450	0.9	1	15.1	26.9	39.6
16	450	0.7	2	14.9	27.9	39.2
17	350	0.7	2	14.8	26.7	38.9
18	350	0.7	1	14.6	26.1	38.3
19	484.09	0.8	1.5	16.9	30.3	44.5
20	400	0.8	2.3409	16.4	29.4	43.2

5.2 Statistical Analysis of Compressive strength models

In the statistical significance test method, the significance of the difference between the specimens was very significant when the probability p of the difference between the samples caused by sampling error was less than 0.01. p-value between 0.01 and 0.05 was considered significant, $p > 0.05$ is not significant (Singh P. and Kapoor K., 2022). The p value usually measures the misfit error between the model function f and the proper function. In the case of $p < 0.05$, the error was significant, and the fitted model equation was invalid. The larger the p value (which does not exceed 1), the better the effect of the fitted model equation (Dollente I. J. R., 2021). Table 5 presents the summary of fit statistics from analysis of variance (ANOVA). It can be seen that the model F-values for the three compressive strengths (responses) are higher than the critical F-value of 3.5 obtained from statistical table, indicating that the quadratic models are significant at 5% level of significance. Also, the models p-values for the responses and the factors, (A, B & C) are lower than the level of significance. Therefore, the linear terms significantly affect the three models. The quadratic terms p-values are also, lower than the significance level, indicating that the three quadratic models are significantly affected by the quadratic terms (A^2, B^2 & C^2). The interaction terms (AB, AC and BC) are all observed to be insignificant with respect to the three responses, implying that the combination of the factors has no significant effect on the responses. The quadratic models suffer no lack of- fit because the p-values for the three responses are larger than the significant level of 5%, indicating that both the models and the factors can significantly predict the three dependent variables (Muhammad 2018). The PRESS values of 13.30, 34.76 and 93.77 for the 3day, 7day and 28day compressive strengths are less than the sum of squares values of 19.77, 65.37 and114.10 for the same, suggesting that the models have predictive abilities. Each of the three quadratic models has R^2 value higher than 90% indicating that the models fit the data. Also, the predicted R^2 and the adjusted R^2 are close to each other by having differences of less than 0.2, implying that the models are good ones. The adequate precision ratio of 10.60, 11.28 & 10.47 for 3day, 7day and 28day compressive strengths are higher than 4.00, implying that the three models are desirable and can be used to navigating the design space.

As can be seen from Table 5, the 3 day, 7 day and 28 day compressive strength models are quadratic polynomial model type, with the smallest p value of (<0.0001). Model is very significant when the p value of the lack-of-fit test is > 0.05. The fitted model equation produced the best results. Hence, the quadratic polynomial model was used. After filling the experimental test data in Table 4 using the ANOVA method of analysis of central composite design in response surface methodology, the 3 day compressive strength Y_{3d}, 7 day compressive strength Y_{7d} and 28 day compressive strength Y_{28d} regression equation in terms of coded factors were obtained as shown in equations 1, 2 and 3.

$$Y_{3d} = 16.77 + 0.2117A + 0.2280B + 0.3295C - 0.0250AB - 0.0250AC + 0.000BC - 0.2572A^2 - 0.9820B^2 - 0.5401C^2. \text{--------------------------------} (1)$$

$$Y_{7d} = 30.08 + 0.4866A + 0.2826B + 0.6976C - 0.1750AB + 0.1000AC - 0.1750BC - 0.4615A^2 - 1.75B^2 - 0.9564C^2. \text{------------------------------------} (2)$$

$$Y_{28d} = 44.01 + 0.5881A + 0.6008B + 0.8877C - 0.1000AB - 0.0750AC - 0.0250BC - 0.6463A^2 - 2.56B^2 - 1.39C^2. \text{---------------------------------------} (3)$$

According to Guanji L. V. and Tao J. I., 2021, the F-test is a significance test of the quadratic model as a whole, and p is the probability. When the F value is more extensive and the p value is smaller, the model is more significant, that is., the smaller the probability that the original hypothesis of the model does not hold, the smaller the error of the simulation. It can be observed from Table 5, that the p value of the 3 day 7 day and 28 day compressive strength models are 0.0003, <0.0001 and <0.0001, respectively, and the F values are 12.36, 15.66 and 30.73, respectively. These F-values are all higher than the critical F-value of 3.59 in the statistical table, which confirm that all the models are highly significant, especially the 7day and 28 day compressive strength. From the three quadratic equations (Y3d, Y7d and Y28d), it can be seen that the main effect is most significant on Y28d followed by Y7d and lastly on Y3d. Among the three single factors (A, B, and C) for the compressive strength models, the C factor is most significant, followed by factor B which is more significant than factor A. Summarily, the overall effects on the compressive strengths could be deduced as follows: C > B > A.

The practical significance test is performed using the model summary output table and this is captured in table 5. The coefficient of determination R2, the adjusted R2 values are observed to be between 92% and 97% indicating that the model parameters can explain variation in the dependent variables that is the compressive strengths very well. Therefore, the three models have good practical significance.

The coefficient of determination R2, the coefficient of variation CV, and the signal-to-noise ratio were used to measure the credibility of the models. When R2 is larger, the coefficient of variation is smaller, and the signal-to-noise ratio is >4, indicating that the test is more reliable. As is shown in Table 5, for the 3day, 7day and 28day samples, the R2 values are 0.9175, 0.9338 and 0.9158 respectively, the corrected R2 values are 0.9677, 0.9449 and 0.9635, and the coefficients of variation are 2.71%, 2.44% and 2.72%, respectively. The signal-to-noise ratios are 10.6045, 11.2776 and 10.4728 as depicted in Table 5, respectively, indicating that the test models are highly credibility.

Table 5. Comprehensive analysis of various compressive strength models.

Source	3 day	7 day C.	28 day	Remark
Model type	C.S.	S.	C.S.	
Model sum	Quadratic	Quadratic	Quadratic	Significant
of squares	19.77	65.37	114.10	Significant
Model F-	12.36	15.66	30.73	Significant
value	0.0003	0.0001	0.0001	Significant
Model p-	0.0332	0.0247	0.0293	Significant
value	0.0468	0.0101	0.0249	Significant
A:MK Cont.	0.0161	0.0036	0.0146	Insignificant
p-value	0.8701	0.4840	0.8045	Insignificant
B:L/S ratio	0.8701	0.6867	0.8526	Insignificant
p-value	1.0000	0.4840	0.9506	Significant
C:SS/SHratio	0.0430	0.0278	0.04900	Significant
p-value	0.0001	0.0001	0.0001	Significant
AB—p-value	0.0007	0.0003	0.0008	Insignificant
AC---p-value	0.0734	0.0633	0.0547	
BC---p-value	0.9175	0.9338	0.9158	
A^2----p-value	0.9677	0.9449	0.9635	
B^2----p-value	0.8632	0.8378	0.8467	
C^2----p-value	10.6045	11.2776	10.4728	
Lack of Fit	13.30	34.76	93.77	
p-value				
R^2				
Adjusted R^2				
Predicted R^2				
Adequate				
Precision				
PRESS				

Figures 3 display the relationship between the forecast values and the experimental values (predicted vs. actual) which are distributed comparatively adjacent to the straight line. It is seen that the experimental results are in good agreement with the predicted ones. Figure 4 is the residual versus the observation order (residual vs. run) plot, which show no obvious pattern rationally close to the margin line, and suggested that errors are distributed normally and no digression of the variance. The general trend is that the plot is irregularly distributed, suggesting that the models do not show any violation of independence or that the variance is constant for every response value. All of the above show that the presented regression equations are appropriate to be used for the prediction of 3day, 7day and 28day compressive strength.

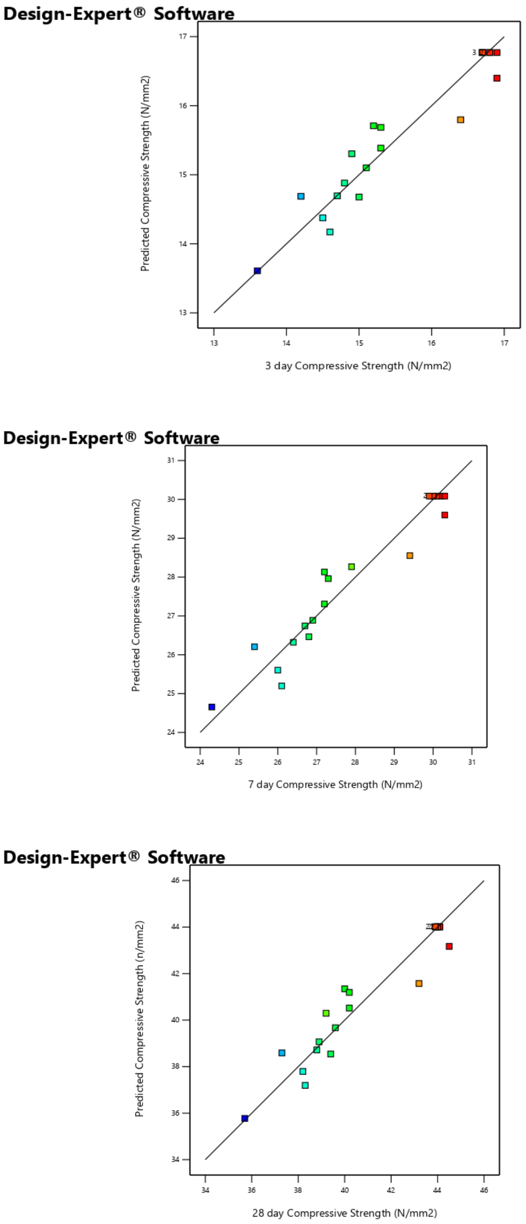
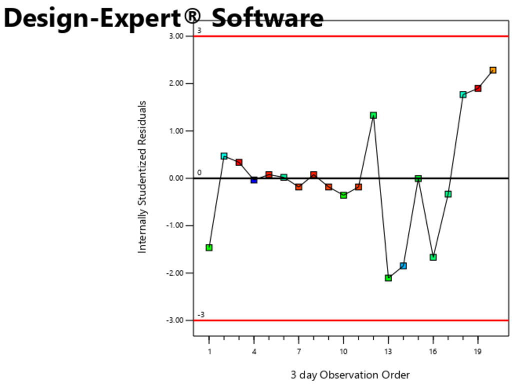


Figure 3: Variation of Predicted versus Actual Compressive Strengths



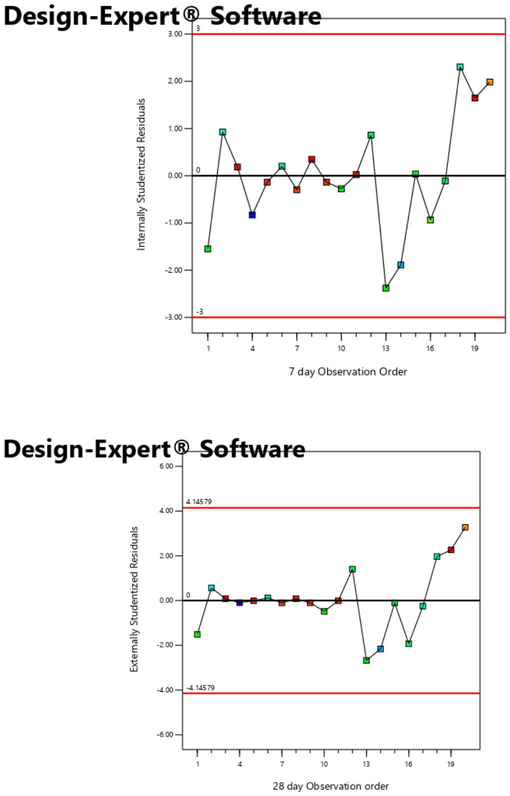


Figure 4: Variation of Residuals versus the 28 day Observation Order

5.3 Numerical Optimization

Numerical optimization in response surface methodology technique is the process that searches for a combination of factors levels that simultaneously satisfy the criteria placed on each of responses and factors. To include a response in the optimization criteria, it must have a model fit through analysis supplied via an equation only. The desired goal for each factor is “in range” while the ones for the responses are maximize as depicted in table 6. The best factors setting and desirability of the predicted responses are presented in table 7. From the table, it can be observed that the variation between the actual measured and predicted test data are less than 5% level of significance, indicating that the factor setting is significantly adequate to predict the responses. Table 8 presents the coefficient table after the post analysis of the numerical optimization. It can be observed from the table that the coefficient for factor C (0.8876) in the 28 day compressive Strength equation is higher than the coefficient for factor C (0.697614) in the 7 day compressive Strength equation and the coefficient for factor C (0.329503) in the 3 day compressive Strength equation. This shows that factor C in the 28 day Compressive Strength influences the three models more than the two other factors for the 7 day and 3 day Compressive strengths. . Figure 5 presents the numerical optimization bar graph, which is a graphical view of each optimal solution. The optimal factors setting are shown in blue bars while the ones for the responses are in red bars. The combined desirability of 0.989845 is closed to 1, which indicates that the settings seem to achieve favourable results for all the responses as a whole. However, the individual desirability indicates that the settings are more effective at maximizing the 7day compressive strength (1.000) than the 3day (0.991736) and 28day (0.977926).

Table 6: Constraints Considered for the Experiment

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:MK Content	is in range	350	450	1	1	3
B:L/S Ratio	is in range	0.7	0.9	1	1	3
C:SS/SH Ratio	is in range	1	2	1	1	3
3day C/S	maximize	13.6	16.9	1	1	3
7day C/S	maximize	24.3	30.3	1	1	3
28day C/S	maximize	35.7	44.5	1	1	3

Table 7: The Predicted and Experimental Results for the Optimized Mixes

Response	A	B	C	Exp.	Pred.	Residual	Desirability
3day C/S	40.509	0.811	1.651	16.900	16.873	0.03	0.99
7day C/S	40.509	0.811	1.651	30.400	30.338	0.06	1.00
28day C/S	40.509	0.811	1.651	44.500	44.306	0.19	0.98

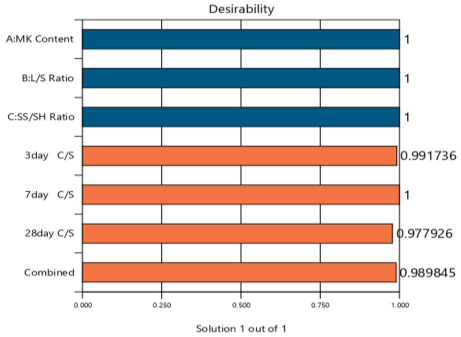


Figure 5: Desirability bar graph for the Factors and the Responses

Table 8: Coefficients Table

p-value shading: $p < 0.05$ $0.05 \leq p < 0.1$ $p \geq 0.1$

	Intercept	A	B	C	AB	AC	BC	A^2	B^2	C^2
3day C/S	16.77	0.211679	0.227989	0.329503	-0.025	-0.025	-2.70277E-15	-0.25721	-0.982	-0.540053
p-values		0.0932	0.0735	0.0161	0.8701	0.8701	1.0000	0.0430	< 0.0001	0.0007
7day C/S	30.0845	0.486596	0.282572	0.697614	-0.175	0.1	-0.175	-0.461469	-1.75195	-0.956444
p-values		0.0247	0.1562	0.0036	0.4840	0.6867	0.4840	0.0278	< 0.0001	0.0003
28day C/S	44.0096	0.588108	0.60076	0.88766	-0.1	-0.075	0.025	-0.646297	-2.5555	-1.38876
p-values		0.0793	0.0739	0.0146	0.8045	0.8526	0.9506	0.0520	< 0.0001	0.0008

VI. CONCLUSION

In the present study, the effects of varying three independent variables on the performance of local kaolin powder from Alkaleri in Bauchi State geopolymer has been investigated. A series of laboratory experiments were carried out to study the 3 day, 7 day and 28 day compressive strengths based on the response surface methodology.

The central composite design method of response surface analysis was used to establish the relationships between the three factors of metakaolin content, liquid/solid ratio and sodium silicate/sodium hydroxide ratio, and the three response values of 3 day, 7 day and 28 day compressive strengths. Based on the experiments, it was found that the highest compressive strengths of the 3 day, 7 day and 28 day samples were 16.9N/mm^2, 30.2 N/mm^2 and 44.1N/mm^2. As the factors increase by one level each, the compressive strength at 3day, 7day and 28day rises by 16.0%, 16.0% and 15.0% respectively. Quadratic polynomial equations for 3 day, 7 day and 28-day curing compressive strengths were obtained, which described the interaction between the independent variables. According to the correlation coefficients and the comparison between the measured values and the predicted values, the models presented a satisfactory fit to the factual data.

The best factors setting for the quadratic models is A=400 grams, B =0.8, C =1.5, while the optimized one is A=420 grams, B = 0.8, C = 1.7 and desirability = 0.990. It can then be concluded that the quadratic model factors setting influences the responses more than the optimized one.

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