

Influence of Constituent Mix Proportions on Concrete Workability: A Predictive Model Using RSM

Jibrin Abubakar^{*1}, Abdullahi Abolaji Afolabi² and Aminu Ahmed³

^{1,2,3}Department of Civil Engineering, Joseph Sarwuan Tarka University, Makurdi, Nigeria

Corresponding author: ¹ jibo008@yahoo.com

Abstract: *The existence of voids affects the ultimate strength of concrete. With adequate workability, voids are significantly reduced and hardened properties of concrete are enhanced. The workability of concrete is affected by factors including water content, size, shape and content of aggregate, and use of admixtures. Hence, understanding how the interaction of these factors influence concrete workability is crucial if concrete with desirable properties is sort. This study investigated the workability of fresh concrete using Kuta river gravel as aggregate. Water/cement ratio (W/C), coarse aggregate/total aggregate ratio (CA/TA) and total aggregate/cement ratio (TA/C) were assigned values and used as variables for design. Central Composite Design (CCD) in Minitab 21 was used to generate 20 mixes with different combinations of the design variables. Slump test was used to test workability of the concrete mixes. Further to this, Response Surface Methodology (RSM) was employed to develop a regression model for the slump. It was determined that the aggregate can be used to make concrete with slump ranging between 0-270mm (ranging between no workability concrete to very high workability concrete) depending on proportion of mix constituents. The lowest slump (0mm) was recorded for mixes with W/C ratio of 0.4, CA/TA ratio of 0.65, and TA/C ratio of 6, and W/C ratio of 0.4, CA/TA ratio of 0.55 and TA/C ratio of 6. While the highest slump was recorded for the mix with W/C ratio of 0.5, CA/TA ratio of 0.6 and TA/C ratio of 2.38. The model developed has overall P-value of 0.000, R² value of 92.34% and Adjusted R² value of 88.80%. It was concluded that workability of concrete increases with increase in W/C ratio and decrease in TA/C ratio and vice versa, change in the CA/TA ratio has insignificant effect on the workability of concrete, and that the developed model is adequate in predicting slump of concrete.*

Keywords: *modelling, slump, workability, kuta river gravel, concrete*

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1. INTRODUCTION

Researchers and engineers have over time, placed more priority on the mechanical properties of concrete, being the determinants of durability and structural stability of structures. Concrete strength is the most valued property of concrete by quality control engineers and designers (Mehta and Moteiro, 2014). However, the mechanical properties of concrete are highly affected by the properties of the fresh concrete. The ultimate strength of hardened concrete for instance, can be increased when adequate workability is maintained

(Alsadey and Mohamed, 2020). The presence of voids affects the strength of concrete (Faradiwala and Jamnu, 2012). These voids can be reduced or avoided when the concrete mix is sufficiently workable in the fresh state. Understanding workability in concrete is very important because it does not only influence fresh concrete properties but also, the performance of the hardened concrete in service (Odumade *et al.*, 2020). Hence, the importance of investigating the workability of concrete cannot be overemphasized.

A few of the necessary but short-term requirements of fresh concrete include its ability to be mixed and transported easily, being able to flow and fill forms completely, and setting in a reasonable time period (Li, 2011). How easily a concrete mix can be placed, compacted and finished without losing its homogeneity is known as workability of concrete (Steven and Kosmatka, 2008; Yeh, 2007; Odumade *et al.*, 2020). Workability is affected by several interacting factors including the type and grading of aggregate, water content, fineness of the cement, aggregate/cement ratio and admixtures (Neville and Brooks, 2010; Shetty, 2005). It is therefore, pertinent to understand how the interaction of these variables affect concrete workability. The degree of workability required depends on the job application (Shetty, 2005). By this, different professionals in the construction industry require concrete specific degree of workability to achieve their construction objective.

There are various methods used in determining workability of fresh concrete. Some of these methods include slump test, vebe-test, flow table test, K-slump tester, free orifice test and compaction factor test (Shetty, 2005; Koehler and Fowler, 2003; Neville and Brooks, 2010). Slump test was invented by Chapman in 1913 (Stanley, 2011). Slump test is the most widely

used, basic and most understood method of measuring workability of fresh concrete (Koehler and Fowler, 2003; Bartos *et al.*, 2011). Interestingly, this method is convenient for determining workability of concrete both in the field and in the laboratory.

Researchers have adopted several tools, using different concrete constituent material types and proportions to optimize and model slump or workability of fresh concrete (Yeh, 2007; Chen and Wang, 2010; Chandwani *et al.*, 2014; Kumar and Baskar, 2014; Yusuf *et al.*, 2021). One of such tools is Response Surface Methodology (RSM). It is a collection of mathematical/statistical techniques useful for product design and improvement, experimental design, regression modelling and process optimization (Carley *et al.*, 2004; Lamidi *et al.*, 2023). The method is quite useful in cases where several variables affect the performance characteristic.

This investigation is aimed at using Central Composite Design (CCD) in Response Surface Methodology (RSM) to model the slump of fresh concrete containing Kuta gravel as coarse aggregate and using water/cement (W/C), coarse aggregate/total aggregate (CA/TA) and total aggregate/cement (TA/C) ratios as variables.

II. MATERIALS AND METHODS

A. MATERIALS

The concrete constituent materials employed for this study are:

Portland Limestone Cement (PLC)

Portland Limestone Cement (grade 42.5N) was obtained from a retail outlet in Minna and used for this study.

Fine Aggregate (Sand)

The fine aggregate employed for this investigation was river sand obtained from Gidan Mangoro, Minna, Nigeria. In conformity with the requirements of BS EN 12620 (2008) for natural aggregates, the river sand is free of organic matter and the particles are sharp. The properties of the river sand are as presented in Table 1.

Coarse Aggregate (Kuta River Gravel)

The coarse aggregate component of concrete employed in this study was obtained from Kuta in Niger state. It is popularly known as Kuta gravel. The gravel conforms to the requirements of BS EN 12620 (2008) for natural aggregates. Table 1 presents the properties of the gravel (physical and mechanical).

Water

For mixing of concrete, potable water obtained from F.U.T, Minna was used. The water is free from salts, suspended particles impurities. With these characteristics, the water requires no further testing before use (BS EN 1008, 2002).

Table 1: Properties of constituent materials

| Material | Properties | Material | Properties |
|-------------------|--|--------------------|---|
| River sand | Specific gravity:2.64 Water absorption: 0.79% Loose bulk density: 1588.83kg/m ³ Loose bulk density: 1697.56kg/m ³ Fineness Modulus: 2.2 Grading: falls within limit of graded fine aggregates | Kuta gravel | Specific gravity:2.67 Water absorption:0.6% Loose bulk density: 1523.47kg/m ³ Compacted bulk density: 1640.52 kg/m ³ Aggregate Impact Value (AIV): 16.45% Flakiness Index: 26% Elongation Index: 29% Grading: falls within limit of graded coarse aggregates |

B. METHODS

Factor Setting

To understand how different combinations of design variables affect the slump, Central Composite Design (CCD) was used to generate mix combinations. It is predominantly used fractional factorial design in Response Surface Methodology (RSM). The use of this method has been proved to adequately find functional relationships between the dependent variable (response) and the design variables (Haque *et al.*, 2021). Using this important tool, the effects of different design variables on the response is easily understood by designers (Olaoye, 2020).

The independent variables were arrived at by assigning values to proportions of the concrete constituents. Equation (1) to (3) shows the independent variables and assigned values.

$$W/C (x_1) = 0.4, 0.5, 0.6 \tag{1}$$

$$CA/TA (x_2) = 0.55, 0.6, 0.65 \tag{2}$$

$$TA/C (x_3) = 3, 4.5, 6 \tag{3}$$

Where: W/C= Water to Cement ratio, CA/TA=Coarse Aggregate/Total Aggregate ratio, TA/C= Total Aggregate/Cement Ratio and TA= Total Aggregate = FA+CA

These assigned variables were used in generating coded variables in Minitab 21. The coded variables were then converted to uncoded variables and used in computing quantities of materials to be used for mixing. Table 2 presents the uncoded values of the variables using a default α value of 1.4142.

Design of Concrete Mixes

The method of absolute volume was used in preparing concrete mix compositions. The equation of absolute volume is as presented in Equation (4).

$$\frac{W_W}{1000} + \frac{W_C}{1000SG_C} + \frac{W_{FA}}{1000SG_{FA}} + \frac{W_{CA}}{1000SG_{CA}} + AV = 1 \tag{4}$$

Where:

W_W=Weight of water, W_C=Weight of cement, W_{FA}=Weight of fine aggregate, W_{CA}=Weight of coarse aggregate, SG_C=Specific gravity of cement, SG_{FA}=specific gravity of fine aggregate, SG_{CA}=Specific gravity of coarse aggregate and AV=air void=2%=0.02

So as to incorporate the design variables into the absolute volume equation, the weights of sand and Kuta gravel (fine and coarse aggregates) were expressed in terms of the CA/TA and TA/C ratios while the weight of mixing water was expressed in terms of W/C ratio to yield equation (5).

$$W_c = \frac{1-AV}{\frac{W_W}{W_C} + \frac{1}{1000SG_C} + \frac{(1-\frac{W_{CA}}{W_{TA}})(\frac{W_{TA}}{W_C})}{1000SG_{FA}} + \frac{(\frac{W_{TA}}{W_C})(\frac{W_{CA}}{W_{TA}})}{1000SG_{CA}}} \tag{5}$$

The uncoded combinations of the variables (W/C, CA/TA and TA/C) presented in Table 2 were inserted in Equation (5) to compute quantities of constituent materials required per unit volume of concrete. The quantities of materials per cubic meter as computed using the absolute volume equation are also listed in Table 2.

Table 2: Uncoded Combinations of the Design Variables and Proportions of concrete constituents needed per cubic of Concrete

| Run Order | Uncoded Variables | | | Water (kg/m ³) | Cement (kg/m ³) | Fine Aggregates (kg/m ³) | Coarse Aggregates (kg/m ³) |
|-----------|----------------------|------------------------|-----------------------|----------------------------|-----------------------------|--------------------------------------|--|
| | W/C(x ₁) | CA/TA(x ₂) | TA/C(x ₃) | | | | |
| 1 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |
| 2 | 0.6 | 0.55 | 3 | 287.28 | 478.80 | 646.37 | 790.01 |
| 3 | 0.6 | 0.65 | 3 | 287.46 | 479.09 | 503.05 | 934.23 |
| 4 | 0.36 | 0.6 | 4.5 | 148.33 | 413.66 | 744.59 | 1116.88 |
| 5 | 0.5 | 0.67 | 4.5 | 195.28 | 390.57 | 578.75 | 1178.81 |
| 6 | 0.5 | 0.53 | 4.5 | 195.07 | 390.15 | 826.41 | 929.26 |
| 7 | 0.5 | 0.6 | 2.38 | 286.15 | 572.29 | 544.53 | 816.79 |
| 8 | 0.6 | 0.65 | 6 | 185.28 | 308.80 | 648.48 | 1204.31 |
| 9 | 0.4 | 0.55 | 3 | 212.26 | 530.65 | 716.37 | 875.57 |
| 10 | 0.4 | 0.65 | 6 | 131.83 | 329.57 | 692.09 | 1285.32 |
| 11 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |
| 12 | 0.5 | 0.6 | 6.62 | 148.10 | 296.20 | 784.48 | 1176.72 |
| 13 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |
| 14 | 0.4 | 0.65 | 3 | 212.41 | 531.01 | 557.57 | 1035.48 |
| 15 | 0.64 | 0.6 | 4.5 | 237.03 | 369.54 | 665.17 | 997.76 |
| 16 | 0.4 | 0.55 | 6 | 131.71 | 329.29 | 889.07 | 1086.64 |
| 17 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |
| 18 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |
| 19 | 0.6 | 0.55 | 6 | 185.13 | 308.55 | 833.09 | 1018.22 |
| 20 | 0.5 | 0.6 | 4.5 | 195.18 | 390.36 | 702.64 | 1053.97 |

Test for Workability

Slump test was performed on the fresh concrete to determine its workability. This was executed in conformity with the method prescribed in BS EN 12350-2 (2009). Fig. 1 shows the measurement of slump for the fresh concrete.

**Fig. 1. Measuring the slump of the fresh concrete****Slump Model**

To model the relationship between the response (slump) and the independent variables (W/C, CA/TA and TA/C ratios), the Response Surface Methodology (RSM) in Minitab 21 was used. Minitab is a mathematical/statistical software for analysis, design, optimizing and modelling products. Linear, interaction, pure quadratic, reduced full quadratic and full quadratic models were developed and the best model that fits the experimental data was chosen.

Model Validation

Validation of the chosen model was done using parameters such as standard coefficient of determination (R^2), adjusted coefficient of determination (R^2 Adj) and residual plots.

III. RESULTS AN DISCUSSION

A. Slump

The result of workability for the concrete mix is as presented in Table 3. Slump values between 0 and 270mm were measured. Abbasi *et al.* (1987), Alhaji (2016) and Yusuf *et al.* (2020) reported similar range of slump values for concrete with similar constituent proportions. The slump readings are observed to differ depending on the constituent material proportion. Water/Cement (W/C), total aggregate/cement (TA/C) and fine aggregate/coarse aggregate ratios affect concrete workability (Li, 2011). Additionally, with the right constituent material proportion, normal concrete has good workability (Kosmatka, 2008).

Mixes 10 and 16 were observed to yield no slump at all (0mm). The low W/C ratio combined with a relatively high TA/C ratio is the reason why the concrete mix is unable to slump. At constant W/C ratio, workability of fresh concrete declines with rise in the TA/C ratio (Neville and Brooks, 2010).

Slump between 10 to 40mm were recorded for 4, 5, 9, 11, 12, 13, 14 and 18. For this range, slump is

Table 3: Slump of the fresh concrete

| Mix No. | W/C (x_1) | CA/TA (x_2) | TA/C (x_3) | Slump (mm) |
|---------|---------------|-----------------|----------------|------------|
| 1 | 0.5 | 0.6 | 4.5 | 50 |
| 2 | 0.6 | 0.55 | 3 | 250 |
| 3 | 0.6 | 0.65 | 3 | 230 |
| 4 | 0.35858 | 0.6 | 4.5 | 10 |
| 5 | 0.5 | 0.67071 | 4.5 | 40 |
| 6 | 0.5 | 0.52929 | 4.5 | 60 |
| 7 | 0.5 | 0.6 | 2.3787 | 270 |
| 8 | 0.6 | 0.65 | 6 | 120 |
| 9 | 0.4 | 0.55 | 3 | 40 |
| 10 | 0.4 | 0.65 | 6 | 0 |
| 11 | 0.5 | 0.6 | 4.5 | 40 |
| 12 | 0.5 | 0.6 | 6.6213 | 10 |
| 13 | 0.5 | 0.6 | 4.5 | 40 |
| 14 | 0.4 | 0.65 | 3 | 30 |
| 15 | 0.64142 | 0.6 | 4.5 | 220 |
| 16 | 0.4 | 0.55 | 6 | 0 |
| 17 | 0.5 | 0.6 | 4.5 | 50 |
| 18 | 0.5 | 0.6 | 4.5 | 40 |
| 19 | 0.6 | 0.55 | 6 | 160 |
| 20 | 0.5 | 0.6 | 4.5 | 50 |

B. Slump model

The summary of analysis of variance (ANOVA) and overall model summary for the slump models of concrete containing Kuta gravel as coarse aggregate is displayed in Table 4. The R^2 and adjusted R^2 Adj

classified as slump class S1 (BS EN 206-1: 2000) and considered concrete with low workability (Shetty, 2005).

For mixes 1, 17 and 20, slump loss of 50mm was recorded while a 60mm slump was recorded for mix 6. The two classes fall within slump class S2 (BS EN 206-1: 2000) and are classified as concrete with medium workability concrete (Shetty, 2005).

Mix 8 yielded concrete with high workability, having a slump of 120mm and falling under the category of slump class S3.

Mix 19 has a slump loss of 160mm (Slump class S4) while mixes 2, 3, 7 and 15 had slump values ≥ 220 mm (Slump class S5). The two categories of slump here are considered mixes with very high degree of workability (Shetty, 2005). Lower TA/C in the mixes increases the volume of water in the concrete mix when compared to the total aggregate surface, consequently resulting in high slump loss.

values are observed to be very high for the full quadratic, reduced full quadratic and pure quadratic models. The models also showed low standard deviation (S), indicating adequate interpretation of the laboratory data. The reduced full quadratic model having the highest R^2 Adj value (88.80%), was hence, chosen as the model for slump. Accordingly, the

regression model for predicting the slump of Kuta gravel concrete is presented as Equation (6).

$$\text{slump} = 661 - 1336x_1 - 164x_2 - 137.1x_3 + 2646x_1^2 + 17.31x_3^2 - 108.3x_1x_3 \tag{6}$$

Table 4: Summary of analysis of variance for slump models

| Source | Full Quadratic | | Reduced Full Quadratic | | Interaction | | Pure Quadratic | | Linear | |
|-------------------|--------------------|---------|------------------------|---------|--------------------|---------|--------------------|---------|--------------------|---------|
| | Model Summary | | Model Summary | | Model Summary | | Model Summary | | Model Summary | |
| | S | 33.09 | S | 29.8 | S | 49.91 | S | 32.09 | S | 46.65 |
| | R ² | 92.73% | R ² | 92.34% | R ² | 78.51% | R ² | 91.12% | R ² | 76.89% |
| | R ² Adj | 86.19% | R ² Adj | 88.80% | R ² Adj | 68.59% | R ² Adj | 87.01% | R ² Adj | 72.56% |
| | ANOVA Summary | | ANOVA Summary | | ANOVA Summary | | ANOVA Summary | | ANOVA Summary | |
| | DF | P-value | DF | P-value | DF | P-value | DF | P-value | DF | P-value |
| Model | 9 | 0.000 | 6 | 0.000 | 6 | 0.001 | 6 | 0.000 | 3 | 0.000 |
| Linear | 3 | 0.000 | 3 | 0.000 | 3 | 0.000 | 3 | 0.000 | 3 | 0.000 |
| W/C | 1 | 0.000 | 1 | 0.000 | 1 | 0.000 | 1 | 0.000 | 1 | 0.000 |
| CA/TA | 1 | 0.411 | 1 | 0.358 | 1 | 0.579 | 1 | 0.393 | 1 | 0.552 |
| TA/C | 1 | 0.000 | 1 | 0.000 | 1 | 0.003 | 1 | 0.000 | 1 | 0.001 |
| Square | 3 | 0.010 | 2 | 0.001 | - | - | 3 | 0.005 | - | - |
| W/C*W/C | 1 | 0.038 | 1 | 0.021 | - | - | 1 | 0.028 | - | - |
| CA/TA*CA/TA | 1 | 0.631 | - | - | - | - | 1 | 0.617 | - | - |
| TA/C*TA/C | 1 | 0.006 | 1 | 0.002 | - | - | 1 | 0.003 | - | - |
| 2-Way Interaction | 3 | 0.551 | 1 | 0.147 | 3 | 0.807 | - | - | - | - |
| W/C*CA/TA | 1 | 0.605 | - | - | 1 | 0.729 | - | - | - | - |
| W/C*TA/C | 1 | 0.195 | 1 | 0.147 | 1 | 0.374 | - | - | - | - |
| CA/TA*TA/C | 1 | 0.917 | - | - | 1 | 0.945 | - | - | - | - |
| Error | 10 | | 13 | | 13 | | 13 | | 16 | |
| Pure Error | 5 | | 5 | | 5 | | 5 | | 5 | |
| Total | 19 | | 19 | | 19 | | 19 | | 19 | |

C. Slump model validation

P-value

P- value measures the significance of a regression model. It is defined as the measure of degree of disparity of fit of a given model (Gelman, 2013). Furthermore, the relevance of the effects of the terms of a regression model are analysed using p-value.

From Table 4, the overall p-value of the reduced full quadratic model is zero (0), which is less than 0.05. This implies that the reduced full quadratic slump model chosen is highly significant and is adequate in predicting concrete slump. A P-value that is close to zero (0) for a regression model implies that the model is highly significant and adequate in predicting the response (Triola, 2018).

For the reduced full quadratic model chosen, the linear model has an overall p-value of 0, indicating the overall significance of the linear terms in the model. Individually, all the linear terms have a p-value of 0 except CA/TA with a p-value of 0.358, indicating that CA/TA ratio is not significant in the slump model.

The cumulative effect of the square terms of the full quadratic model shows a p-value of 0.01, indicating that the square terms are significant in the model. Observing the individual square terms, the two terms involved have p values less than 0.05, indicating their significance in the model.

Fig. 2 shows the standardized effects of the individual terms of the regression equation for slump.

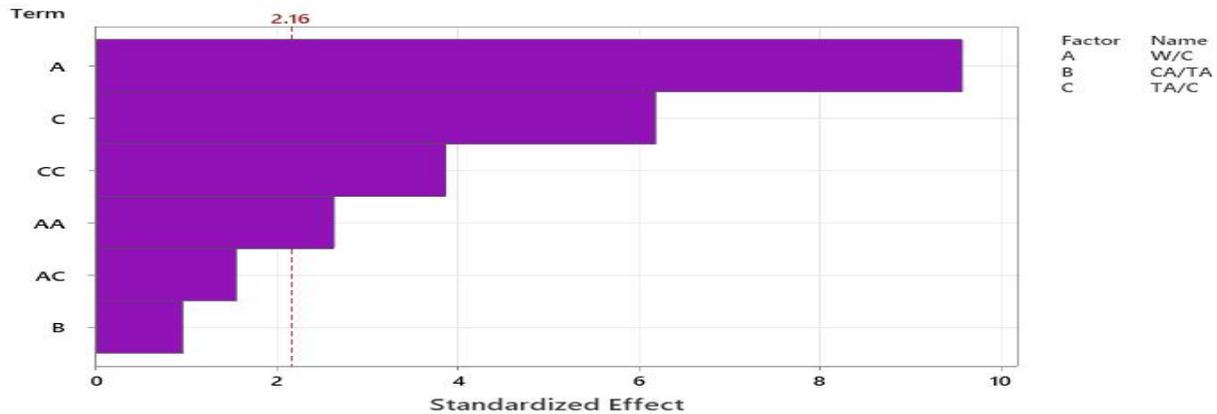


Fig. 2. Pareto chart of standardized effects of the polynomial terms of slump model

R² and R² Adj

From Table 4, R^2 for the regression equation for slump is 92.34%. This value is reasonably high and implies that 92.34% of the variation in slump is accounted for by the independent variables in the model equation. The high R^2 value implies that the model is well fitted and adequate in interpreting the experimental data. This conclusion however, needs to be checked because model equations having R^2 values close to 100 or 100% may not necessarily reflect a true relationship between the dependent and independent variables (Sapra, 2014; Keer *et al.*, 2023). Relying only on R^2 value does not provide an accurate assessment of fitness of a regression model since its value can be made higher by the addition of variables (Montgomery and Runger, 2003). The adjusted coefficient of determination (R^2 Adj) is therefore, best in assessing fitness of regression models.

R^2 Adj is that given value of R^2 that is expected when the developed regression model is used on a new sample from the same population (Kirk, 1999). Its advantage when compared to R^2 is that its value does not change with addition of new variables. R^2 Adj of

88.80% was determined for the slump model. This is a reasonable adjustment and the high value indicates that the model is well fitted and adequate in predicting the slump.

Residual Plots

Plots that show deviations of observed values from the experimental (observed values) are referred to as residual plots (Keer *et al.*, 2023).

The normal plot of residuals for slump is as presented in Fig. 3. The plot of residual versus the normal percent of probability is seen to approximately follow a straight line. The implication of this is that the developed model can be used in navigating the design space. The model is hence, valid.

The residual versus fitted value plot slump is as presented in Fig. 4. Ideally, the points should fall randomly on either sides of the zero line and should not have any recognizable pattern. The developed slump model is observed to be well fitted and adequate since the plot shows no regular pattern. Well fitted residual plots should not follow any distinct pattern and shouldn't appear wider or thinner when observed from left to right (Triola, 2018).

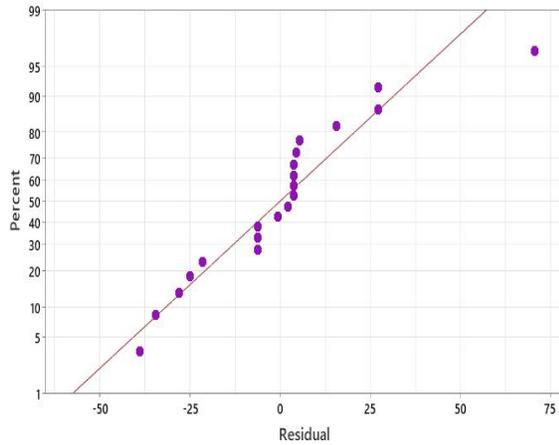


Fig. 3. Normal probability plot for slump model

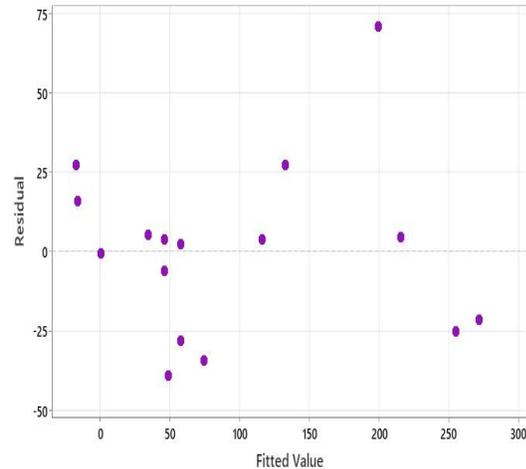


Fig. 4. Residual versus fits plot for slump model

D. relationship between concrete constituent proportions and workability

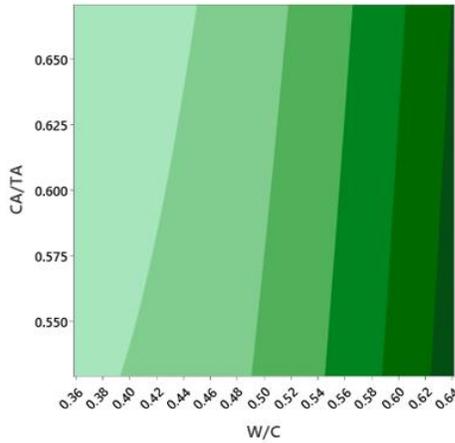
Figs. 5 to 7 presents contour and response surface plots that shows effects of the interaction of the variables on the slump of Kuta gravel fresh concrete.

The contour and surface plots in Fig. 5 show the effect of W/C and CA/TA ratios while holding the mid value of the TA/C ratio on the workability of concrete. The surface plot shows a continuous increase in the workability of the concrete as the W/C ratio increases. Generally, workability increases with increase in W/C ratio (Yalley and Sam, 2018; Odumade *et al.*, 2020). Furthermore, there is an almost linear relationship between concrete workability and W/C ratio (Dehghan *et al.*, 2018). It is observed that for a constant W/C ratio, slump value remains almost the same irrespective of the CA/TA ratio. The contour plot reveals that slump value upwards of 100mm is achieved for all values of CA/TA with W/C ratio above 0.545. This also explains

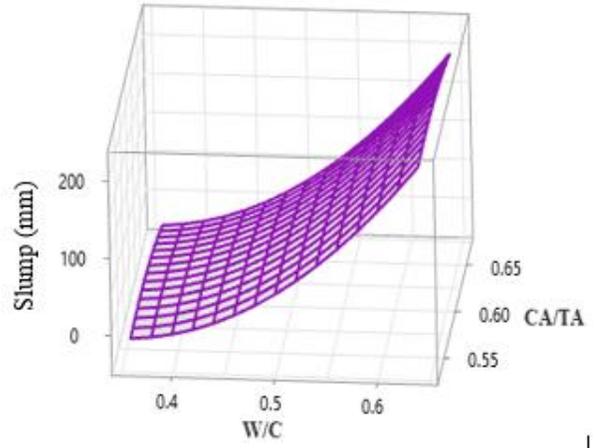
that the effect of CA/TA ratio on the workability of the Kuta gravel concrete is negligible.

From the contour plot in Fig. 6 (a), it is observed that slump above 400mm can be achieved with W/C ratio ≥ 0.58 and TA/C ratio ≤ 3 . Lower slump values are observed with combinations of lower W/C ratio and higher TA/C ratio. This same relationship is observed in the surface plot presented in Fig. 6 (b). The slump values are higher at higher W/C and lower TA/C ratios, and lower at lower W/C and higher TA/C ratios. Practically, workability is prone to increase when the aggregate to cement ratio decreases at constant W/C ratio (Neville and Brooks, 2010; Li, 2011).

Fig. 7 (a) and (b) shows the effect of TA/C on the workability of concrete. Increase in TA/C ratio leads to a corresponding decrease in the workability of the concrete. For TA/C values below 3, it is observed that there is higher workability for all CA/TA values. This further shows the negligible effect of CA/TA on the workability of the Kuta gravel concrete.

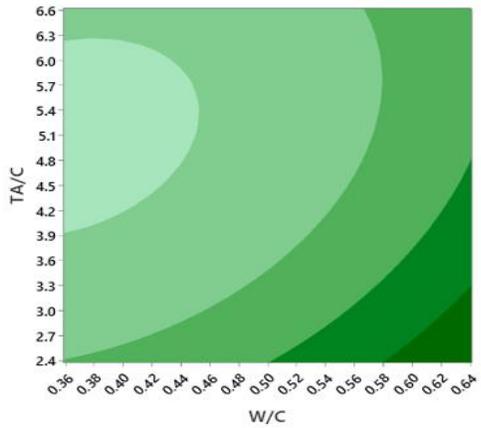


(a) Contour plot

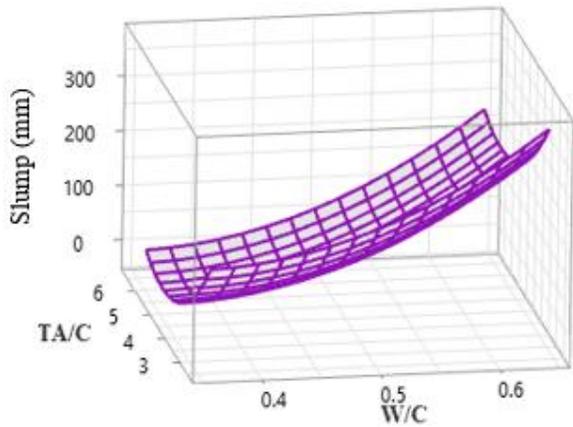


(b) Surface plot

Fig. 5. Plots of slump versus CA/TA, W/C

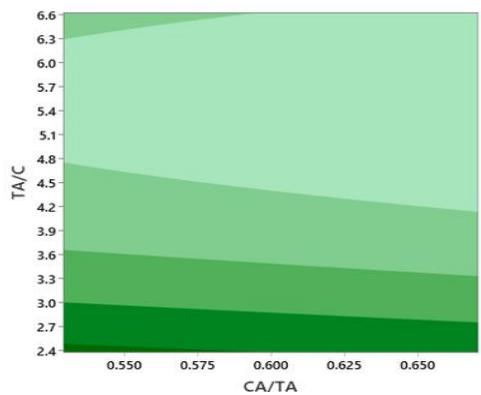


(a) Contour plot

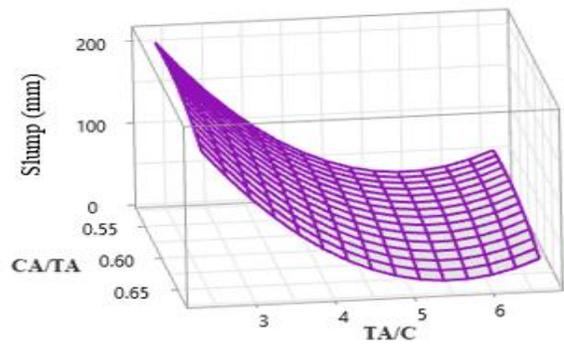


(b) Surface plot

Fig. 6. Plots of slump versus TA/C, W/C



(a) Contour plot



(b) Surface plot

Fig. 7. Plots of slump versus TA/C, W/C

IV. CONCLUSION AND RECOMMENDATIONS

Slump values vary depending on the proportion of the concrete constituent materials.

Workability of concrete increases with increase in W/C ratio and decrease in TA/C ratio and vice versa. Change in the CA/TA ratio has an insignificant effect on the workability of concrete.

The lowest slump (0mm) was recorded for mixes with W/C ratio of 0.4, CA/TA ratio of 0.65, and TA/C ratio of 6, and W/C ratio of 0.4, CA/TA ratio of 0.55 and TA/C ratio of 6. While the highest slump was recorded for the mix with W/C ratio of 0.5, CA/TA ratio of 0.6 and TA/C ratio of 2.38.

Full quadratic, reduced full quadratic, interaction, pure quadratic and linear models were developed for slump and were compared. In all, the reduced full quadratic model was chosen as the best considering its statistical significance. The model is proven to be accurate and valid in predicting the slump of Kuta gravel concrete.

The slump model is recommended for use in predicting slump of concrete produced using Kuta gravel as coarse aggregate.

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