Original Research Article

Development of Models for the Prediction of Mechanical Properties of Concrete using Bida Natural Stones as Coarse Aggregate

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ABSTRACT

This paper presents the results of statistical models for the mechanical properties of concrete made using Bida natural stones (pebbles) as coarse aggregate. Fresh and hardened concrete properties were analyzed using response surface methodology (RSM). The research employed central composite design using three (3) independent variables with equivalent ranges as W/C=0.4, 0.5, 0.6, CA/TA=0.55, 0.615, 0.68 and TA/C= 3.0, 4.5 and 6.0. Minitab 14 (2004) selected 20 possible mix proportions for the experiment. The concrete specimens that were used for this research work include 150mmm x 150mm x 150mm concrete cube, Ø150mm x 300mm concrete cylinder and 100mm x 100mm x 500mm concrete prism for compressive strength, elastic modulus/splitting tensile strength and flexural strength respectively. For each mix, five (5) numbers of specimens were cast and cured for 7, 14, 21 and 28days. The twenty-eight days (28 days) measured responses were used to develop models for the mechanical properties. Statistical and experimental model validations were employed. The p-value for all individual terms were less than 0.05, p-values for lack of fit were also greater than 0.05 in all cases tested, coefficient of determination (R^2), adjusted coefficient of determination (adjR^2) were in the range of 89.7% to 100% for compressive strength, splitting tensile strength, elastic modulus, flexural strength, and slump respectively which indicated adequate model validity. The predicted responses closely agree with experimental values, this further confirms the validity of the models developed. The study therefore suggested interaction, pure quadratic, reduced full quadratic, interaction models for the mechanical properties and slump respectively for the concrete made using Bida natural stones as coarse aggregate. The concrete with mix constituent mentioned above can be used for structural application such as reinforced concrete slabs, beams, columns and foundations.

Keywords: Bida natural coarse aggregates (Pebbles); Mechanical properties; models; Response surface methodology

1. INTRODUCTION

Concrete is regarded as the world's most utilized synthetic construction material, being second only to water [1]. It a product that forms from the mixture of water, cement, aggregates and in some occasions, admixtures. This mixture hardens into a rock-like material through a chemical reaction (hydration) between the cement and water and continues to gain strength with age. Aggregates provide about 75 per cent of the body of concrete and therefore, its properties affect the properties of the concrete. The aggregate must be of acceptable shape, free from dirt, strong and well graded. It should possess chemical stability and, in many cases, exhibit abrasion resistance and resistance to freezing and thawing [2].

Compressive strength, tensile strength, flexural strength which define the degree of resistance a structural element can offer to deformation remain the most important properties of structural concrete, from an engineering point of view. Over time, researchers have made efforts in understanding the relationship between concrete's mechanical properties and composition of constituent materials. The strength of the concrete is determined by the characteristics of the hardened mortar, coarse aggregate, and the aggregate/mortar interfacial zone. Different strengths of concrete have been measured for mixes for mortars are of the same quality but having different aggregate texture, shape and mineralogy. However, the influence of the limitation on water to cement ratio especially as regards high performance concrete has become apparent, with the nature of aggregates used contributing largely to performance [3]. Thus, using a coarse aggregate of higher strength, good mineralogical and textural characteristics may improve the performance and other desirable properties of concrete.

The most important factors which influence a mix design are the water to cement ratio (W/C), total aggregate to cement ratio (TA/C) and the coarse aggregate to total aggregate ratio (CA/TA). Since those factors are interdependent, proper design and analysis of experiments for studying their influences on the mix proportions is necessary. One traditional method of studying the effects of various factors is to vary one factor at a time and keep all others constant, respond readings are taken for different level of these factors one after the other until the entire factors have been treated. This approach may not be satisfactory or may involve a large number of unnecessary experiments if interactions between the factors occur [4]. To overcome this difficulty recourse is made to Response surface methodology (RSM).

Response Surface Methodology encompasses techniques that are mathematically and statistically based to develop and optimize dependent variable expected to be derived from independent variables. RSM is particularly useful where performance characteristics or responses (e.g compressive strength, slump, bulk density and cost of concrete) are influenced by several design factors or variables. Response Surface Methodology can be used to optimize one or more responses or to meet a given set of specifications for example a minimum strength specification or an allowable range of slump values. RSM comprises of three steps, namely; experimental design, modelling and optimization [5]. There are four types of models, one linear while the other three are quadratic. The three quadratic models are interaction, pure quadratic and full quadratic. The full quadratic model comprises of the other models and it has the highest coefficients. These four different models were tried and the model that offers the best fit for the response surface design format of the concrete mix proportion was considered. Thus, this research developed models for the prediction of the mechanical properties of concrete using Bida natural stones as coarse aggregate.

2. SIGNIFICANCE OF THE STUDY

Crushed stones are available in some part of Nigeria, like Abuja and are transported to Bida for production of concrete at high cost. This is because there is no quarry in Bida and its environs thereby increasing the haulage distance. Bida natural coarse aggregate are abundantly available in Bida area. This aggregate is cheaper than the crushed granite. This aggregate has been used for concrete production, but extensive research work has not been conducted on it as compared to the crushed granite. It is therefore appropriate to study the engineering properties of the concrete produced using Bida natural coarse aggregate to make available data that are useful in the mix proportioning, and also in design of mixes for specified compressive strength of concrete and subsequent estimation of optimal quantity of aggregate material to reduce the overall concrete production cost.

3. MATERIALS AND METHODS

3.1 Materials

The materials utilized in this research work are as follows;

a) Cement; Ordinary Portland Cement (42.5N) being the most common binding material used in Nigeria was used.

b) Fine aggregate; The sand was collected from Gidanmongoro, Minna, Niger state, Nigeria. It conforms to the standard requirement of BS EN 12620 [6].

c) Water; Potable drinking water from Civil Engineering Laboratory, Federal University of Technology Minna was used throughout this work. The water is clean, free from deleterious materials and potable as specified by BS EN 1008 [7].

d) Coarse aggregate; The natural stones used for this work were taken from Bida, Niger state in the middle belt region of Nigeria located about 250 Km North-East of Bida in land from the Federal capital city of Abuja. The deposits aggregates lie in zone 31, which falls within the latitude N 90 55′E and longitude N 50 52′ E [8]. The Bida natural deposits aggregates in character occur in middle Niger basin of Nigeria in several million metric tons. These aggregates are characterized with round and smooth surfaces, and are reddish-brown in colour. The aggregates used consist of maximum size of 19mm (Fig. 1). It also conforms to the standard requirement of BS EN 12620 [9].

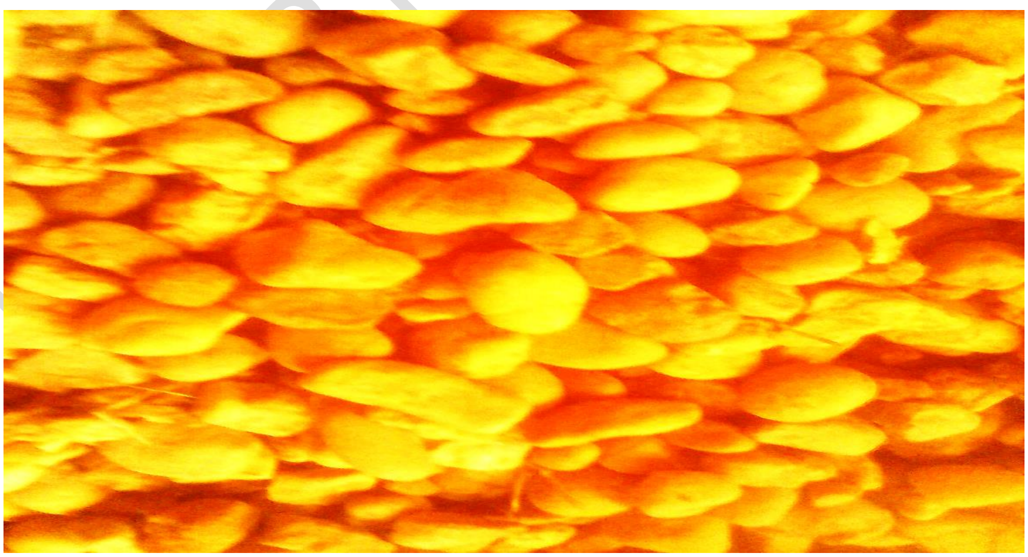

Fig. 1. Cluster of Bida natural coarse aggregate

3.2 Methods

The concrete specimen produced and tested were 150mmx150mmx150mm (cube), 100mmx100mmx500mm (prism), 300mmx150mm (cylinder) and also 300mmx150mm (cylinder) for compressive strength, flexural strength, splitting tensile strength and elastic modulus test respectively in accordance to specifications of BS EN 12390 [10].

Laboratory tests conducted on the sample of Bida natural coarse aggregate and fine aggregate to determine their physical properties include the following: moisture content, specific gravity, sieve analysis, aggregate impart value, aggregate crushing value, bulk density (compacted and uncompacted), water absorption and silt test in accordance with BS EN 12620 [6]. Also, the laboratory test conducted on the fresh and hardened concrete are: slump test, compacting factor test (compacted and uncompacted) according to BS EN 12350-1 [11]. The mechanical property tests were carried out on accordance with relevant parts of BS EN 12390 [10].

A total of 1600 samples were cast. Five samples per mix point for the 20 mix proportions generated by Minitab to test the 7, 14, 21 and 28 days strength of each of the mechanical properties.

a) Production of Concrete for Compressive strength

The sample was thoroughly mixed manually until the required homogeneity was achieved; the standard iron moulds of (150×150×150) mm3 were used. The moulds were lubricated with engine oil in other to reduce friction and to ease the removal of cubes from the moulds, they were then filled with fresh concrete in three layers and each layer was tamped 25 times. The same procedure was carried out for other concrete specimen (that is prism and cylinder for flexural strength, and splitting tensile and elastic modulus respectively).

b) Curing and crushing of the concrete

The curing method used was total immersion, the hardened concrete samples were demoulded after 24 hours, cured and crushed for 7, 14, 21 and 28 days respectively. The mechanical properties that were determined are the elastic modulus, compressive, splitting tensile and flexural strengths.

4. MODEL DEVELOPMENT

The experimental result of the elastic modulus, compressive, splitting tensile and flexural strengths were used for model development. All models: linear, linear +square, linear + interaction and full quadratic were tried for each property. The best models were chosen for each property, having satisfied the statistical validation parameters (Standard deviation S, R^2, $adjR^2$ and lack of fit value respectively). Table 1 shows the model summary and summary of ANOVA for the chosen models.

a) **Model adequacy checking**; Summary of the coefficients and significant p-value for each term in selected models are as follow

i. P- value (Level of significance)

The p-value of individual terms in all cases for the mechanical properties and slump are all less than 0.05 which is an indication that, all terms are highly significant in the model. Hence, this is a confirmation of the model adequacy.

ii. Standard deviation, S

The standard deviations of individual terms are very low in all cases of the properties as shown in Table 1. This is also a proof that the models in all cases are adequate to explain the data fully well.

iii. R^2 and adjR^2

The values of the R^2 and adjR^2 for the models are displayed in Table 1. These values range between of 93.7% - 100.0%, indication that the models are adequate to explain the data. This implies that about 93.7% -100% of the variability in all the properties, viz compressive strength, flexural strength, splitting tensile strength and slump is accounted for by the variables in the models developed.

iv. ANOVA

The results of the analysis of variance for all models are also displayed in Table 1. The lack of fit test is regarded as testing the lack of fit for a model under consideration. If the p-value of this parameter is high (That is greater than 0.05), it implies that there is no lack of fit and the model is regarded to be adequate. It is against this background that suggestion is made for the adequacy of the models developed in each case having satisfied the specification. Thus, p-values of lack of fit should be greater than 0.05 [12].

The p-values for linear, interaction and square models as shown in Table 1 for all the properties are less than 0.05 suggesting that the models are adequate to explain the variability in the data, thus the terms contribute significantly to the model. In addition, the values of residual error are considerably very close to that of pure error in all cases (that is in all models) as shown in Table 1. This also indicates that there is no lack of fit. Thus, the ANOVA test on model in all cases further confirms the adequacy of the models mentioned above. This is in agreement with the result obtained by Abdullahi [4]; Senthil and Baskar [13].

Table 1. The coefficients and significant p-value of each term in the selected models

Terms	Compressive Strength (Interaction)	Flexural Strength (Pure Quadratic)	Splitting Strength (Reduce Full Quadratic)	Elastic Modulus (Interaction)	Slump (Reduced Full Quadratic)

	Coefficient	p-value	Coefficient	p-value	Coefficient	p-val	Coefficient	p-val	Coefficient	p-val
Constant	-121.71	0.000	18.67	0.001	-24.16	0.001	117.21	0.000	-201.4	0.007
x_1	172.04	0.000	30.37.	0.001	44.89	0.001	121.66	0.000	1181.6	0.001
x_2	435.64	0.000	-76.14	0.000	37.88	0.001	-95.24	0.000	376.63	0.000
x_3	-10.01	0.000	2.98	0.000	1.55	0.000	-36.93	0.000	-120.7	0.019
x_1^2	-	-	-36.54	0.000	-	-	-	-	-232.1	0.000
x_2^2	-	-	64.03	0.000	-	-	-	-	-	-
x_3^2	-	-	-0.43	0.000	-0.19	0.000	-	-	15.09	0.000
$x_1 x_2$	-630.17	0.000	-	-	-72.92	0.001	-320.1	0.000	-	-
$x_1 x_3$	50.83	0.000	-	-	-	-	14.49	0.000	-129.1	0.000
$x_2 x_3$	-29.67	0.000	-	-	-	-	46.21	0.000	-	-
S	0.2619		0.0810		0.1643		0.07981		2.480	
R-sq %	99.8		99.8		93.7		100.0		93.7	
adjRsq%	99.6		99.7		89.8		100.0		89.8	
Lack of fit	0.572		0.661		0.612		0.790		0.612	

Regression equation for each response is as follows;

$$Y_1 = -121.71 + 172.04x_1 + 435.64x_2 - 10.01x_3 - 630.17x_1x_2 + 50.83x_1x_3 - 21.67x_2x_3 \quad (1)$$

$$Y_2 = 117.21 + 121.66x_1 - 95.24x_2 - 36.93x_3 - 320.05x_1x_2 + 14.49x_1x_3 + 46.21x_2x_3 \quad (2)$$

$$Y_3 = -24.164 + 44.89x_1 + 37.875x_2 + 1.546x_3 - 0.193x_1x_3 - 72.92x_1x_2 \quad (3)$$

$$Y_4 = 18.666 + 30.372x_1 - 76.137x_2 + 2.978x_3 - 36.543x_1^2 + 64.029x_2^2 - 0.426x_3^2 \quad (4)$$

$$Y_5 = -201.37 + 1181.602x_1 + 376.63x_2 - 120.67x_3 - 232.05x_1^2 + 15.09x_2^2 - 129.06x_1x_3 \quad (5)$$

Where:

Y_1 = Compressive strength

Y_2 = Elastic modulus

Y_3 = Splitting tensile strength

Y_4 = Flexural strength

Y_5 = Slump

x_1, x_2 and x_3 are as previously defined

b) Residual plot

It is mandatory that the developed models provide an adequate similarity to the true system, proving that none of the least square regression assumptions are violated. Proceeding with exploration and optimization of a fitted response surface will likely give a poor or misleading result unless the model is adequately fitted [12].

The residual from the least square fit plays an important role in judging model adequacy. Fig. 2 to 6 present normal probability plots of residual for the mechanical properties and slump. The normal probability plot shows that the points lie approximately along the straight line as shown in these Figures, hence no apparent problem with the normality in the plot, this implies that the normality assumption is satisfied. However, the straight line in this normal probability plot was determined by inspection concentrating on the central portion of the data [12].

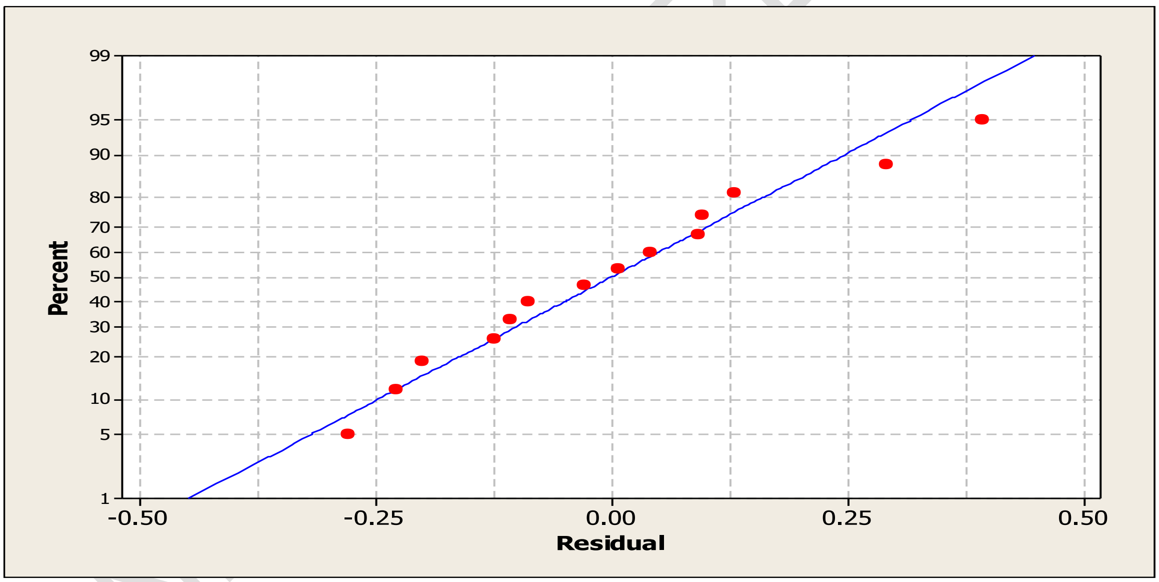

Fig. 2. Normal probability plot of the residuals for compressive strength

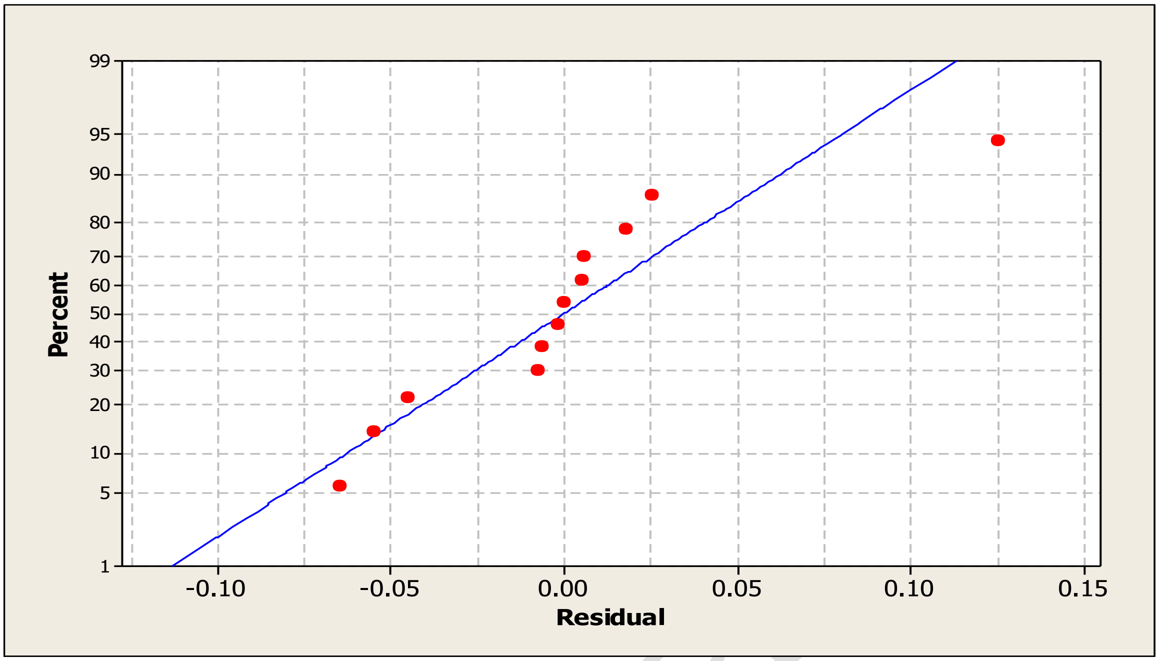

Fig. 3. Normal probability plot of the residuals for elastic modulus

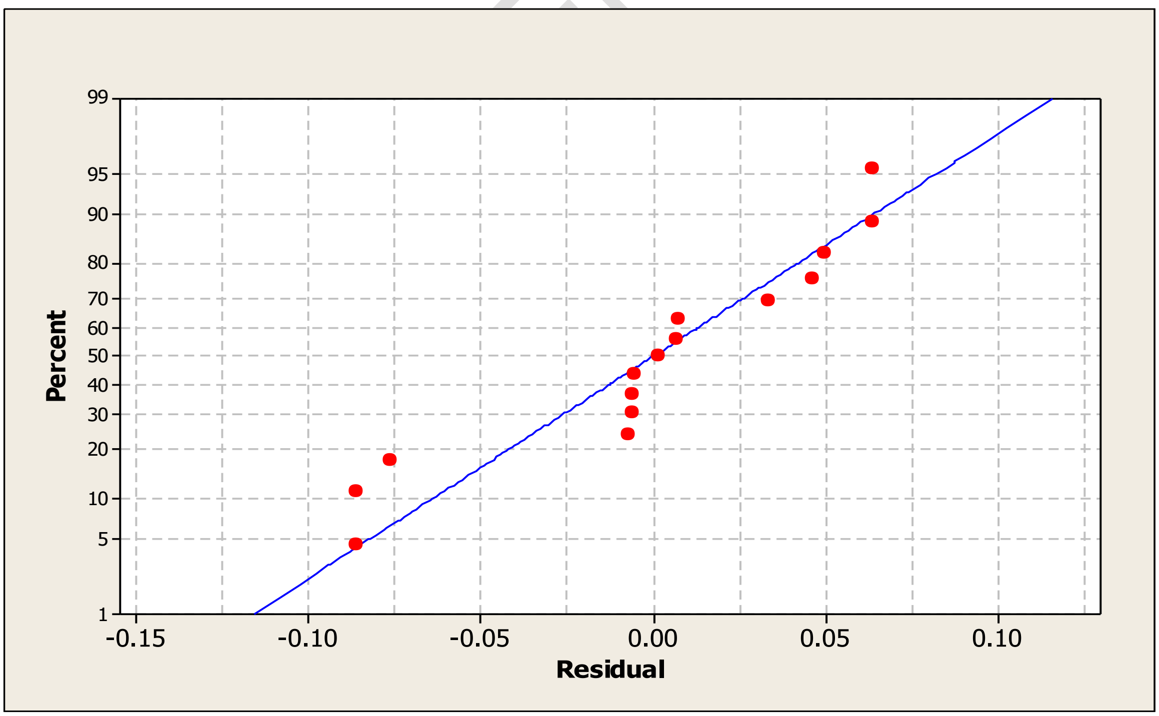

Fig. 4. Normal probability plot of the residuals for splitting tensile strength

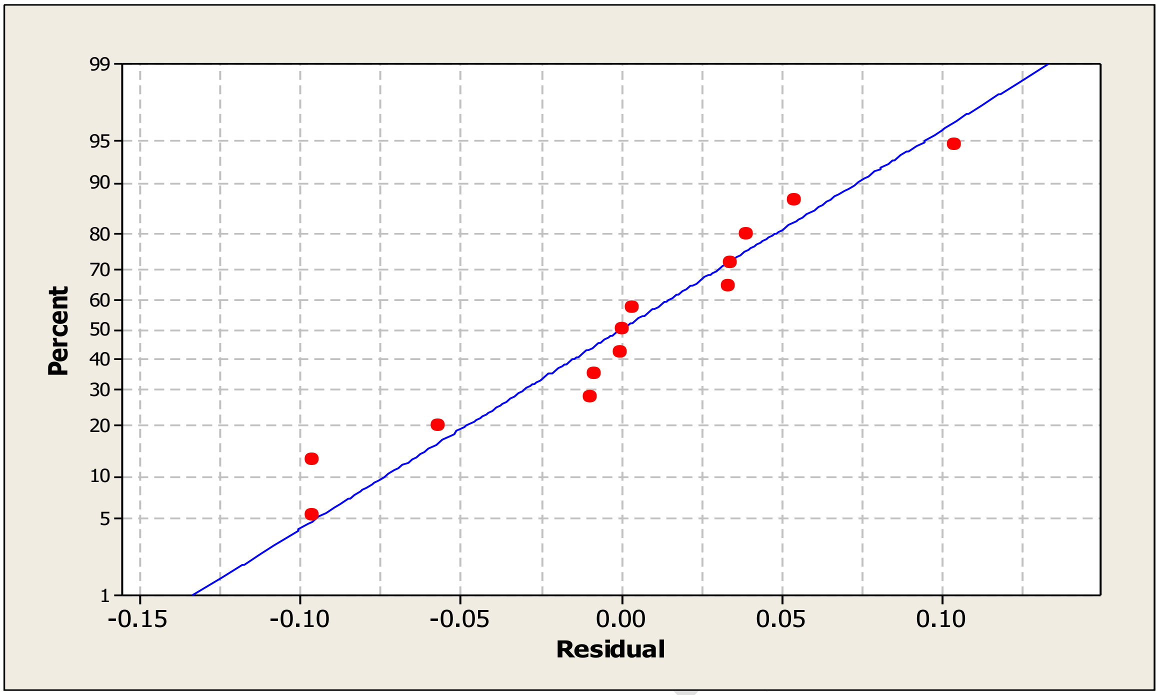

Fig. 5. Normal probability plot of the residuals for flexural strength

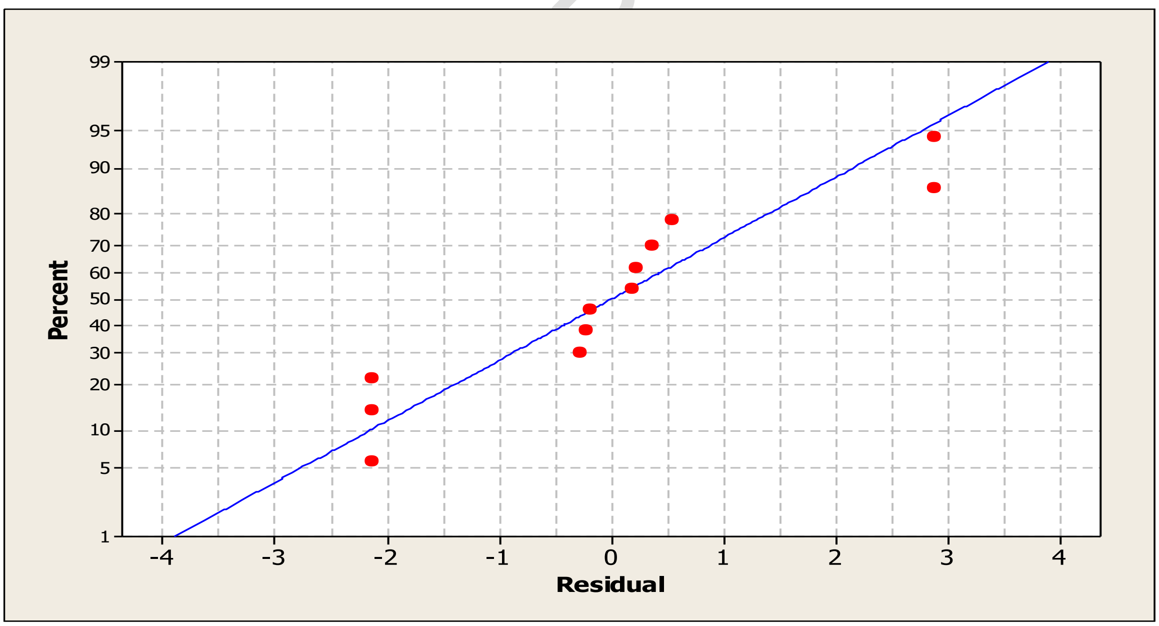

Fig. 6. Normal probability plot of the residuals for flexural strength

c) Experimental Model Validation

To validate each of the regression model five (5) numbers of specimens for five (5) different mixes were cast and tested at 28days for compressive strength, flexural strength, splitting tensile strength and elastic modulus. The independent variables as shown in Table 2 were fixed into the regression model equations to arrive at the predicted values (responses) for the samples [13].

Table 2. The Variables Used for Experimental Validation

Validation	W/C	CA/TA	TA/C
Mix order	X1	X2	X3
1	0.45	0.55	4.5
2	0.55	0.615	4.5
3	0.6	0.55	6.0
4	0.4	0.68	4.5
5	0.5	0.55	6.0

d) Percentage errors of experimental and predicted values for the validated sample

In addition to the statistical validation of the developed models, the experimental model validations were also carried out. Table 3 shows the percentage errors of experimental and predicted values. It is obvious that the percentage errors were negligible, that is, the predicted responses are very closed to the experimental results which further confirms the validity of the developed models in each case of the compressive strength, flexural strength and elastic modulus. Hence the predicted models are reliable.

Table 3. Percentage Errors of Experimental and Predicted Values for the Validated Samples

Mix order	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)			Splitting tensile strength (N/mm^2)			Elastic modulus (N/mm^2)		
	Exp	Pre	% error	Exp	Pre	% error	Exp	Pre	% error	Exp	Pre	% error
M1	24.1	23.8	1.263	6.8	7.2	-5.88	5.5	5.39	2	17750	17890	-0.79
M2	26.04	26.32	-1.09	6.6	6.48	1.82	5.6	5.63	-0.54	14940	14860	0.54
M3	35.91	38.18	-6.31	3.9	3.76	3.59	8	8.12	-1.5	15090	15280	-1.26
M4	27.73	27.59	0.491	7.3	7.57	-3.70	6.5	6.32	2.77	15160	15360	-1.32
M5	25.07	25.13	-0.25	4.7	4.74	-0.85	7.2	7.76	-7.78	12910	12030	6.82

% error= (Exp-Pre)/Expx100

5. CONCLUSION

It can be concluded, based on the findings of this research that;

1. Central composite design has been proven to be a robust tool in evaluating parameters effect of mixture and the interaction between the parameters of concrete

made using Bida natural stones and can reduce the number of trials to achieve balance among mix variables.

2. The statistical models developed for compressive strength, flexural strength, splitting tensile strength, elastic modulus and slump are interaction, pure quadratic, reduced full quadratic, interaction and reduced full quadratic model respectively.

3. Graphical analysis of the results shows the deviation between the measured and fitted data could be effective methods to test the adequacy of the regression model.

Recommendation

The concrete with mix constituents listed in this study can be used for structural application such as reinforced concrete slabs, beams, columns and foundations.

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