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Statistical Model for Predicting Slump and Strength of Concrete Containing Date Seeds

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Abstract: Incorporating agro-based waste in concrete can reduce environmental pollution and lead to preserving the ecosystem. In order to reduce trial and error in achieving desired slump and compressive strength of concrete containing Date Seed (DS), this paper examines the slump and compressive strength of concrete using date seeds as a partial replacement for crushed granite. Preliminary tests were conducted on the aggregates to ascertain their suitability for concrete production. Concrete with DS-crushed granite ratios of 0:100, 5:95, 10:90, 15:85, and 20:80 were prepared using a mix ratio of 1:2:4 and a water-cement ratio of 0.5. Slump loss was used to estimate the workability of the fresh concrete. The freshly prepared concrete was cast in 150 x 150 x 150 mm and the compressive strength was determined after curing by full immersion in water for 7, 14, 21 and 28 days. Results showed that the slump of concrete increased with an increase in the content of date seed. The compressive strength was inversely proportional to the date seed content with a DS-crushed granite ratio of 20:80 recording the lowest compressive strength (20N/mm^2). Linear regression models for slump and compressive strength were developed and found to be sufficient in explaining the experimental data based on a Mean Square Error (MSE) of 0.37 and 0.029 and R^2 of 88% and 99% obtained for slump and compressive strength respectively. The study has concluded that DS can be used as a partial replacement for crushed granite in concrete and a linear model is sufficient in predicting the slump and strength of concrete containing date seeds.
Keywords: Compressive strength, Concrete, Date seed, Model, Slump

1. Introduction

Infrastructural development is essential for developing countries such as Nigeria, which records a spontaneous increase in population annually. Consequently, engineers have made efforts to develop sustainable and cost-effective materials for the Nigerian construction industry. Concrete is the major construction material used for various types of infrastructure in Nigeria due to the availability and affordability of its constituent materials. Concrete is a composite material made up of aggregates (fine and coarse aggregate), cement, and water in the required proportion [1][2]. Coarse aggregate which is the least expensive material in concrete accounts for about 55% of the total concrete volume and plays an active role in the workability, volume stability, strength and durability of concrete [3][4][5]. It is usually obtained from fragments of rocks (crushed granite) or gravels of different mineralogy. Due to the increasing population of Nigeria, construction materials are being overstretched. Intrinsically, efforts have been made to replace conventional crushed granite with sustainable and cost-effective materials obtained from agricultural, municipal, and construction wastes for the production of concrete [6][7][8] [9][10][11] [12][13].

Research has shown that Date Seed (DS) is a viable agricultural waste used to substitute crushed granite in concrete. DS is obtained as a waste product after date stoning when producing pitted dates or date paste. It is a hard-coated seed with a grooved oblong shape as depicted in Figure 1.

Figure 1: Date Seed

DS has been used in the production of concrete by lots of researchers in the past. [14] studied the durability of lightweight concrete made from date palm seeds using a mix ratio of 1:2.2:1.5. Similarly, [15] examined the compressive strength of concrete containing DS using replacement levels of 25, 50, 75, and 100% and recommended using DS as lightweight aggregate material. [16] also studied the compressive strength of concrete using coarse aggregate-date seed ratios of 100:0, 95:05, 90:10, 85:15, 80:20 and 75:25 for grades M20, M25 and M30 designated concrete. The study concluded that only 10% replacement of coarse aggregate with date seed showed acceptable compressive strength. Research into the modelling of compressive strength of concrete using DS as coarse aggregate is scarce in the literature. There seems therefore, to be a research gap in this regard. Hence, this research is focused on developing a statistical model for predicting the strength of concrete containing DS.

2. Materials and Methods

2.1 Materials

The properties of all the materials used in work are given in Table 1. These properties were tested based on guidelines contained in [17] and [18].

Coarse Aggregate: Crushed granite with a maximum size of 20mm used in this study was sourced from Pyata quarry in Bosso Local Government, Minna, Nigeria. The result of sieve analysis for the crushed granite is shown in Table 2.

Date seeds: The date seeds were obtained from local retailers and dried in the open air to reduce their moisture content. The result of sieve analysis for the DS is also presented in table 2.

River Sand: River sand not containing any particles of clay and silt obtained from Chanchaga river in Minna, Niger State, was used as fine aggregate in the study. The result of the sieve analysis is shown in Table 3.

Ordinary Portland Cement (OPC) classified as grade 42.5 in [18] possessing specific gravity (SG) of 3.14 sourced from retailers was used in the study.

Water: Potable water from the tap located at the laboratory of the Civil Engineering Department, Federal University of Technology, Minna, was used for mixing and curing.

Table 1: Properties of materials used.

Material	Specific Gravity	Moisture Content (%)	Bulk Density (kg/m^3) Compacted	Uncompacted	Aggregate Impact Value (%)
Cement	3.14	-	-	-	-
River Sand	2.60	3.8	1447	1310	
Crushed Granite	2.54	2	757	703	14.3
Date Seed	1.28	11.78	1470	1406	19.2

2.2 Methods and Experimental Programme

A mixed ratio of 1:2:4 with a water-cement ratio of 0.5 was adopted in the study. A DS replacement level of 5, 10, 15, and 20 percent by weight of crushed granite was added to the measured quantity of cement, sand and crushed granite in each case. The materials in the desired proportion were adequately mixed until a uniform blend was achieved. The required quantity of water was added to each blend and mixed thoroughly to achieve a consistent blend. A slump test was carried out on each of the freshly prepared concrete in accordance with [19] to determine the workability of each blend. Five representative cube specimens of 150 x 150 x 150 mm size were cast for each replacement level. The cubes were demoulded after 24 hours and allowed to cure in a water curing tank for 7, 14, 21 and 28 days. In compliance with [20] guidelines, the compressive strength of the specimens was determined at the appropriate curing age using a 2000 kN compressive strength testing machine.

2.3 Model Development

Slump test results and 28 days compressive strength results were used as the response parameters, while the percentage of DS was used as the predictor in each case. The statistical models were developed and validated using the data analysis toolbox available in [21] following the procedure shown in Figure 2. Analysis of variance (ANOVA) was performed at a 95 % confidence interval and 0.05 significance level.

Figure 2: Procedure of Model Development in Excel

3. Results and Discussion

3.1 Sieve Analysis

Sieve analysis results of the DS and crushed granite used showed the distribution of the DS having the majority of the aggregate less than 14mm, while the crushed granite, on the other hand, contained particles ranging between 10 mm and 20 mm. The aggregates do not conform to limits prescribed by [22] for aggregates in concrete, as presented in Table 2.

The sieve analysis result of the river sand used is shown in Table 3. The fine sand satisfied grading limits prescribed by [22]. As such, the aggregate is suitable for concrete production.

Table 2: Sieve Analysis for Date Seed and Crushed Granite

Sieve Size (mm)	Mass Retained (g)	Percentage Mass Retained (%)	Cumulative Percentage Mass Retained (%)	Percentage Passing (%)	Grading Limits Prescribed by BS 882 (%)
			Date Seed		
20	0	0	0	100	90 - 100
14	0	0	0	100	40 - 80
10	130	13	13	87	30 - 60
6.3	840	84	97	3	
5	30	3	100	0	0 - 10
Total	**1000**				
			Crushed granite		
20	400.5	40.05	40.05	59.95	90 - 100
14	505.7	50.57	90.62	9.38	40 - 80
10	93.8	9.38	100	0	30 - 60
6.3	0	0	100	0	
5	0	0	100	0	0 - 10
Total	**1000**				

Table 3: Sieve Analysis of River Sand

Sieve size (mm)	weight of sieve + sample (g)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage passing (%)	Grading Limits Prescribed by BS 882 (%)
5	5.4	1.08	1.08	98.92	98 - 100
3.35	16.5	3.3	4.38	95.62	
2.36	32.1	6.42	10.8	89.2	60 - 100
2	16.8	3.36	14.16	85.84	
1.18	71.3	14.26	28.42	71.58	30 - 100
850	53.3	10.66	39.08	60.92	
600	70.4	14.08	53.16	46.84	15 - 100
425	60.8	12.16	65.32	34.68	
300	32	6.4	71.72	28.28	5 to 70
150	92.6	18.52	90.24	9.76	0 - 15
75	38.6	7.72	97.96	2.04	
pan	304.7	1.42	99.9	0.1	

3.2 Slump and Compressive Strength

The slump test result (to the nearest 5 mm) of the fresh concrete and compressive strength of concrete cubes for different percentages of DS is presented in Table 4. From the results, there exists an increase in a slump as the percentage of DS increased. This may be due to the smooth surface texture of the DS, as aggregates with smooth surfaces have been reported to possess higher workability than aggregates with rough surfaces [23]. The slump test results agree with the slump values reported by [15] and [16]. The compressive strength decreased with an increase in the percentage of date seed used. Smooth surface aggregates are detrimental to the bond between aggregates and cement paste according to [4][23]. This can be attributed to why the compressive strength decreased with an increase in the percentage of DS at all curing ages. The trend in the compressive strength result conforms with compressive strength reported by [14], [15] and [16] (19.6 - 23.44 N/mm^2) using date seeds with similar properties.

Table 4. Slump and Compressive Strength

% Replacement of DS	Slump	Compressive Strength (N/mm^2)			
		7 days	14 days	21 days	28 days
0	30	13.3	16.4	20.8	23.5
5	30	12.9	15.4	20.3	22.9
10	30	12.5	14.9	19.9	21.6
15	30	11.9	14.1	19.2	20.9
20	35	11.0	13.6	18.1	20.0

3.3 Model Development

Regression models for slump and 28 days compressive strength were developed using data analysis in Microsoft Excel (2010). The percentage replacement of DS was selected as the independent variable labeled x while slumping and compressive strength results labeled Y1 and Y2 were used as the dependent variable, respectively. The regression equations obtained for the slump and compressive strength model are given in Equations 1 and 2 respectively while the regression statistics and Analysis of Variance (ANOVA) are presented in Tables 5 and 6. The coefficient of determination (R^2) ranges from 0 – 100%, where a percentage close to 100% suggests adequate goodness of fit [24][25][26]. The R^2 obtained for the slump model was 88%. This affirms that 88% of the model parameters fit the model developed and 88% variance in the slump values in the neighborhood of the mean are described by the percentage increase in DS. Similarly, a very high R^2 of 99% was obtained for the compressive strength model as shown in Table 5. This proves that the percentage increase in DS explains 99% variation of the compressive strength data within the mean.

From the ANOVA result shown in Table 6, the slump model recorded a Mean Square Error (MSE) of 0.37 and a significance F of 0.02. MSE ranges from 0 to 1, with values closer to 0 suggesting a minimal error between the observed and predicted responses. Furthermore, the significance related to the p-value is less than the 0.05 significance level. An indication that the data has discrete means. In the same vein, the compressive strength model recorded MSE of 0.029 and significance F of 0.0005 which is less than 0.05 significance level. A suggestion that means of the compressive strength data is distinct.

$$Y1 = 0.18x + 27.18 \quad (1)$$

$$Y2 = 23.58 - 0.18x \quad (2)$$

Where,
Y1 = slump
Y2 = compressive strength and
x = percentage increase in DS

The residual, line and normal probability plots are presented in Figures 3, 4 and 5 for the slump model while Figures 6, 7 and 8 are for the compressive strength model. The residual plots show that the residuals are arbitrarily scattered over the negative and positive sides of zero. An indication that the residuals do not follow a regular path.

Table 5: Regression Statistics for slump and compressive strength models

	Slump	Compressive Strength
Multiple R	0.94	0.99
R Square	0.88	0.99
Adjusted R Square	0.84	0.99
Standard Error	0.61	0.17
Observations	5	5

Table 6: ANOVA for slump and compressive strength models

	df	*SS*	*MS*	*F*	*Significance F*
			Slump		
Regression	1	8.1	8.1	22.09	0.02
Residual	3	1.1	0.37		
Total	4	9.2			
			Compressive Strength		
	1	8.1	8.1	276.136	0.0005
	3	0.09	0.029		
	4	8.19			

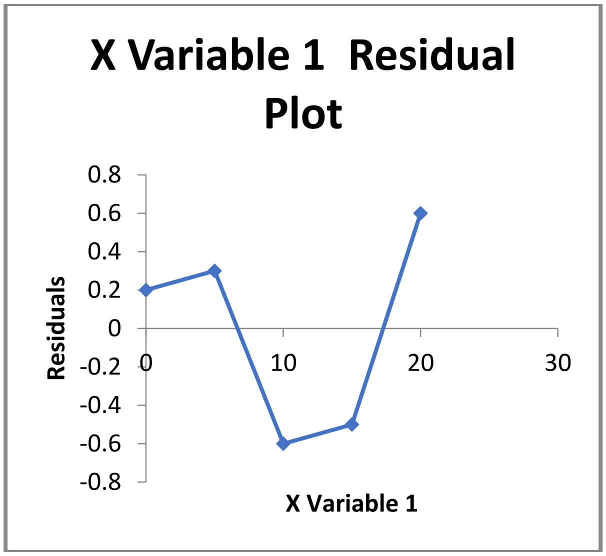

Figure 3: Residual Plot for Slump Model

The normal probability plot depicts that the residuals are not so far away from the straight line. This indicates that the residuals are normally distributed.

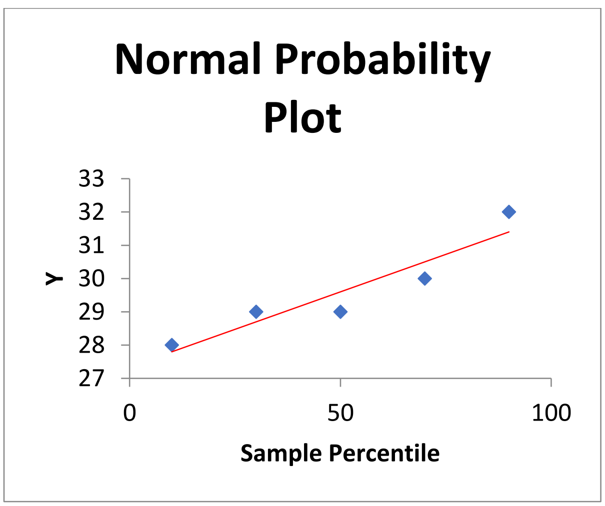

Figure 4: Normal Probability Plot for Slump Model

The experimental vs. model slump results are shown in Figure 5. The experimental slump data are not so close to the predicted slump results. This accounts for why it recorded an R^2 of 88% and MSE of 0.37. The slump model is therefore adequate to a reasonable extent in predicting the slump of concrete containing DS.

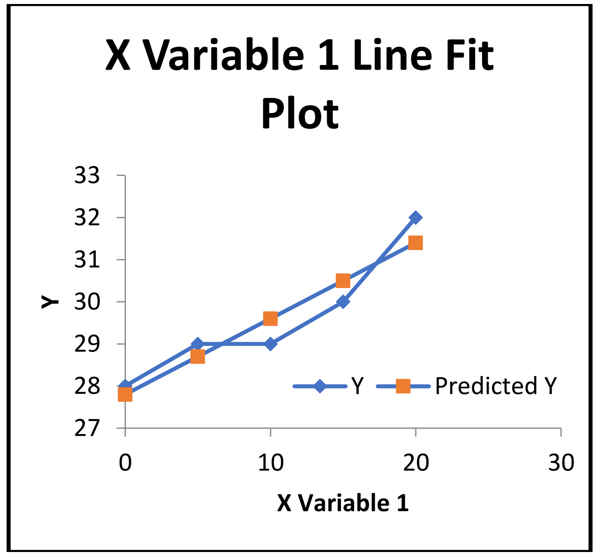

Figure 5: Experimental vs. Predicted Slump Result

The residual plots for the compressive strength model illustrate that the residuals are haphazardly represented on the negative and positive sides of zero. Therefore, the residuals do not follow a regular path.

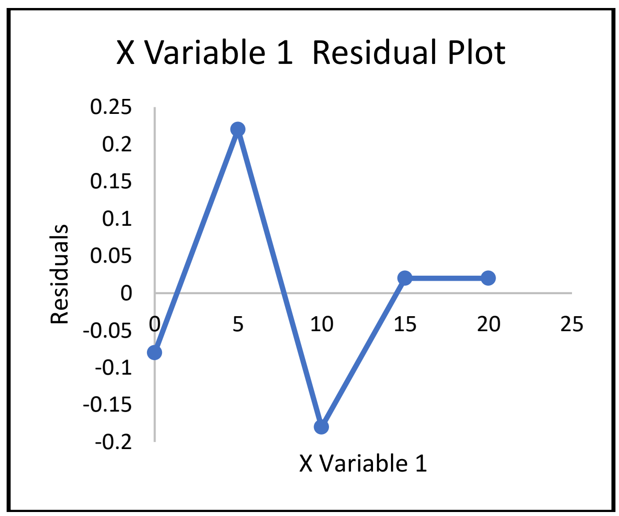

Figure 6: Residual Plot for Compressive Strength Model

The normal probability plot for the compressive strength model shown in Figure 7 indicates that the residuals are very close to the straight line. A clear signal that the residuals are normally distributed. This gives an insight as to why it recorded a very low MSE (0.029) and a very high R^2 (99%).

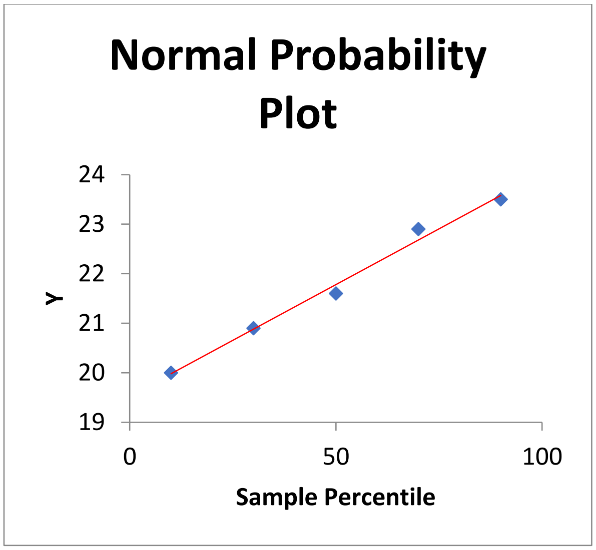

Figure 7: Normal Probability Plot for Compressive Strength Model

The result of the compressive strength vs model is shown in Figure 8. The observed compressive strength is very close to that of the predicted compressive strength. This is an indicator that the error between the actual and predicted compressive strength results is negligible. It is, therefore, safe to oblige that the model is adequate in predicting the compressive strength data.

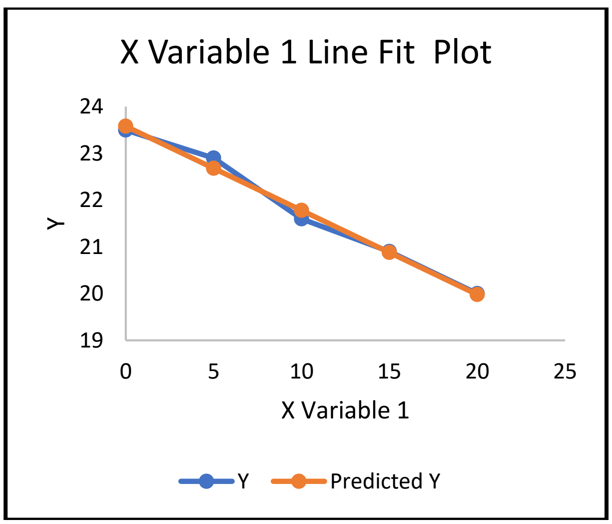

Figure 8: Experimental vs. Predicted Compressive Strength Result

4. Conclusion

The conclusion arrived at based on findings in this research are;

i. The higher the quantity of DS as partial replacement of coarse aggregate in concrete, the higher the slump of the resulting concrete.

ii. The compressive strength of concrete reduces with an increase in the percentage of date seed in concrete. A percentage increase in date seed of 20% recorded the lowest compressive strength of 20N/mm^2. Concrete with 5 - 20% replacement levels is thus suitable for structural applications.

iii. A linear regression model is sufficient in predicting the slump and 28 days compressive strength of concrete containing date seeds with an R^2 of 88% and 99% and MSE of 0.37 and 0.029 respectively.

iv. From the results of the compressive strength, DS is suitable for normal-weight concrete.

Conflict of Interest

There is no conflict of interest associated with this work.

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