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Development of Statistical Models to Predict the Compressive Strength of Concrete Produced Using Quarry Dust as Partial Replacement for Fine Aggregate

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Abstract

Concrete is an assemblage of Cement, aggregates and water. The most frequently used fine aggregate for concrete production is sand sourced from river banks. The continuous use of this river sand as a result of rapid infrastructural development has resulted in its scarcity and often high cost. This paper examines the suitability of using quarry dust (QD) as partial replacement for fine aggregate in concrete production. Preliminary test (specific gravity) was conducted on the aggregates to determine their suitability for concrete production. Concrete with 5, 10, 15, 20 and 25% QD – Fine aggregate content was cast with a mix ratio of 1:2:4. The freshly prepared Quarry Dust Concrete (QDC) was cast in moulds measuring 150 x 150 x 150mm and cured using ponding method. The Compressive strength result shows that replacement of fine aggregate with QD leads to a general increase in compressive strength of concrete. Statistical package for the Social Sciences (SPSS) version 21 was utilised to develop the linear regression models for the 7 and 28 days compressive strength of the QDC. The developed models were found to be sufficient in predicting the 7 and 28 days compressive strengths with R^2 values of 98.9% and 95.2 % respectively.

Keywords: Concrete, Compressive Strength, Model, Quarry Dust

Introduction

Concrete is an extensively used construction material in the world, second to water as the most utilised substance on earth (Alhaji, 2016: Gupta *et al.*, 2021). It is obtained by mixing the right quantities of Cement, water and aggregates (with admixtures). Aggregates ideally constitute 75% of concrete as such are extremely important in the quality of concrete produced, this makes it important that they meet certain standards in order to achieve a strong, durable and economical concrete (Alhaji, 2016).

The importance of fine aggregate (Natural River sand) in concrete production can never be over emphasized, this is as a result of its relative importance in concrete production. This has resulted in its high demand in the construction industry. Also, Nigeria as one of the developing nations is seriously experiencing excessive excavation and mining of natural river sand which has negative environmental consequences. Among these are erosion and failure of river banks, lowering of river beds, damage of structures situated closer to the rivers, saline water intrusion into surrounding land and coastal erosion (Ajamu *et al.*, 2020). Furthermore, the high cost of building materials over the years has led to a clamour for alternative sources of materials for construction. The challenge for the use of locally sourced materials for the construction of buildings is as a result of such clamour and has been linked to strategies to reduce the cost of buildings and construction (Asuzu *et al.*, 2017: Dhurvey and Tiwari, 2020: Nduka *et al.*, 2019).

According to Ajamu *et al.* (2020) Quarry dust is a residue which is obtained from quarrying of rocks, over the years it has gained the trust of many construction industry professionals as an alternative material for fine aggregate in concrete production. It is a by-product of crushing of rocks (Prakash and Rao, 2016). The advantages of utilization of residue or aggregates obtained as waste materials are evident in the aspects of the reduction in environmental degradation and waste management cost, reduction of production cost as well as augmenting the quality of concrete. Several researches have been conducted on the use of Quarry dust as partial replacement for fine aggregate; according to Celik and Mirra (1996) the compressive and flexural strength of concrete increased with addition of Quarry dust up to 10% replacement level, the impact resistance of the concrete also improved with 5% of the dust content. The researchers opined that an increase above 10% replacement level resulted in a general decrease in the compressive strength, flexural strength and drying shrinkage of concrete.

The coarse aggregate used for this research was sourced from Bida, Niger State, Nigeria. It is mostly found in Bida basin (Trough), it is a by-product of the Precambrian decomposition, transportation and deposition of rocks in this Basin. It is an extension of the Inllumedin Basin which runs through Niger Republic and Mali in West Africa. Bida basin is found in Northern Nigeria and is delimited to the North East and South West by Basement Complex. The Precambrian rocks in Northern Nigeria can generally be classified into four groups namely: Basement Complex, Older Granite series, Younger Metasediments, and Volcanic Rocks. It is referred to as Bida Natural Stone (BNS). This research utilized locally available natural aggregate along with Quarry dust to produce concrete as against the conventional crushed granite with Quarry dust in similar researches. The use of BNS for concrete production is gaining wide acceptance especially among the dwellers of the Bida basin because the production of crushed granite is more labour intensive and expensive. However, despite the wide acceptance of its use, the body of literature is still not robust with research related to the use of BNS as coarse aggregate for concrete production (Kolo *et al.,* 2019). This research developed statistical models to predict the compressive strength of concrete produced utilising Quarry dust as partial replacement for fine aggregate.

Materials and Methods

Ordinary Portland Cement (OPC)

The Cement used was Dangote brand of cement obtained from the Building Materials Market Minna, Niger State, Nigeria. The bags of Cement were stored on a raised Platform where adequate protection from external effect was guaranteed. The OPC conforms with BS 12 (1996).

Fine Aggregate

The sand was collected from Chanchaga, Minna, Niger State. It was ensured that the sand was clean, sharp, free from clay and dirt's. Fine Aggregates generally refer to aggregates passing through sieve size 4.75 mm BS 882 (1992).

Water

Water fit for drinking was sourced from the Civil Engineering Laboratory, Federal University of Technology Minna and used in casting the cubes. BS EN 1008 (2002) stipulates that water to be used for concrete production must be clean, drinkable and free from deleterious materials.

Coarse Aggregate

The Coarse Aggregate used for this work was sourced from Bida, Niger State, Nigeria. Bida is located in the Middle belt region of Nigeria. Bida precisely falls within Latitude N 9^{o} 55' E and Longitude N 5^{o} 52' E. The coarse aggregates conform to specifications for natural aggregates as in BS 882 (1992). The coarse aggregate herein referred to as Bida Natural Stone (BNS) is depicted in Plate I.

Quarry dust

The quarry dust used for this research was sourced from local retailers within Minna, Niger State.

Plate I: Cluster of Bida Natural Stones (BNS)

Plate II: Cluster of Quarry dust

Casting of Concrete Cubes for Compressive Strength Test

The Concrete specimens tested were cast in 150 mm x 150mm x 150 mm moulds for compressive strength test. The samples were thoroughly mixed with the aid of a Concrete mixer until the desired homogeneity of the mixture was achieved. The standard iron moulds of 150 mm x 150mm x 150 mm were used, it was ensured that the moulds were well lubricated with oil in order to reduce friction and enhance removal of the cubes from the mould. Each mould was then filled with concrete in three layers each tampered 25 times. The cubes were cured for 28 days using Ponding method of curing. Cube casting was performed in accordance to BS 1881 (1983).

Compressive Strength Test

Compressive strength test on Concrete Cubes were determined using the Compressive testing machine. The weight of each cube was taken before crushing. The compressive strengths were calculated using Equation (1). The test was conducted in accordance with BS 1881:116.

$$F_{cu} = \frac{Average\ Load}{Area}\ (N/mm^2) \quad (1)$$

Model Development

Linear regression analysis was employed in developing the models. Statistical package for social sciences version 23 (SPSS) was the tool employed in developing the models. The percentage replacement level of QD was selected as the independent variable and labelled P, while the compressive strength of the QDC concrete was selected as the dependent variable and labelled Y, Y1 for 7 days strength and Y2 for 28days compressive strength. Linear regression is the most utilized multivariate technique used in analysing relationships and predicting future values between several independent variables and a single dependent variable. (Kolo, 2019).

Results and Discussion

Table 1 presents the results for specific gravity test performed on the Fine aggregate, an average specific gravity of 2.7 was achieved and is within the natural aggregates range of 2.6 – 2.7 as proposed by: (Neville and Brooks, 2008).

Table 1: Specific gravity result for Fine Aggregate

Trial	1	2	3
Weight of cylinder	115.0	116.5	116.6
Weight of cylinder + sample	207.2	240.6	248.9
Weight of cylinder + sample + water	487.3	512.0	484.9
Weight of cylinder + water	428.0	435.7	402.2
Specific gravity of sample (S.G)	2.80	2.60	2.70
Average specific gravity (S.G)		2.70	

Table 2 presents the results for specific gravity test performed on the quarry dust, an average specific gravity of 2.53 was achieved.

Table 2: Specific Gravity results for Quarry Dust

Trial	1	2	3
Weight of bottle W_1 (g)	117.00	117.00	117.00
Weight of bottle + sample W_2	310.3	321.6	325.7
Weight of bottle + sample + water W_3	547.1	555.8	559.8
Weight of bottle + water W_4	432.4	432.6	432.4
Weight of water added to sample (W_3-W_2)	236.8	234.2	234.1
Weight of sample (W_2 - W_1)	193.3	204.6	208.7
Weight of water displaced (W_4 - W_1) - (W_3 -W_2) = W(g)	78.6	81.4	81.3
Specific gravity of Sample	2.5	2.51	2.57
Average Specific Gravity		2.53	

Table 3 presents the results for specific gravity test performed on the Coarse aggregate, an average specific gravity of 2.6 was obtained and is within the natural aggregates range of 2.6 – 2.7 (Neville and Brooks, 2008). This implies that the aggregate is suitable for construction work.

Table 3: Specific Gravity for Coarse Aggregate (BNS)

Trial	1	2	3
Weight of bottle W_1 (g)	129.50	129.50	129.50
Weight of bottle + sample W_2	267.4	292.4	267.6
Weight of bottle + sample + water W_3	583.2	600.1	583.5
Weight of bottle + water W_4	497.9	495.4	497.9
Weight of water added to sample (W_3-W_2)	315.8	307.7	315.9
Weight of sample (W_2 - W_1)	137.9	162.9	138
Weight of water displaced (W_4 - W_1) - (W_3 -W_2) = W(g)	52.6	58.2	52.4
Specific gravity of Sample	2.62	2.79	2.63
Average Specific Gravity		2.68	

Figure 1 presents results for 7- and 28-days compressive strength conducted on the quarry dust concrete (QDC). A general increase in compressive strength values was achieved with increase in quarry dust content for the 7days curing. The highest strength achieved was at 25% replacement level with compressive strength of 15N/mm^2 while for the 28 days curing age a general increase in compressive strength values was achieved with increase in quarry dust content with highest strength achieved at 25% replacement level with compressive strength of 24.2 N/mm^2. This result is in line with findings of research conducted by Nduka *et al*. (2018), Biswaprakash and Mahendra (2018), and Fayaz *et al*. (2017) where quarry dust performed significantly well when utilised as replacement for fine aggregate in concrete production.

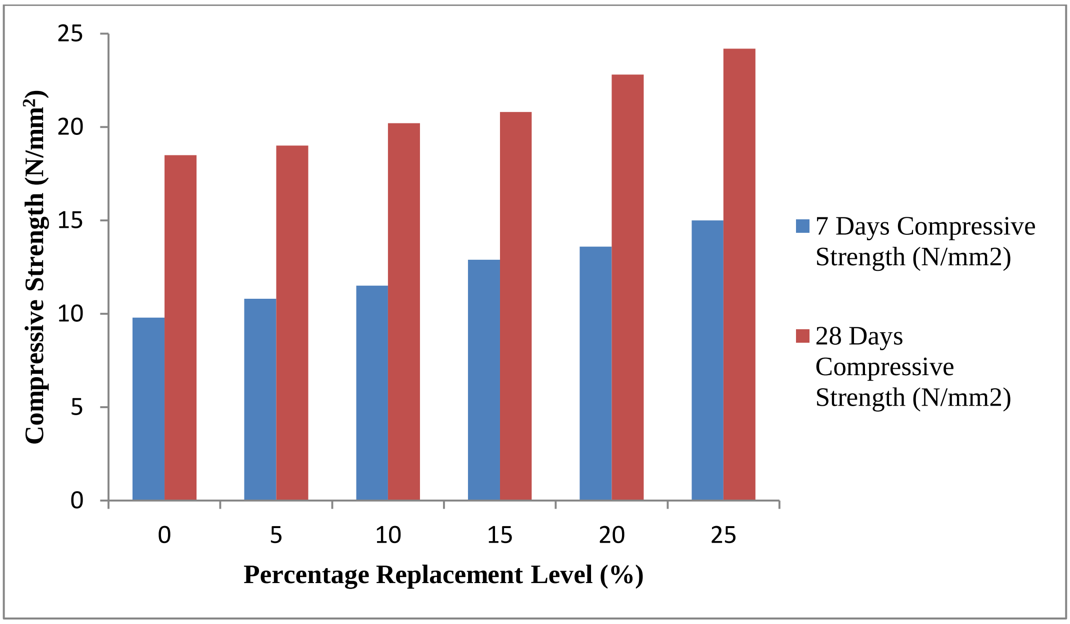

Figure 1: 7- and 28-Days Compressive Strength results for QDC

Table 4 presents the model summary for the 28 days compressive strength model developed. The model achieved a coefficient of determination (R^2) value of 0.991 and an adjusted R^2 value of 0.989. This implies that the developed model can predict 7 days compressive strength of QDC with an accuracy of 98.9%.

Table 4: Model Summary (7 days Compressive Strength)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.996	0.991	0.989	0.20260

Tables 5 and 6 presents results for the ANOVA and Model coefficients results for the 7 days compressive strength model developed. As can be seen on Table 5, the model recorded a mean square of 0.041 with a significance of 0.000 which is less than the significance level. This implies the data under consideration has discrete means. The developed model is can be seen on equation (2).

Table 5: ANOVA for 7 days compressive strength model

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	18.309	1	18.309	446.0	0.000
1	Residual	0.164	4	0.041	46	
	Total	18.473	5			

Table 6: Model Coefficients (7 days Compressive Strength)

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	9.710	0.147		66.217	0.000
	% Replacement	0.205	0.010	0.996	21.120	0.000

$$Y1 = 9.710 + 0.205P \quad (2)$$

Where Y1 = 7 days Compressive Strength

P= Percentage replacement level

Figure 2 presents the result of normal probability plot for data used in developing the seven (7) days compressive strength model, it shows points lying close to the straight line. This indicates that the residuals are approximately normally distributed.

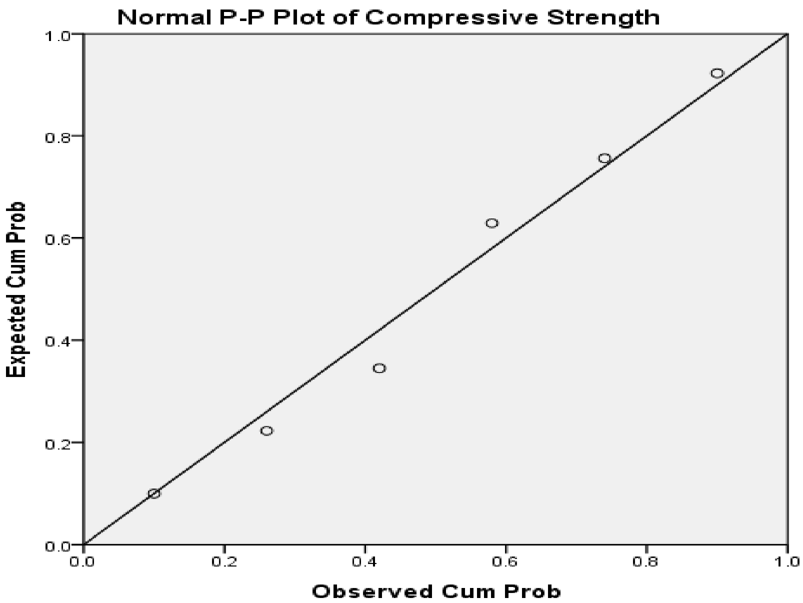

Figure 2: Normal Probability plot for 7 days compressive strength values

Table 7 presents the model summary for the 28 days compressive strength model developed. The model achieved a coefficient of determination (R^2) value of 0.962 and an adjusted R^2 value of 0.952. This implies that the developed model can predict the 28 days compressive strength of QDC with an accuracy of 95.2%.

Table 7: Model Summary (28 days compressive strength)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.981	0.962	0.952	0.48378

Table 8: ANOVA for 28 days Compressive Strength model

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	23.432	1	23.432	100.1	0.001
	Residual	0.936	4	0.234	17	
	Total	24.368	5			

Tables 8 and 9 presents results for the ANOVA and Model coefficients for the 28 days compressive strength model developed. As can be seen on Table 9, the model recorded a mean square of 0.234 with a significance of 0.001 which is less than the significance level. This implies the data under consideration has discrete means. The developed model is represented by equation (3).

Table 9: Coefficients for 28 days Compressive Strength model

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	18.024	0.350		51.476	0.000
	% Replacement	0.231	0.023	0.981	10.006	0.001

$$Y2 = 18.024 + 0.231P \quad (3)$$

Where Y2 = 28 days Compressive Strength
P = Percentage replacement level

Figure 3 presents the result of normal probability plot for data used in developing the 28 days compressive strength model, it shows points lying close to the straight line. This indicates that the residuals are approximately normally distributed.

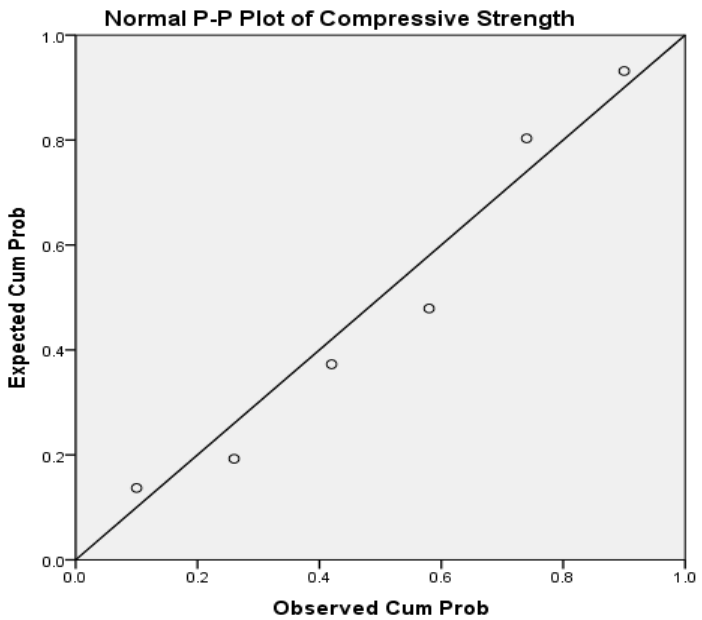

Figure 3: Normal Probability plot for 28 days Compressive Strength values

Conclusion

The study developed statistical models to predict the 7- and 28-days compressive strength of natural aggregate concrete produced utilising Quarry dust as partial replacement for fine aggregate. The idea of replacing fine aggregate with Quarry dust as seen in this study could invariably improve the utilisation of the produced quarry dust and hence reduce to a great amount the need to exploit the available fine aggregate. The following conclusions were drawn from the study:

i. The higher the quantity of quarry dust in concrete, the higher the compressive strength achieved. This research however suggests quarry dust can conveniently be used as partial replacement of fine aggregate up to 25% replacement level.

ii. The linear regression models can sufficiently predict the 7- and 28-days compressive strength of concrete with adjusted R^2 values of 98.9% and 95.2% respectively.

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