International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 4 Issue 9, September – 2020, Pages: 18-31

Predicting the Compressive Strength of Blended Concrete at Different Replacement Levels and Curing Time Using Regression Model Method

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Abstract: *Compressive strength of concretes are one of the prerequisite in the engineering design of appropriate cost efficient load bearing concrete structures such as beams, columns and slabs. Due to the limited or high cost of construction materials, there are needs to be conscious not to be wasteful. This study attempts to develop a predictive model equation describing the compressive strengths of blended concretes using treated drill cuttings. Regression analysis based on the least square regression method was used to obtain the functional relationship between the compressive strength of the blended concrete and the independent variables such as curing time and percentage replacement levels. The developed model was validated with the experimental data results. A high coefficient of determination R^2 values in the range of 0.658 to 1.000 and a low Root Mean Square Error (RMSE) in the range of 0.0160 to 2.6917 between the predicted and experimental compressive strength values showed that the model is good. Hence, the obtained predictive model is appropriate for determining the compressive strength requirements of the blended concrete up to approximately 82.9%*

Keywords — Modeling; Concrete; Compressive Strength; Regression Analysis; Time; Replacement levels; Drill Cuttings

1. INTRODUCTION

The suitability of concrete classes for application in any load bearing concrete structures such as beams, columns and slabs is largely dependent on their mechanical properties such as compressive strength, flexural strength, hardness permeability, durability, shrinkage etc. these properties are controlled by different variables such as concrete constituents, mix design ratios, water-binder ratios, curing time etc. compressive strength is the engineering property used for determining the behavior of constituent in concrete mix.

Thermally desorbed oil based drill cuttings can be recycled for use as a major constituent of mixes for making substantially monolithic specialized civil engineering concrete structures of large sizes such as roads and drilling pads [1]. The oil based drill cuttings being used as a partial replacement for cement in concrete production was treated by a thermal desorption unit at 500oC in 3 hours [2].

These drill cuttings are generated from oil and gas wells during drilling operations. The quantity of cuttings, or drilled solids generated from holes during drilling operation is tremendous and often as much as 100,000ib/day of cuttings must be carried by mud [3]. Also, Al-Ansary and Al-Tabaa, [4] reported that about 50,000-80,000 tonnes of wet weight of oily drill cuttings are produced annually on the UK continental shelf. This drilled cuttings that consists of rock and low-yielding clays incorporated into the mud during drilling is one of the sources of solids in a mud apart from the commercial solids added to the mud and chemically precipated solids. It is worthy finding ways and means of processing these drill cuttings (a waste) into a useful product (a concrete constituent), thereby providing solution to an environment problem [2].

1.1. Modeling Processes

In everyday use, the word model may be taken as an imitation of something on a smaller scale; this may be taken as an example of a physical model. There is also a mathematical model that stands as a mathematical representation of the behavior of real devices and objects or a system of postulates, data and inferences presented as a mathematical description of an entity or state of affairs. It could be descriptive, explanatory or predictive. In general, the act of constructing or fashioning a model of something or finding a relationship between variables is called modeling [5]. Due to the limited or high cost of construction materials, the process of mathematical modeling and prediction puts a check on how effective limited field or experimental data are put to use in decision making. The trend in modeling is to collate existing records (data), establish relations through mathematical equations, calibrate such equations in the way of assigning values to associated constants, and adopting such equation(s) for forecasting or predictions. This prediction takes the study into the future for decision-making, examining different responses arising from change in controlled variables [5]. In practice, mathematical modeling can be of different types, but for the course of this research, emphasis shall be on statistical methods of least squares regression methods.

Various least squares regression modeling techniques that are in use include, linear, parabola/quadratic, cubic curve, hyperbola, exponential curve, modified exponential curve, geometric curve, modified geometric curve, Gompertz curve, modified Gompertz curve and logistic curve [5]. When there are more than two variables and one of them is assumed to be dependent upon the others, the functional relationship between the variables is known as multiple regressions. If the relationship between these variables is a straight line, it is known as multiple linear regression models.

2 MATERIALS AND METHODS

2.1 Theoretical Development

The variable representing the cause is known as independent variable X (predictor or regressor) variable. The variable representing the effect is known as dependent variable Y (predicted) variable. The relationship between the independent and dependent variables may be expressed as a functional relationship called regression.

The linear regression analysis of the function with two independent variables, namely the curing ages (t) and weight (ω) of the drill cuttings content, while compressive strength (f_c) was the dependent variable, as defined in equation 1 were the only two independent variables used in the formulation of this models, while the other concrete constituents such as cement, sand, gravel and water were all kept constant at different replacement levels. So, the linear regression model was only based on changes on the blended concrete weights and curing ages.

$$f_c = = a_0 + a_1 t + a_2 w \quad (1)$$

Where:

f_c = Compressive strength (N/mm^2)

t = Curing age (days)

w = weight of drill cuttings content replaced (kg)

$a_{o,} a_1$ and a_2 = partial regression coefficients

Equation 1 is a linear regression equation of f_c on t and w, because the dependent variable f_c varies partially due to variations in t and w respectively, the coefficients a_1 and a_2 represent partial regression coefficients on f_c on t with w held constant and f_c on w with t held constant respectively.

2.2 Development of the Functional Multiple Linear Regression Equation

Given n sets of measurements, $(f_c, t_{1,} w_2)$… (f_{cn}, t_{1n}, w_{2n}) the least square estimates of a_o, a_1 and a_2 can be obtained by successive elimination (same as matrix triangulation) method [6, 7].

So, multiplying equation 1 by the factors 1, t and w respectively and summing on both sides of the resulting equation obtains:

$$\sum f_c = a_0 n + a_1 \sum t + a_2 \sum w \quad (2)$$

$$\sum f_c t = a_0 \sum t + a_1 \sum t^2 + a_2 \sum wt \quad (3)$$

$$\sum f_c w = a_0 \sum w + a_1 \sum wt + a_2 \sum w^2 \quad (4)$$

After solving for the coefficients of $a_{o,} a_{1,}$ and $a_{2,}$ equation 1 can be expanded further to obtain f_c on t with w held constant and f_c on w with t held constant to obtain the following equations:

1. F_c on w with t held constant:

$$f_{ct_1} = a_o + a_1 t_1 + a_2 w \quad (5)$$

$$f_{ct_2} = a_o + a_1 t_2 + a_2 w \quad (6)$$

$$f_{ct_3} = a_o + a_1 t_3 + a_2 w \quad (7)$$

$$f_{ct_4} = a_o + a_1 t_4 + a_2 w \quad (8)$$

$$f_{ct_5} = a_o + a_1 t_5 + a_2 w \quad (9)$$

Where:

f_{ct_1},f_{ct_2}, f_{ct_3}, f_{ct_4}, and f_{ct_5}, are compressive strength of the concrete at 7, 28, 56, 90 and 120 days curing age (N/mm^2)

t_1, t_2,t_3, $t_4$and $t_5$are the curing ages at 7, 28, 56, 90 and 120 days respectively.

w is the weight of drill cuttings content at different replacement levels of 5, 10, 15, 20 and 25%.

2. $F_c$on t with w held constant:

$$f_{cw_1} = a_o + a_1 t + a_2 w_1 \quad (10)$$

$$f_{cw_2} = a_o + a_1 t + a_2 w_2 \quad (11)$$

$$f_{cw_3} = a_o + a_1 t + a_2 w_3 \quad (12)$$

$$f_{cw_4} = a_o + a_1 t + a_2 w_4 \quad (13)$$

$$f_{cw_4} = a_o + a_1 t + a_2 w_5 \quad (14)$$

f_{cw_1}, f_{cw_2},f_{cw_3},f_{cw_4}, and f_{cw_5} are compressive strength of the concrete at 5, 10, 15, 20 and 25% replacement levels (N/mm^2).

W_1,W_2,$W_3 W_4$ andW_5 are the weight of drill cuttings content at replacement levels of 5, 10, 15, 20 and 25% respectively.

t is the curing ages in 7, 28, 56, 90 and 120 days. By determining the unknown parameters $a_{0,}$ a_1, and $a_{2,}$ the model was validated by comparing the experimental data with the predictions.

2.3 Experimental Determination of the Compressive Strengths of the Cement –Drill Cuttings Concrete

The test was carried out according to BS 1881:116 method [8]. The concrete cubes of sizes 150 x 150x 150mm prepared using the predetermined optimum water-binder ratio (w/b), with different percentages of drill cuttings as substitute of cement. Three cubes for each concrete mix were cast and cured for 7,28,56,90 and 120 days before crushing. The compression testing machine plunger was set under a CBR ring capacity of 50kN and the samples crushed at a uniform rate of 1mm/min. The readings of the maximum force required to shear the samples were recorded.

2.4 Model Validation

Under the varying factors of curing time and percentage replacement levels, the compressive strengths of the cement-drill cuttings concrete was determined experimentally and fitted into the developed models. The model compressive strengths were determined as regression analysis as computed using Ms Excel 2010 Version at experimental curing time of 7, 28, 56, 90 and 120 days and replacement levels of 0, 5, 10, 15, 20 and 25%.Ms Excel (2010 Version) software were used in analyzing the compressive strength values of the cement-drill cuttings concrete, which involved graphical computations and modeling. The validity (goodness of fit) of the compressive strength models were tested by comparison with the experimental data and the modeling efficiency was estimated using the following parameters: Coefficient of determination (R^2) and root mean square error (RMSE).The best model describing the compressive strength of cement-drill cuttings concrete at different curing time and percentage replacement levels was chosen based on the higher value of R^2 and lower value of RMSE [9, 10]

The coefficient of determination R^2 and the root mean square error were calculated using the following equations:

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N}\left(Cs_{pre} - Cs_{pre.i}\right)^2}{\sum_{i=1}^{N}\left(Cs_{pre} - Cs_{pre.i}\right)^2}\right] \quad (15)$$

$$RMSE = \frac{\sum_{i=1}^{N}\left(Cs_{pre} - Cs_{pre.i}\right)^2}{N} \quad (16)$$

Where: $Cs_{prei=the\ ith}$ experimental compressive strength; CS_{predi} = the ith predicted compressive strength; N = number of observations, bar – C_{spre} = mean of predicated compressive strength.

Another method used in the validation of the predicted model was by the comparing the predicted compressive strengths with the experimental compressive strength graphically. When a straight line is obtained, it indicates the suitability of the model to describe the compressive strength behavior of the blended concretes.

3. RESULTS AND DISCUSSIONS

The linearized form of the predicted equation for compressive strength of the blended concrete at different curing time and replacement levels are as presented: at 0% replacement levels at different curing time of 7, 28, 56, 900 and 120 days;

$$Y = 0.1344X + 22.396 \quad (17)$$

Where:

Y = Predicted compressive strength of the blended concrete (N/mm^2)

X = Curing time (Days)

At 5% replacement levels at different curing times

$$Y = 0.1209X + 22.638 \quad (18)$$

At 10% replacement levels at different curing times

$$Y = 0.103X + 25.61 \quad (19)$$

At 15% replacement levels at different curing times

$$Y = 0.0851X + 23.421 \quad (20)$$

At 20% replacement levels at different curing times

$$Y = 0.063X + 20.701 \quad (21)$$

At 25% replacement levels at different curing times

$$Y = 0.0409X + 17.975 \quad (22)$$

Also at 7 days curing time at different replacement levels of 0, 5, 10, 15, 20, 25%,

$$Y = -0.1267X + 236388 \quad (23)$$

Where:

Y = Predicted compressive strength of the blended concrete (N/mm^2)

X = Replacement levels (%)

At 28 days curing time at different replacement levels

$$Y = -0.3595X + 29.674 \quad (24)$$

At 56 days curing time at different replacement levels

$$Y = -0.426X + 33.25 \quad (25)$$

At 90 days curing time at different replacement levels

$$Y = -0.4379X + 35.458 \quad (26)$$

At 120 days curing time at different replacement levels

$$Y = -0.6446X + 41.007 \quad (27)$$

The result of the experimental and predicated compressive strengths of the blended concretes at constant replacement level at different curing times are as presented in Table 1.-6 generated from equations 17 to 27.

Table 1: Predicted and Experimental Compressive Strengths at Different Curing Time at 0% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	22	23.34
28	28.93	26.14`
56	29.64	29.92
90	31.64	34.49
120	40.23	28.52

Table 2: Predicted and Experimental Compressive Strengths at Different Curing Time at 5% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	21.38	23.48
28	26.2	26.02

56	32.62	29.41
90	34.06	33.52
120	35.33	37.15

Table 3: Predicted and Experimental Compressive Strengths at Different Curing Time at 10% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	25.47	26.33
28	28.57	28.49
56	32.69	31.38
90	35.1	34.88
120	37.23	37.97

Table 4: Predicted and Experimental Compressive Strengths at Different Curing Time at 15% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	24.4	24.02
28	25.77	25.80
56	27.6	28.19
90	30.98	31.08
120	33.96	33.63

Table 5: Predicted and Experimental Compressive Strengths at Different Curing Time at 20% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	21.16	21.14
28	22.46	22.44
56	24.2	24.23
90	26.37	26.37
120	28.27	28.26

Table 6: Predicted and Experimental Compressive Strengths at Different Curing Time at 25% Replacement Level

Curing Time (Days)	Experiment (N/mm^2)	Predicted (N/mm^2)
7	17.91	18.26
28	19.15	19.12
56	20.8	20.27
90	21.75	21.66
120	22.58	22.88

The graphs of the predicted compressive strengths against the curing times from Table 1-6 are as presented in Figure 1-6

International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
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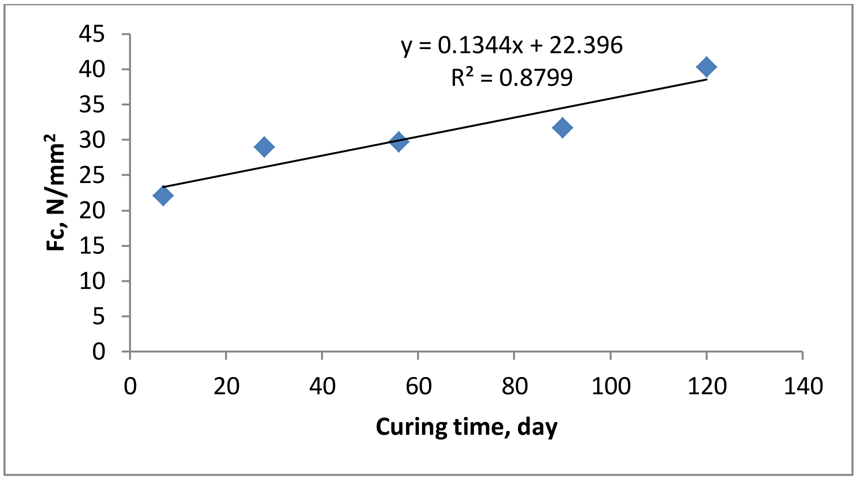

Figure 1: Compressive Strength of Concrete Samples Containing 0% of Drill Cuttings at Different Curing Time.

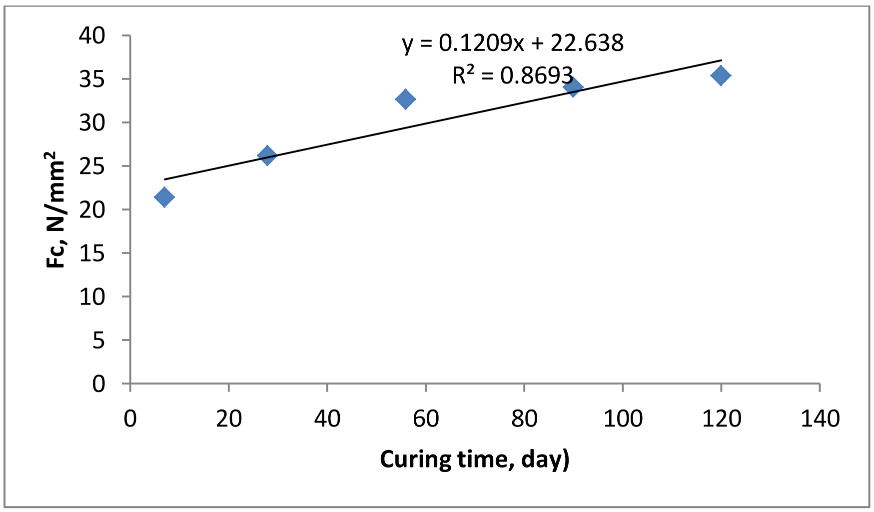

Figure 2: Compressive Strength of Concrete Samples Containing 5% of Drill Cuttings at Different Curing Time.

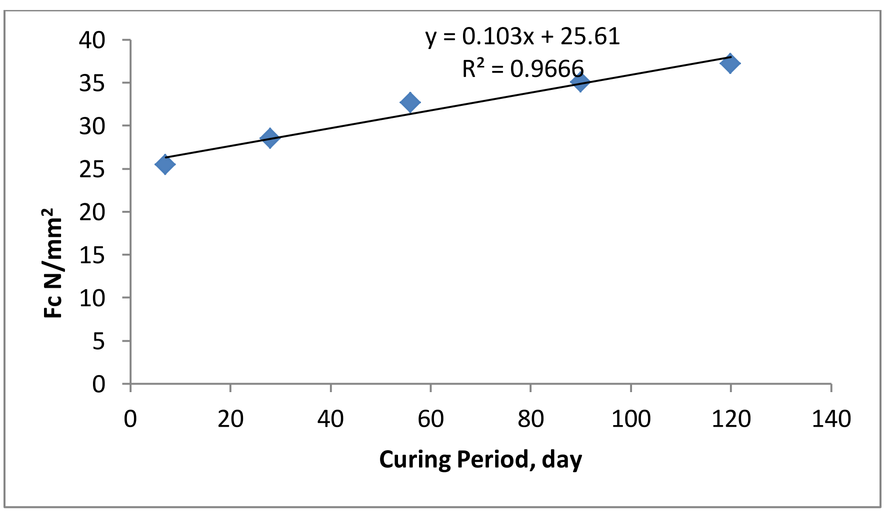

Figure 3: Compressive Strength of Concrete Samples Containing 10% of Drill Cuttings at Different Curing Time.

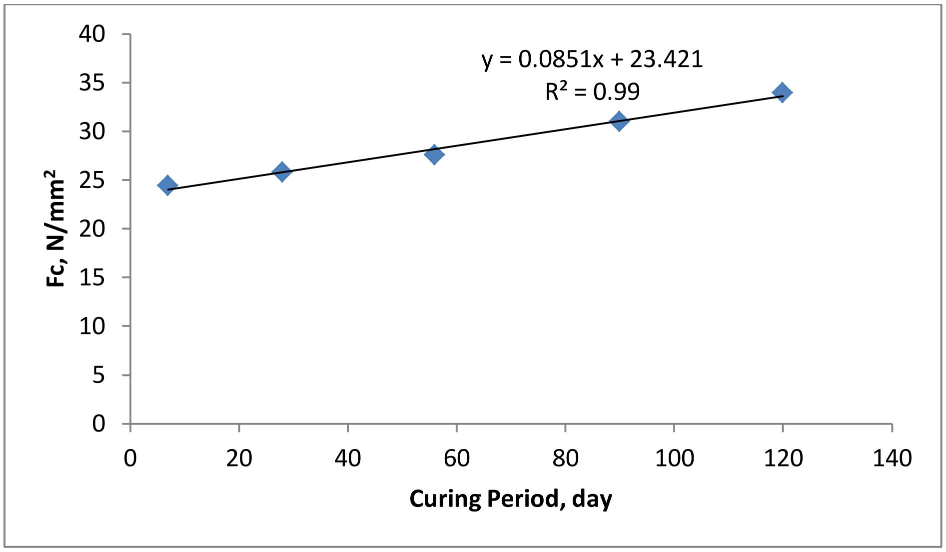

Figure 4: Compressive Strength of Concrete Samples Containing 15% of Drill Cuttings at Different Curing Time.

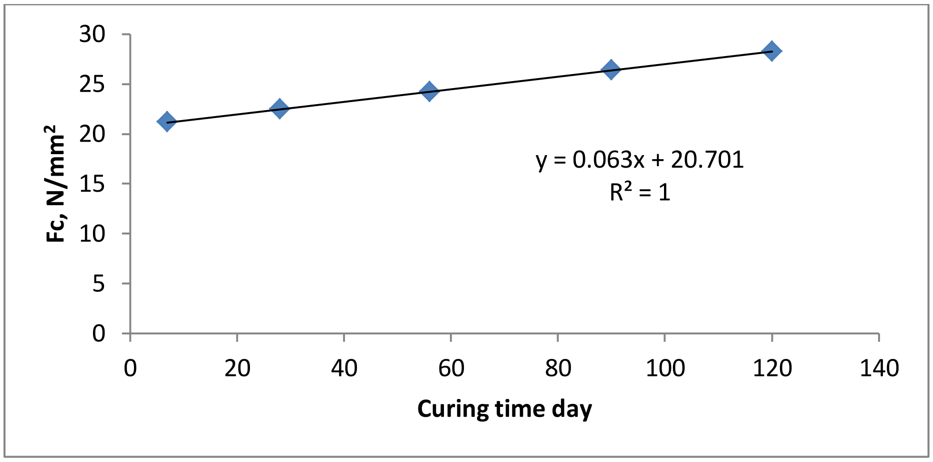

Figure 5: Compressive Strength of Concrete Samples Containing 20% of Drill Cuttings at Different Curing Time

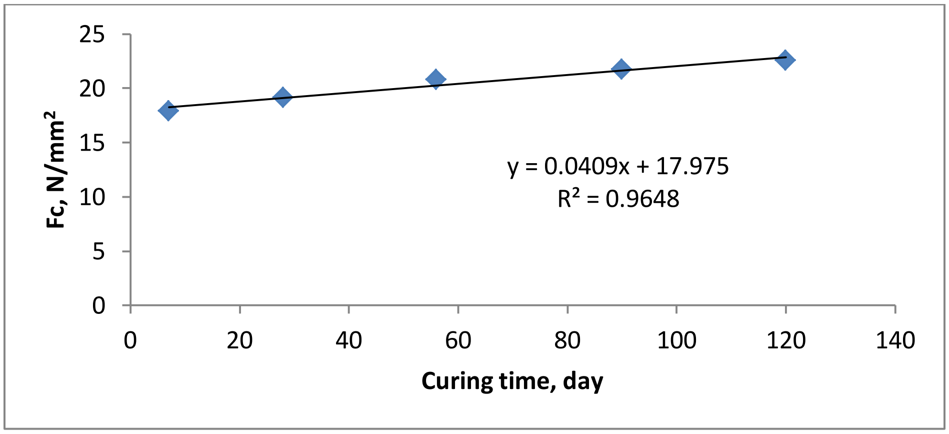

Figure 6: Compressive Strength of Concrete Samples Containing 25% of Drill Cuttings at Different Curing Time

Also, the results of the experimental and predicted compressive strengths of the blended concretes at constant curing time at different replacement levels are as presented in Table 7-11

Table 7: Predicted and Experimental Compressive Strengths at Different Replacement Level at 7 Days Curing Time

Replacement Level (%)	Experiment (N/mm^2)	Predicted (N/mm^2)
0	22	23.64
5	21.38	23.00
10	25.47	22.74
15	24.4	21.74
20	21.16	21.10
25	17.91	20.47

Table 8: Predicted and Experimental Compressive Strengths at Different Replacement Level at 28 Days Curing Time

Replacement Level (%)	Experiment (N/mm^2)	Predicted (N/mm^2)
0	28.93	29.68
5	26.2	27.88
10	28.57	26.08
15	25.77	24.28
20	22.46	22.48
25	19.15	20.69

Table 9: Predicted and Experimental Compressive Strengths at Different Replacement Level at 56 Days Curing Time

Replacement Level (%)	Experiment (N/mm^2)	Predicted (N/mm^2)
0	29.64	33.25
5	32.62	31.12
10	32.69	28.99
15	27.6	26.86
20	24.2	24.73
25	20.8	22.6

Table 10: Predicted and Experimental Compressive Strengths at Different Replacement Level at 90 Days Curing Time

Replacement Level (%)	Experiment (N/mm^2)	Predicted (N/mm^2)
0	31.64	35.46
5	34.06	33.27
10	35.1	31.08
15	30.98	28.89
20	26.37	26.7
25	21.75	21.75

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Table 11: Predicted and Experimental Compressive Strengths at Different Replacement Level at 120 Days Curing Time

Replacement Level (%)	Experiment (N/mm^2)	Predicted (N/mm^2)
0	40.23	41.01
5	35.33	37.78
10	37.33	34.56
15	33.96	31.34
20	28.27	28.12
25	22.58	24.89

The graphs of the predicted compressive strengths against the replacement levels from Table 7-11 are as presented in Figures 7-11.

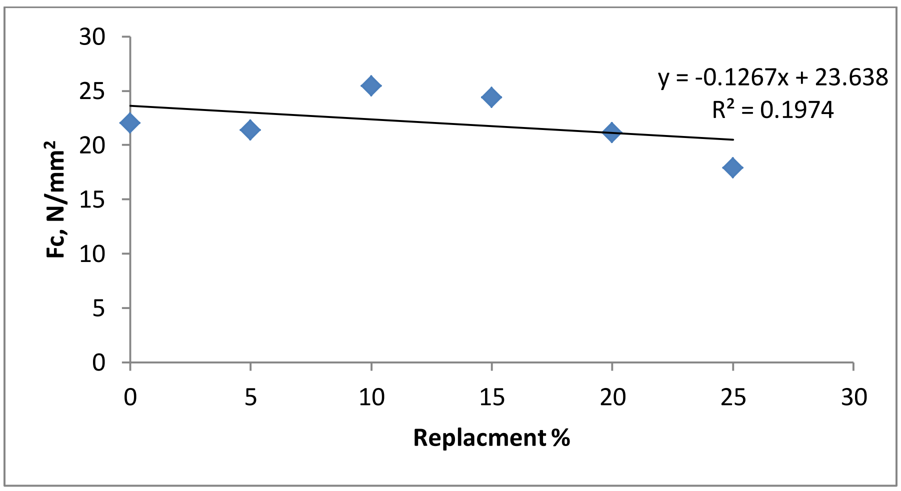

Figure 7: Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 7 Days Curing Time.

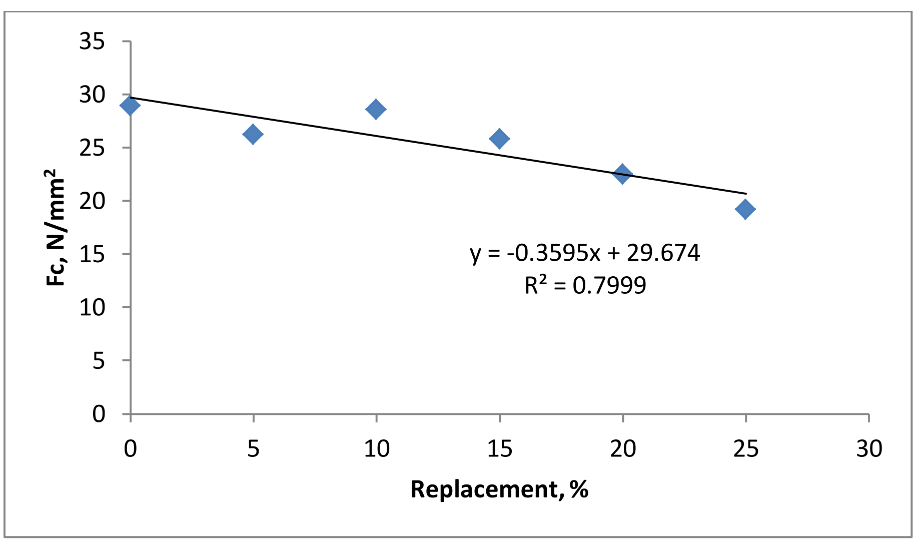

Figure 8: Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 28 Days Curing Time.

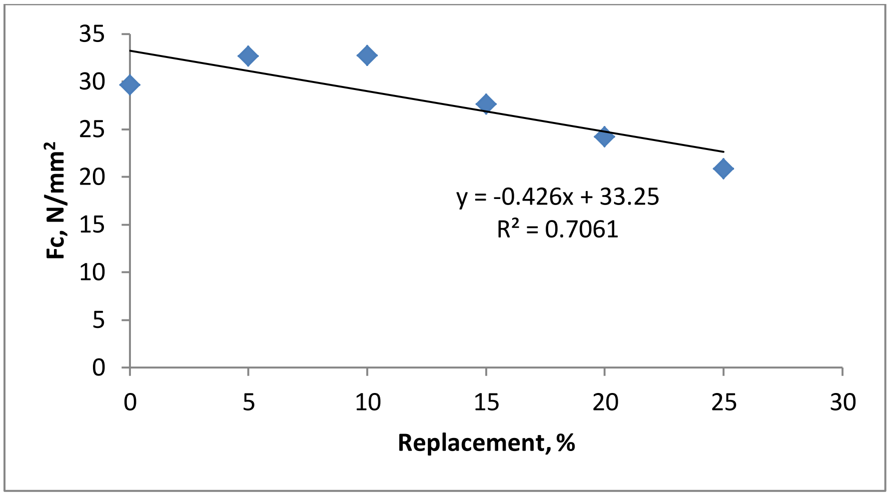

Figure 9: Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 56 Days Curing Time.

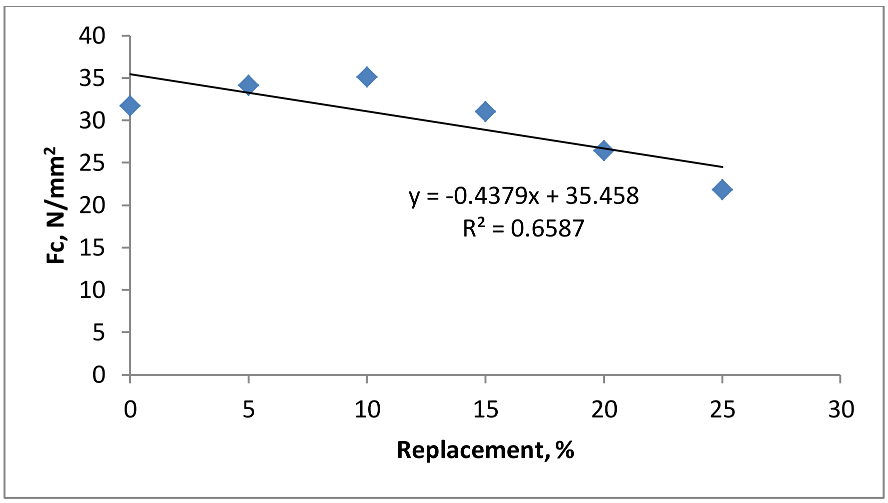

Figure 10: Compressive Strength of Concrete Samples Containing Different Percentages of Drill Cuttings at 90 Days Curing Time.

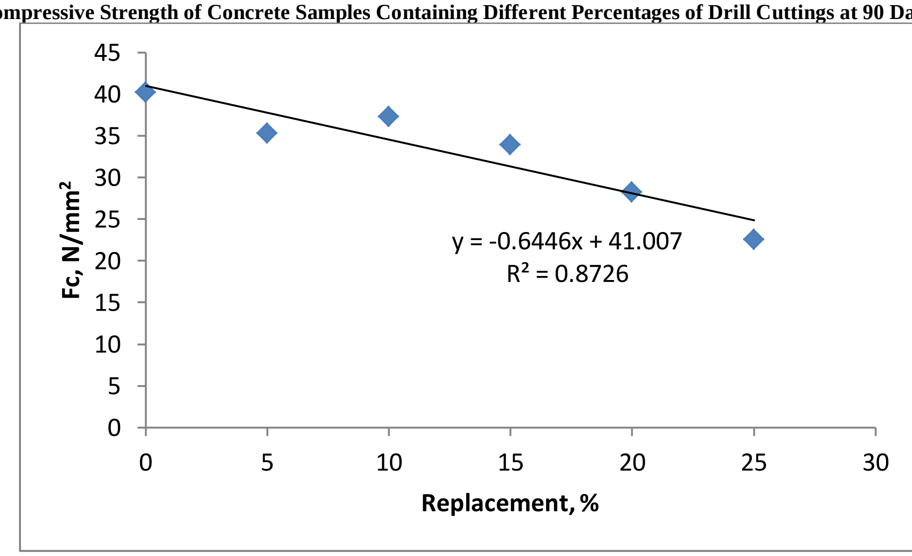

Figure 11: Compressive Strength of Concrete Samples Containing Different Percentages of Drill Cuttings at 120 Days Curing Time.

The coefficient of determination R^2 values from Figures 1-11 for the compressive strength of the blended concrete ranged between 0.658 to 1.000 at different curing time and replacement levels except that of blended concrete at 7 days curing time at different replacement levels that have R^2 of 0.197, this may be as a result of the late strength development of pozzolans Lea (2000) 11. This high R^2 values obtained is an indication of strong correlation between compressive strength with curing time and percentage replacement levels.

3.1 Model Validation

The multiple linear regression models were validated using the data generated from the blended compressive strength experiments. The model validation was done at two stages; at compressive strength of blended concrete samples at constant replacement levels at different curing times and compressive strength of blended concrete samples at constant curing times at different replacement levels. The method of regression analysis as computed using MS Excel (2010) window was used to describe the relationships, by plotting the graphs of compressive strength experimental values against the predicted values, compute the coefficients of determination (R^2) and root mean square error (RMSE). Experimental values of parameters were substituted into equations 17 to 27 to yield the predicted compressive strengths values different curing time and regalement levels, (Table 1-11), which were plotted against the experimental compressive strength values on a regression curve, (Figure 12-22) in order to obtain the coefficients of determination R^2, while the RMSE were calculated using equation 16.

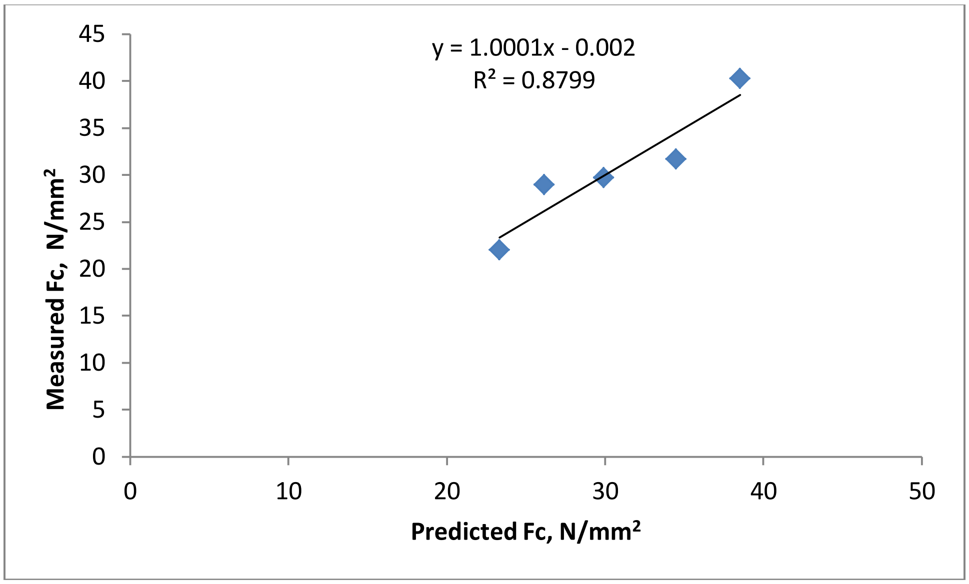

Figure 12: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 0% of Drill Cuttings at Different Curing Time.

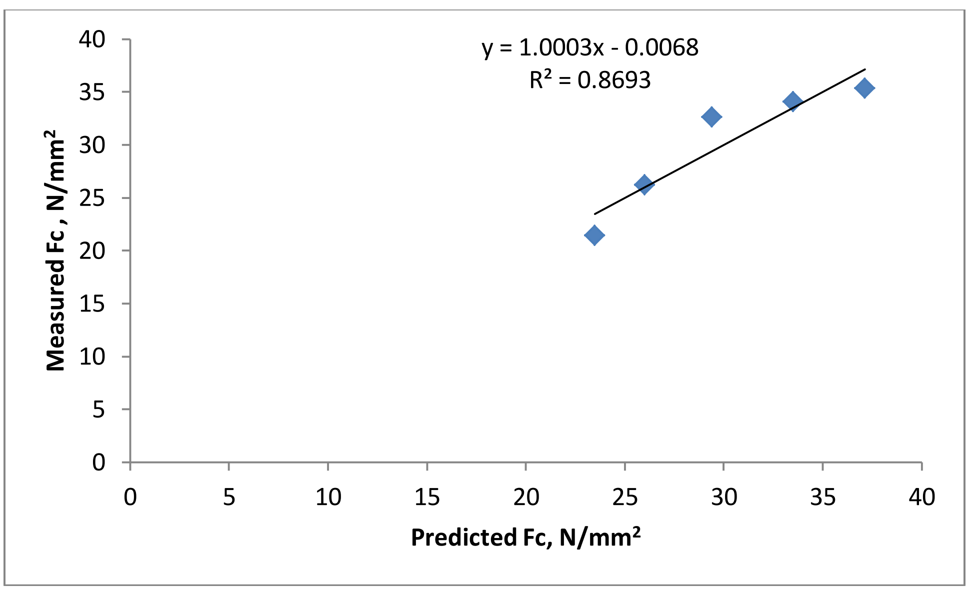

Figure 13: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 5% of Drill Cuttings at Different Curing Time.

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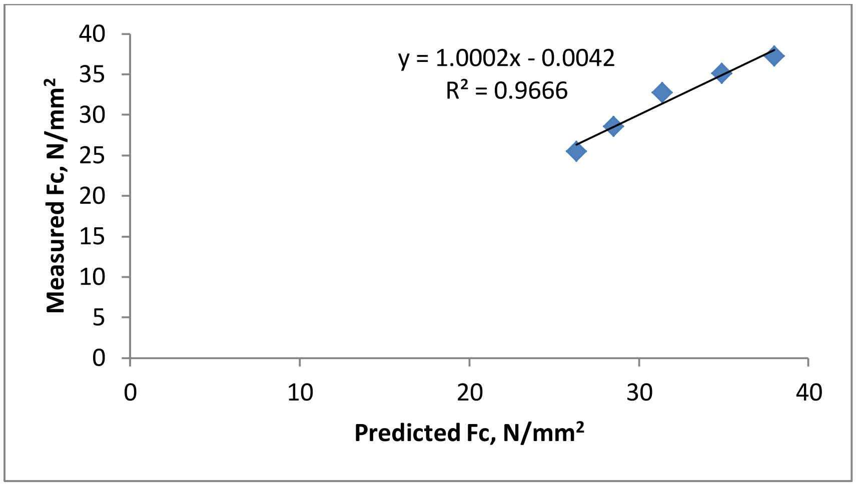

Figure 14: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 10% of Drill Cuttings at Different Curing Time.

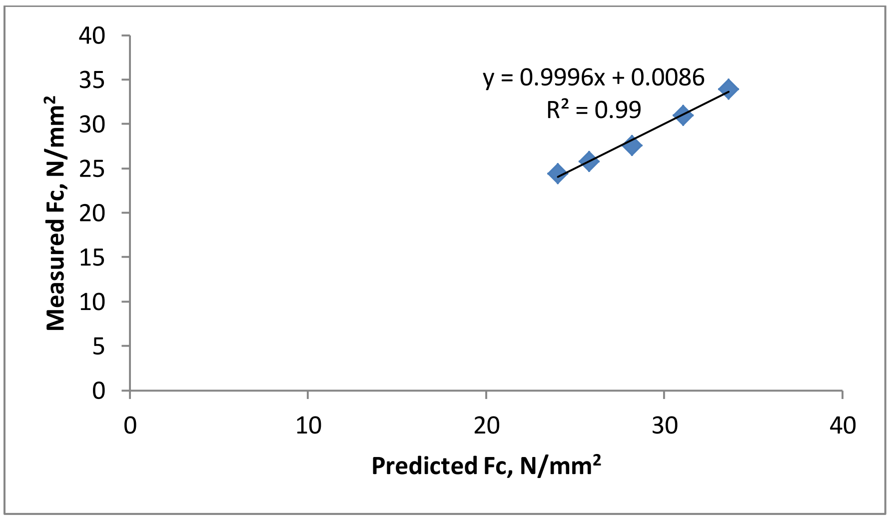

Figure 15: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 15% of Drill Cuttings at Different Curing Time.

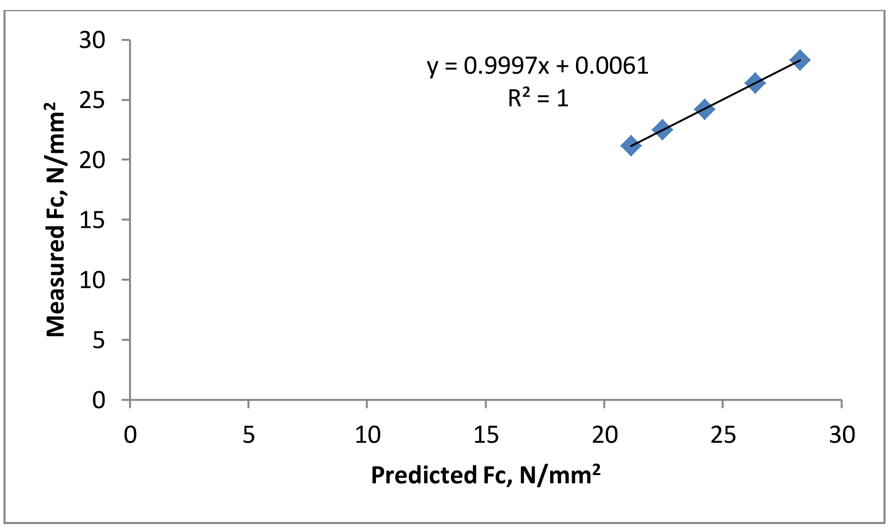

Figure 16: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 20% of Drill Cuttings at Different Curing Time.

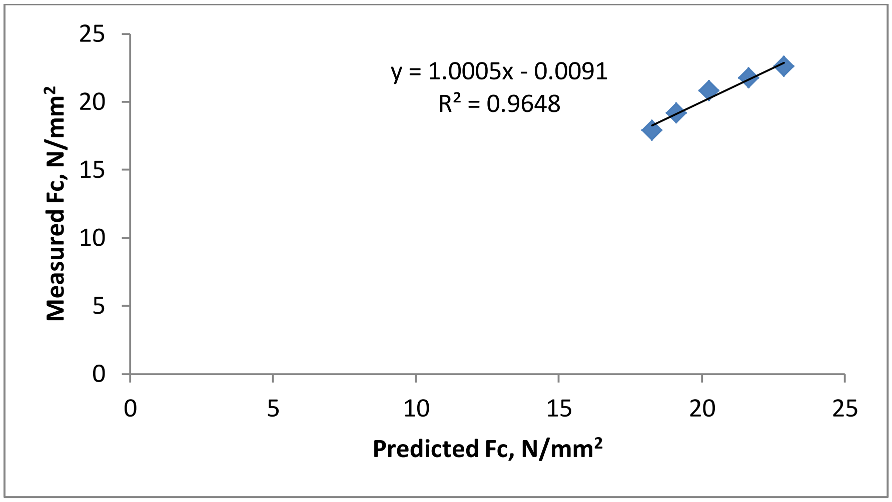

Figure 17: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing 25% of Drill Cuttings at Different Curing Time.

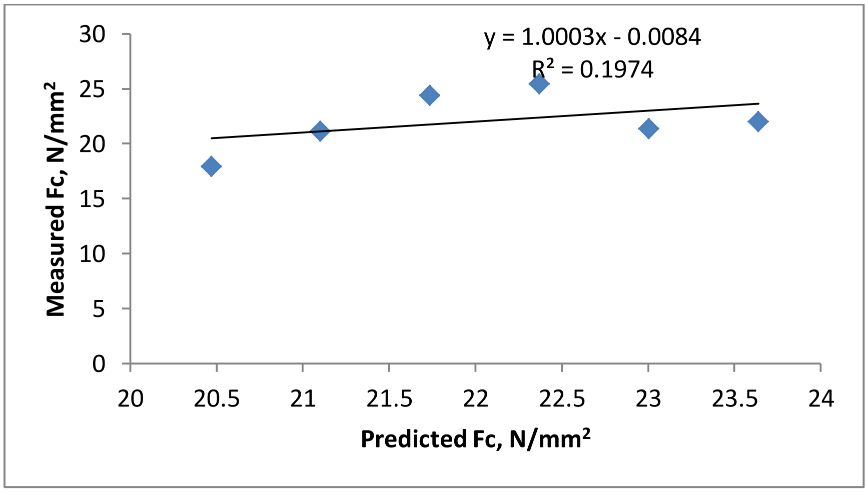

Figure 18: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 7 Days Curing Time.

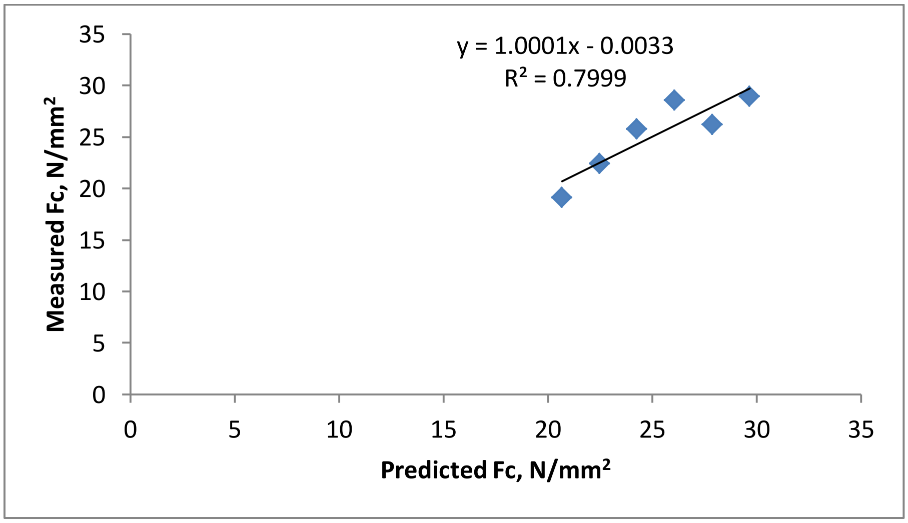

Figure 19: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 28 Days Curing Time.

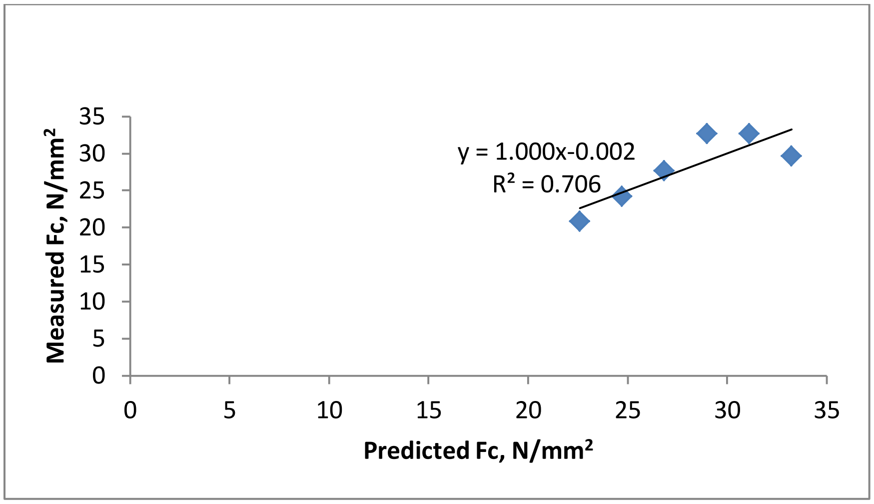

Figure 20: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 56 Days Curing Time.

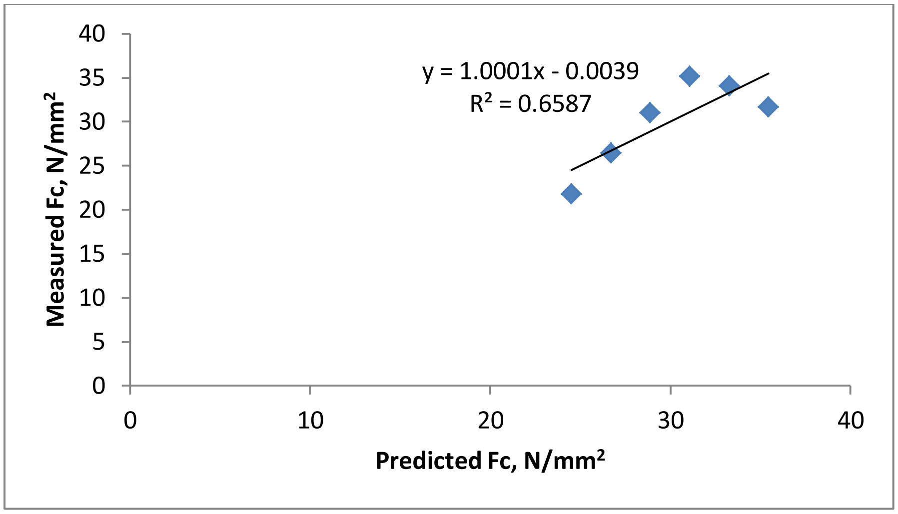

Figure 21: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 90 Days Curing Time.

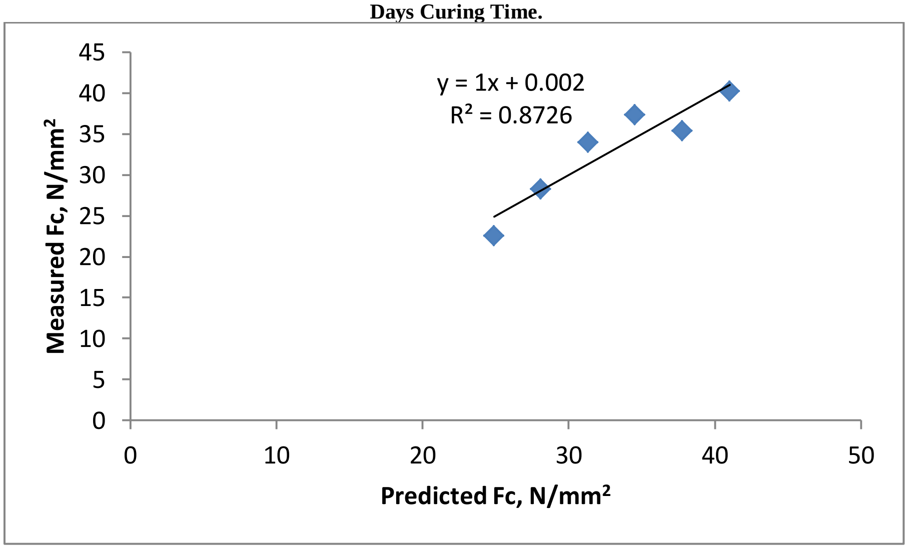

Figure 22: Comparison of Measured and Predicted Compressive Strength of Concrete Samples Containing Different Percentage of Drill Cuttings at 120 Days Curing Time.

The root mean square error as calculated using equation 16 from Tables 1 to 11 is as illustrated in Table 12

Table 12: Predicted and Experimental Compressive Strength RMSE at Different Curing Time and Replacement Levels

Replacement Level (%)	Curing Time (Days)	Curing (Days)	Replacement Levels (%)
0	2.0292	7	2.1823
5	1.9165	28	1.5355
10	0.7829	56	2.3467
15	0.3490	90	2.6917
20	0.0160	120	2.1031
25	0.3196		

The RMSE as shown in Table 12 ranged from 0.016 to 2.6917 so the low values of root mean square error and the high values of R^2 for the blended concrete shows that the model was a good predicting capacity for predicting the compressive strengths at different replacement levels and curing time.

4.0 Conclusion

A multiple linear regression model to predict compressive strengths of concretes containing treated drill cuttings at different replacement levels of 0,5,10,15,20 and 25% and curing periods of 7,28, 56, 90 and 120 days were proposed. These models were validated graphically tested by comparing the predicted and experimental results of the compressive strengths. It was found that there are high coefficient of determination R^2 and low root mean square error on the compressive strengths of the blended concrete models, indicating that the models can be used to predict the compressive strength of the blended concrete at any curing time at different replacement levels.

ACKNOWLEDGMENT

Authors are grateful to TETFund for providing the necessary financial support to the first author..

REFERENCES

[1] Onwukwe, S. I., & Nwakaudu, M. S. 2012). Drilling Wastes Generation and Management Approach.*International Journal of Environmental Sciences and Development*, Vol. 3, No. 1, pp. 3.

[2] Okparanma, R. N; Chikwue, M. I., & Ayotamuno, M. J. (2020). Pozzolanic potential of pre-treated oil-basedc drill cuttings for mortar production. A review paper.

[3] Njobuenwu, D. O., & Nna, E. (2005). The Effect of Critical Wetting Agent Concentration on Drilling Fluids Performance. *Journal on Science Technology Research, Vol. 4,* No. 1, pp 65-71.

[4] Ansary, M. S. ,& Al- Tabbaa, A. (2005).

Stabilization/Solidification of synthetic North sea Drill cuttings containing Oil and chloride. International Conference on Stabilization (solidification treatment and remediation). *Cambridge,Vol.* 4, pp 157- 400.

[5] Nwaogazie, I. L. (2006). Probability and Statistics for Science and Engineering Practice.University of Port-Harcourt Press.

[8] BS 1881-102 (1983). Testing Concrete-Part 102 Method for Determination of Slump.*British Standards Institution (BSI).*

[9] Demir, V., Gunhan, T. I., Yagcioglu, A. K., & Degirmencioglu, A. (2004). Mathematical Modeling and Determination of Some Quality Parameters of Air – Dried Bay Leaves. *Biosystems Engineering*, Vol. 88, pp. 325-335.

[10] Taheri-Garayand, A., Rafieea, S., & Keyhania, A. (2011b). Study on Effective Moisture Diffusivity, Activation Energy and Mathematical Modeling Thin Layer Drying Kinetics of Bell Pepper. *Australian Journal of Crop Science, Vol. 5, No.* 2, pp 128-141.

[11] Lea, F. M. (2000). The Chemistry of Cement and Concrete (3rd Ed) Edward Arnold (Publishers) Ltd, pp. 443-453.