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Predictive Model of the Compressive Strength of Concrete Containing Coconut Shell Ash as Partial Replacement of Cement Using Multiple Regression Analysis

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Abstract:- The increasing demand of cement in construction has raised lots of sustainability concerns. However, the application of agricultural wastes such as coconut shell ash (CSA) as a partial replacement of cement holds great prospects for sustainability in the construction industry. Reliable and rapid model prediction of concrete strength is capable of increasing the pace of construction without compromising the quality control measures.Coconut shells were collected and burnt after which the resulting ash was subjected to fluorescence method of analysis. With the use of a concrete mix design ratio of 1:2:4 and water binder ratio of 0.6, a total of 36 concrete cubes of sizes 150mm x 150mm x 150mm were cast using varying OPC – CSA ratio 100:0, 95:5, 90:10, 80:20. The cubes was cured for 7, 14 and 28 days and thereafter crushed to test the compressive strength. The experimental data was subjected to regression analysis using IBM SPSS Statistics software. The multiple regression model showed that the general form of the equation for the prediction of the compressive strength of concrete from percentage replacement, curing age and density is: Compressive strength of concrete = 0.44 – 0.162 (percentage replacement) + 0.008 (curing age) + 0.006 (density). The result showed that the percentage replacement contributed more to the model followed by the curing age and the density. The experimental result showed that for 20% replacement of cement with CSA, the average compressive strength for 7, 14 and 28 days of curing are 9.80 N/mm2, 11.50 N/mm2 and 13.50 N/mm2. While the corresponding values obtained using the regression model are 9.892 N/mm2, 10.374 N/mm2 and 12. 58 N/mm2. From the above data, it is observed that the experimental results is slightly different from the analyzed results.

Keywords:- *Sustainability, Regression Model, Concrete, Compressive Strength, Multiple Regression.*

I. INTRODUCTION

Sustainable Development has become a pervasive development paradigm—the slogan of development and environmental activists, the catchphrase of international aid agencies, the jargon of development planners and the theme of conferences and academic papers. [1].this term has been defined by different academics, researchers and practitioners in different ways.However, the Brundtland Commission Report, issued in 1989 by the World Commission on Environment and Development, offers the most widely cited definition. Sustainable development, according to the Brundtland Commission Report, is defined as development that meets the demands of the current generation without jeopardizing future generations' ability to satisfy their own needs [2]. The concept of sustainability calls to mind the activities of mankind, their ability to meet human wants and needs without wasting or exhausting the productive resources available to them. In order to achieve global sustainable development, the sustainability concept must be applied to three main areas: environment, economy and society. Environmental sustainability means giving the world to future generation better than taken, protecting ecological balance and natural systems from destruction [3]. As a result, when assessing the degree of use of natural resources, it is necessary to consider not exceeding rates of resource renewal and rates of resource clearing of contaminants [4].

Meanwhile, the increasing demand for the construction of building and other civil engineering structures has led to lots of environmental problems. Construction, maintenance, and upgrading of built environments have the potential to negatively affect the environment, as structures consume the majority of non-renewable resources, generate a significant amount of trash, and emit half of all carbon dioxide [5].Thus to achieve environmental and economic sustainability, the roles of sustainable constructions cannot be over emphasized. As a result, the contemporary construction challenge is to create cost-effective structures that improve life quality while minimizing social, economic, and environmental impacts [5].

In the construction industry, concrete is one of the most important and most widely used construction materials due to its desirable properties such as strength, durability and fire resistant. Concrete is a composite construction material that comprises of cement, aggregate, water and chemical and mineral admixtures. Construction costs have increased due to the high cost of construction materials such as cement and reinforcement bars [6].In addition to cost, cement manufacture has a number of drawbacks, including high energy demand and CO_2 emissions, which contribute to global warming.Another disadvantage is the depletion of lime stone resources [7].Approximately 7% of global CO_2 is released into the atmosphere during cement production, which has a severe ecological impact and humanity's future as a result of global warming [8].The application of agricultural waste such as coconut shell ash as partial replacement of cement offers lots of advantages such as: low capital cost per tonne production compared to cement, low-cost waste treatment, reduced pollution from these wastes, higher economy base of farmers when such wastes are sold, hence promoting additional production, conservation of limestone reserves, and reduction in CO_2 emissions[9] [10].

Consequently, in the recent years, there has been a surge of interests in the study of partial replacement of cement as binder in concrete production. For instance, Mahmoud [7] studied groundnut shell ash as a partial replacement of cement in sandcreteblocks production and concluded that the optimum replacement level was achieved at 20% which had a strength of3.58 N/mm2. Utsev and Taku [11] investigated coconut shell ash (CSA) as partial replacement of cement in concrete and concluded that 10 - 15% replacement of cement was possible while maintaining the strength properties. Similarly, Adeala [12] investigated the potential of coconut shell ash pulverized at a controlled temperature of 800ºC to 1000ºC as partial replacement of Ordinary PortlandCement (OPC) in concrete production and recommended that replacement of OPC with CSA from 5% up to 15% be used for production of normal weight concrete.

It's worth noting, however, that the strength properties of fresh concrete take a considerable time to develop after pouring. The compressive strength achieved by a concrete sample after 28 days is known as its characteristic strength.

Therefore, the compressive strength test on a concrete specimen should be satisfactorily completed after 28 days of curing. The implication of this is that the need for speed in the construction industry will not be met. On the other hand, ignoring the test compromises concrete quality control in large-scale construction projects. As a result, it would be critical to have a model that could predict concrete strength quickly and accurately. [13]. The ability to rely on model prediction would allow mix proportion adjustments prior to placement and curing, this prediction- based approach will allow for the avoidance of situations where the concrete is too weak or unnecessarily strong, as well as a more efficient use of raw materials and fewer construction failures, lowering construction costs [14].There are two types of prediction models for the compressive strength of concrete with mineral admixtures namely: conventional models and artificial intelligent model. Conventional statistical analysis based models typically include a large number of built-in linear and nonlinear regression equations, which have the benefit of generating easy-to-use regression constants and calculating the significance of various input variables [15].

Several attempts have been made to develop an appropriate mathematical model capable of accurately predicting the strength of concrete at various ages [16].For instance, Ali et al. [14] developed the compressive strength statistical model of concrete without admixtures at any age. Chopra et al. [17] used regression model to predict the compressive strength of concrete with or without fly ash. Moreover, Chopra et al. [18] predicted the compressive strength of concrete for varying workability using regression model. However, prediction of compressive strength of concrete containing coconut shell ash (CSA) as partial replacement of cement at various replacement levels has not been investigated despite the enormous environmental and economic sustainability prospects it offers. Consequently, this study used multiple regression model for the prediction of the compressive strength of concrete containing CSA as partial replacement of cement at various replacement levels.

II. MATERIALS AND METHODS

Study Area

Figure 1 below shows the map of the study area.

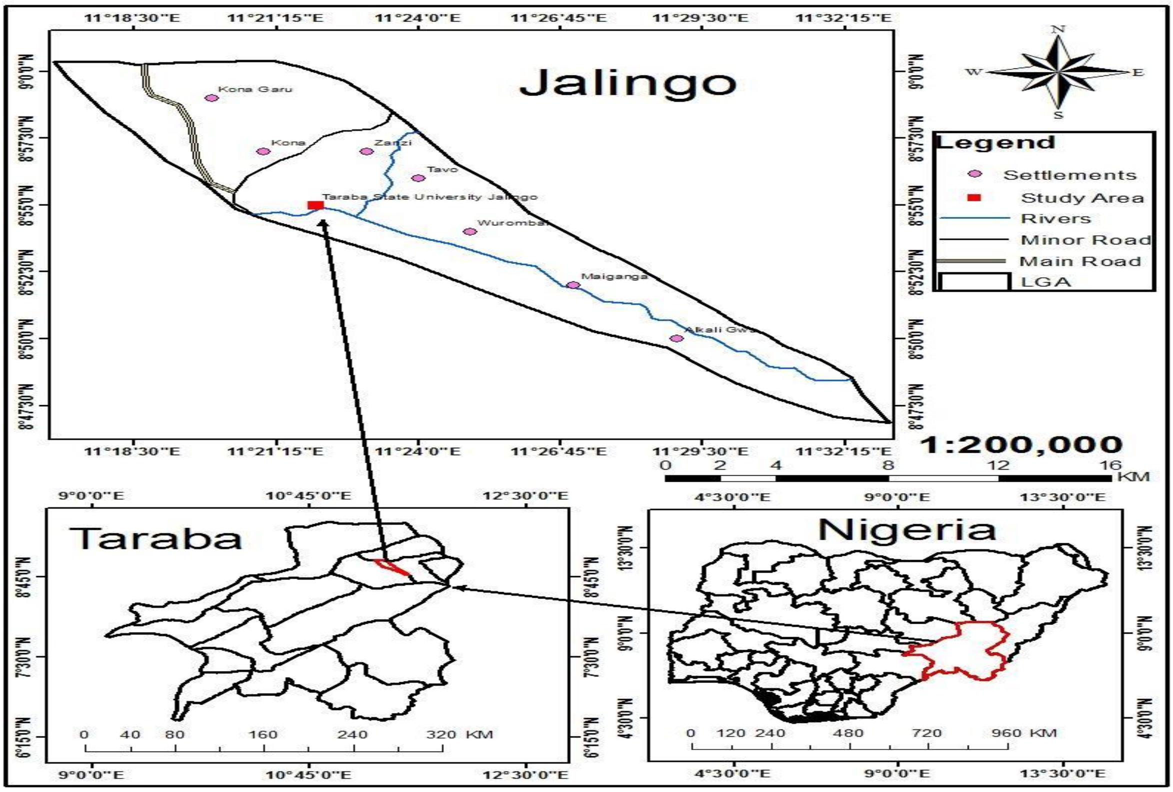

Figure 1: Map of Taraba State showing Jalingo Metropolis[19]

Jalingo, the administrative headquarters of Taraba State lies between latitudes 8^0 47' to 9^0 01'N and longitudes 11^0 09' to 11^0 30'E. It is bounded in the North by Lau Local Government Area, in the East by Yorro Local Government Area and in the South and West by Ardo Kola Local Government Area. According to the 2006 national population census,Jalingo has a total population of 139,845 people, estimated growth rate of 3% and total land area of approximately 195km^2.

Materials

The materials used in this study include:

i. Coarse aggregate made of crush stones from Jalingo quarry site;
ii. Fine aggregate (river sand) from NukaiRiver in Jalingo;
iii. Ordinary Portland Cement (Dangote Cement);
iv. Coconut shell;
v. Water.

Method

Coconut shell (CS) was oven dried at 150 ^{0}C for about 2 hours to remove moisture. Itwas then subjected to uncontrolled combustion bymeans of open air burning for about 2 hours and allowed to cool for about 12 hours. The burnt ash was collected and sieved through a BS sieve (75microns). The resulting ash was collected and analyzed using x-ray fluorescence method of analysis to obtain the percentage composition of oxides in the CSA. With the use a mix design ratio of 1:2:4 and water binder ratio of 0.6, a total of 36 concrete cubes of sizes 150mm x 150mm x 150mm were cast using varying OPC – CSA ratio 100:0, 95:5, 90:10, 80:20. Slump test was first conducted on the fresh concrete before the cubes werecast and cured for 7, 14 and 28 days and then crushed to test the compressive strength.

Data Analysis

The experimental data was subjected to regression analysis using IBM SPSS Statistics software (version 20). The regression output to the experimental data was recorded after a check was carried out and the results proved that all the assumptions of a valid regression model were satisfied. The assumptions have to do with outliers, collinearity of data, independent errors,non-zero variance, random normal distribution of errors and homoscedasticity & linearity of data

III. RESULTS AND DISCUSSION

Density and average compressive strength test results of the specimens are shown in Table 1, while Table 2 and Table 3 show the initial and final setting time and slump test results respectively. Table 4 shows the percentage composition of oxide in CSA while Table 5 and Table 6 showpozzolanic activity index test and percentage water absorption test results respectively.

Table 1: Density and average compressive strength test results

% Replacement	Curing age (days)	Average Density (kg/m^3)	Average Strength (N/mm^2)
0 percent	7	2217	15.10
	14	2380	15.80
	28	2407	16.30
5 percent	7	2166	13.50
	14	2189	13.90
	28	2342	14.00
10 percent	7	2133	12.90
	14	2176	13.50
	28	2339	13.90
20 percent	7	2106	9.80
	14	2177	11.50
	28	2304	13.00

Table 2: Initial and final setting time results

% Replacement	Initial Setting Time(mins)	Final Setting Time(mins)
0	65	83
5	210	310
10	253	330
20	289	401

Table 3: Slump test results

% Replacement	Slump(mm)
0	32
5	30
10	26
20	23

Table 4: Percentage composition of oxide in CSA and OPC

Oxide	CSA Percentage composition (%)
SiO_2	37.87
Al_2O_3	24.22
Fe_2O_3	25.46
CaO	4.97
MgO	1.88
MnO	0.84
Na_2O	0.96
K_2O	0.81
P_2O_5	0.33
SO_3	0.72
LOI	1.94

Table 5: Pozzolanic activity index test results

% Replacement	7days Pozzolanic activity index	14days Pozzolanic activity index	28days Pozzolanic activity index
0	0	0	0
5	95.12	97.25	96.34
10	90.35	93.30	92.87
20	62.84	66.10	57.80

Table 6: Percentage water absorption test results

% Replacement	Wet Mass (g)	Dry Mass (g)	% Water Absorption
0	7879	7777	1.3
5	7533	7473	0.8
10	7480	7395	1.1
20	7411	7296	1.6

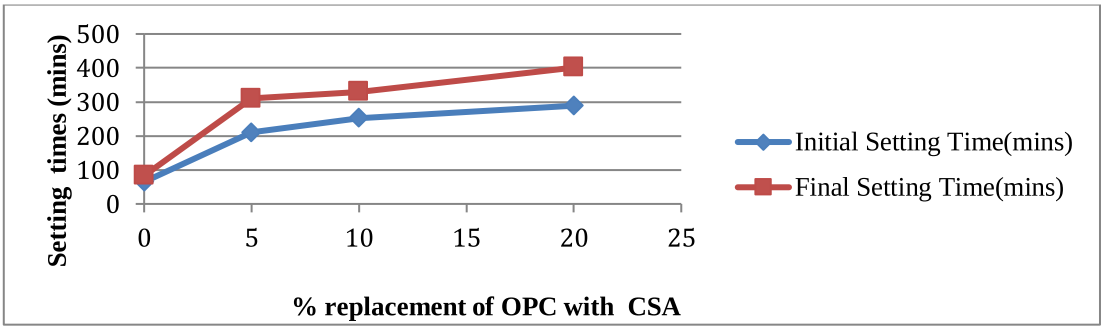

Figure 1: Initial and Final setting time of CSA/OPC paste

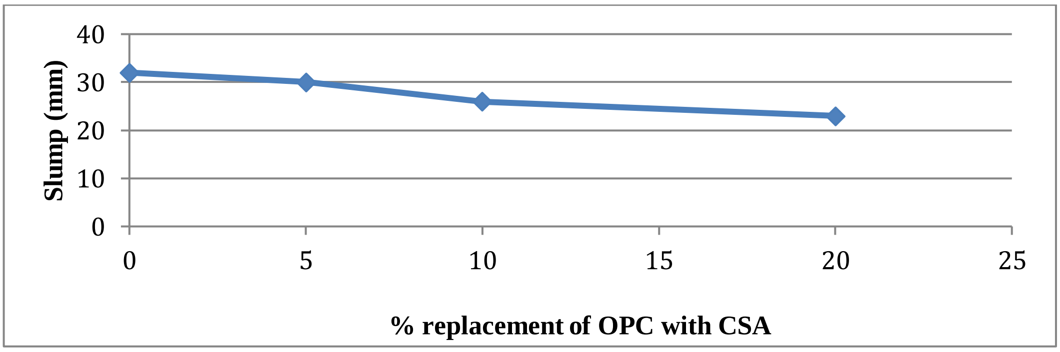

Figure 2: Slump values of OPC/CSA concrete

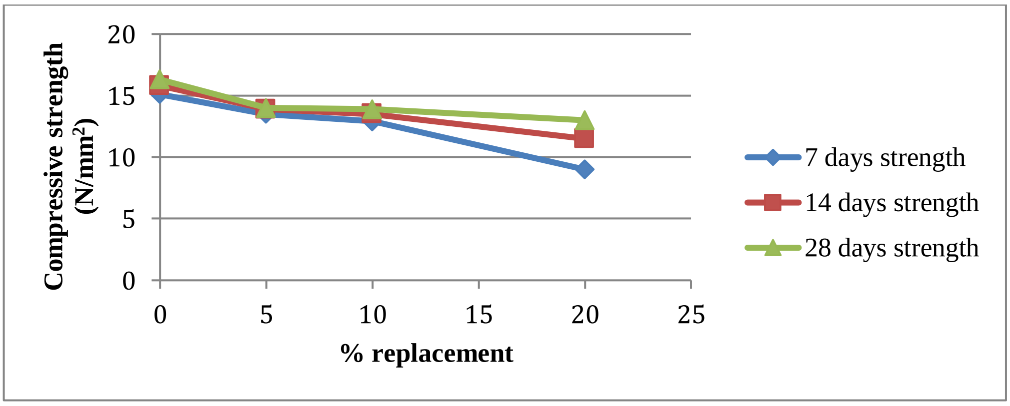

Figure 3: Compressive strength at various percentage replacements

Regression Analysis

There are seven main assumptions that must be satisfied in multiple regressions. The assumptions have to do with outliers, collinearity of data, independent errors,non-zero variances, random normal distribution of errors and homoscedasticity & linearity of data.

Outliers

Outlier is an observation that is abnormally spaced from other values in a random sample of a population. To check for outliners, Table 7 (Residual Statistics) is considered. For there not to be outliers, the minimum value next to Std. Residual (Standardised Residual) should not be equal or less than 3.29, or the maximum value should not be equal or greater than 3.29.

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From Table 7, the standard residuals analysis showed that there exist no outliers on the data (Std. Residual Min = -1.625, Std. Residual Max = 1.201).

Table 7: Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	10.8069	16.1596	13.6000	1.68865	12
Residual	-1.00689	.74457	.00000	.52855	12
Std. Predicted Value	-1.654	1.516	.000	1.000	12
Std. Residual	-1.625	1.201	.000	.853	12

a. Dependent Variable: Compressive Strength (N/mm2)

Collinearity

Collinearity (or multicollinearity) occurs when one feature variable in a regression model has a strong linear relationship with another feature variable. This indicates that the regression coefficients are not determined in a unique way. As a result, the model's interpretability suffers because the regression coefficients are no longer unique and are influenced by other factors.

Collinearity check is done by considering Table 8 (Coefficients table). Concerns over multicollinearity arises when the VIF value is greater than 10, or the Tolerance is less than 0.1. From Table 8, multicollinearity was not a problem (Percentage Replacement, Tolerance = .432, VIF = 2.316; Curing Age, Tolerance = .197, VIF = 5.079; Density, Tolerance = .156, VIF = 6.395).

Table 8: Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	.440	9.835		.045	.965		
Percent_Replacement (%)	-.162	.037	-.707	-4.402	.002	.432	2.316
Curing Age (days)	.008	.046	.043	.180	.862	.197	5.079
Density (kg/m^3)	.006	.005	.376	1.408	.197	.156	6.395

a. Dependent Variable: Compressive Strength (N/mm2)

Independent Errors

To check if the data meet the assumption of independent errors, consider Durbin-Watson value in the Model Summary table. Generally, Durbin-Watson values lie between 0 and 4, however in order to meet the assumption of independent errors the value should be close to 2. If the Durbin-Watson value is less than 1 or greater than 3, it is considered significantly different from 2, indicating that the assumption has not been met. From Table 9 (Model Summary), the data satisfies the assumption of independent errors (Durbin-Watson value = 1.907).

Table 9: Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.954[a]	.911	.877	.61978	1.907

a. Predictors: (Constant), Density (kg/m3), Percent replacement, Curing Age (days)
b. Dependent Variable: Compressive Strength (N/mm2)

Random Normally Distributed Errors and Homoscedasticity & Linearity

Figure 5 (Normal P-P plot of standardized residuals) which shows points that were not totally on the line but were close, and Figure 4 (Histogram of standardised residuals) both suggest that the data had generally normally distributed errors.

Moreover, the data met the requirements of homogeneity of variance and linearity, as shown by Figure 6 (scatterplot of standardised residuals).

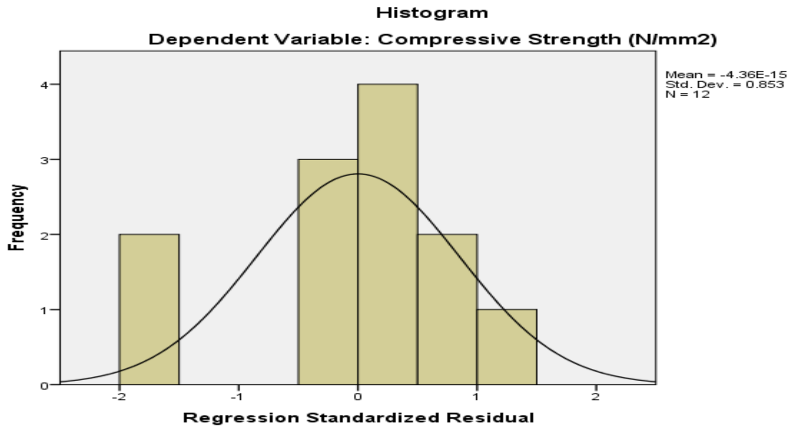

Figure 4: The histogram of standardised residuals

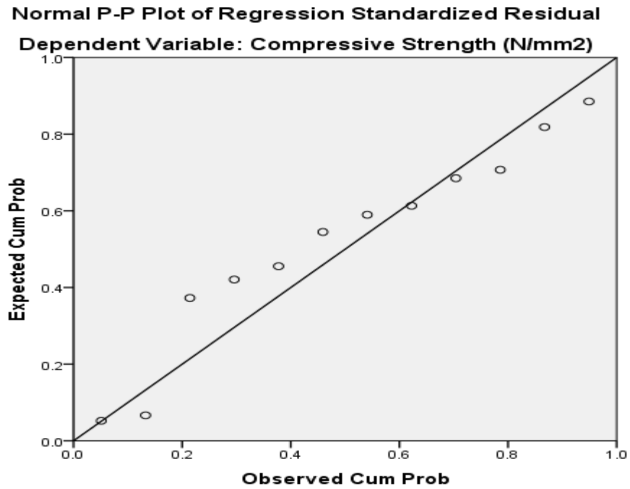

Figure 5: Normal P-P plot of regression standardized residual

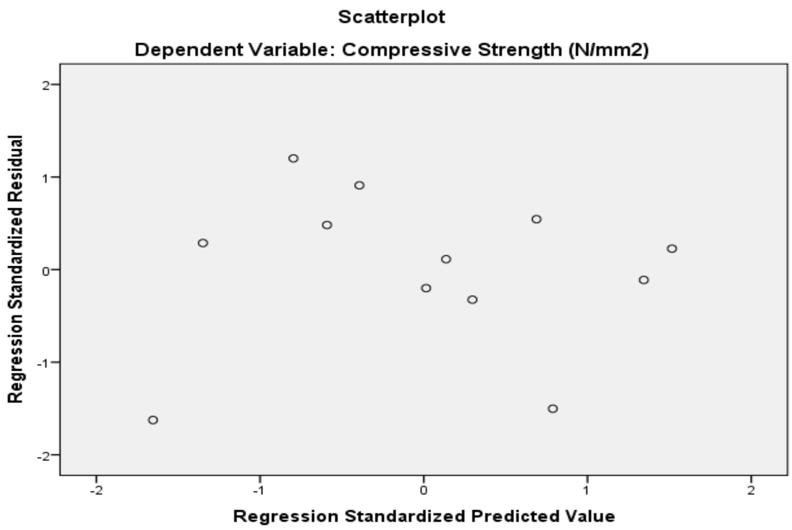

Figure 6: Scatterplot of standardized residuals

Non-Zero Variances

The independent variables (predictors) should have some value variation, i.e., they should not have zero variances. To check for the assumption of non-zero variance, consider the Variance column of Table 10 (Descriptive Statistics table) below. From table 10, the data met the assumption of non-zero variances (Compressive Strength, Variance = 3.31; Percentage Replacement, Variance = 59.659; Curing Age, Variance = 83.152; Density, Variance = 10691.333).

Table 10: Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Compressive Strength (N/mm^2)	12	9.80	16.30	13.6000	1.76944	3.131
Percentage Replacement (%)	12	.00	20.00	8.7500	7.72393	59.659
Curing Age (days)	12	7.00	28.00	16.3333	9.11875	83.152
Density (kg/m^3)	12	2106.00	2407.00	2244.6667	103.39890	10691.333
Valid N (listwise)	12					

Determination of how well the model fits

Consider Table 9 (Model Summary) which provides the R, R^2, adjusted R^2 and the standard error of the estimate and is used to measure a regression model's fit to the data. The R value (also known as multiple correlation coefficient) can be considered to be one measure of the quality of the prediction of the compressive strength of the concrete. From Table 9, the R value is 0.954 which signifies a good prediction level. The "R Square" (also known as the coefficient of determination) is the proportion of variance in the compressive strength of the concrete that can be explained by percentage replacement, densityand curing age. From Table 9, the R^2 value is 0.911. This implies that percentage replacement, density and curingage explain 91.1 % of the variability of the compressive strength of the concrete. And 8.9% (100%-91.1%) of the variation is caused by factors other than the predictors included in this model.

The standard error of a model fit which shows the standard deviation of the residuals is also an indication of the precision of the model. The value shows how wrong an estimate or prediction can be if it were made with the regression model. It is worthy of note that as R^2 increases the standard error decreases. In the present model the standard error value is 0.61978. This implies that on average, the estimates of compressive strength of concrete with this model will be wrong by .61978.

Statistical significance of the model

A statistical test of whether the overall regression model is a good fit for the data is carried out using the F-ratio in Table 11 (ANOVA table) below. The table shows that the percentage replacement, density and curing age statistically significantly predict the compressive strength of the concrete, $F(3, 8) = 27.219$, $p (.000) < .05$.

Table 11:ANOVA[a]

	Sum of Squares	Df	Mean Square	F	Sig.
Regression	31.367	3	10.456	27.219	.000[b]
Residual	3.073	8	.384		
Total	34.440	11			

a. Dependent Variable: Compressive Strength (N/mm^2)
b. Predictors: (Constant), Density (kg/m^3) Percentage Replacement (%), Curing Age (days)

Statistical significance of the independent variables

Statistical significance of each of the independent variables tests whether the unstandardized (or standardized) coefficients are equal to 0 (zero) in the population (i.e. for each of the coefficients, H0: $\beta = 0$ versus Ha: $\beta \neq 0$ is conducted) [20]. When $p<0.05$, the coefficients are statistically different from zero (zero). These tests of significance are useful for determining if each explanatory variable is required in the model, assuming that the others are already present.

The t-value and p-values of the variables are shown in "t" and "Sig." columns of Table 8 (Coefficients) respectively. The test shows that percentage replacement p(0.02)<0.05 is significant while curing age p(0.862)>0.05 and density p(0.197)>0.05 are not significant. This implies that the predictor variables: curing age and density are not that useful in the model when the percentage replacement is already there.

Estimated model coefficients

The general form of the equation to predict the compressive strength of concrete from percentage replacement, curing age and density, is: Compressive strength of concrete = 0.44 – 0.162 (percentage replacement) + 0.008 (curing age) + 0.006 (density).

Unstandardized coefficients indicate how much the dependent variable varies with an independent variable when all other independent variables are held constant [20]. The regression coefficient provides the expected change in the dependent variable for a one-unit increase in the independent variable [20]. From Table 8, the unstandardized coefficient for percentage replacement is -0.707 which implies that for every unit increment in percentage replacement, there is 0.707 N/mm^2 decrease in compressive strength of the concrete. But for each one-day increase in the curing age, there is 0.043 N/mm^2 increase in compressive strength of the concrete.

IV. CONCLUSIONS

Rapid and reliable prediction of concrete strength is very important to the construction industry. It holds a great prospect of increasing the pace of construction work without compromising the quality control measures. This study has successfully developed multiple regression model for the prediction of the compressive strength of concrete containing CSA as partial replacement of cement using percentage replacement, curing age and density as the independent variables. The result showed that the percentage replacement contributed more to the model followed by the curing age and the density.

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