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Experimental and Predictive model data comparison for compressive strength of self-compacting concrete using metakaolin and wood ash as partial replacement for cement

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ABSTRACT
This paper is aimed towards comparing results data from predictive model to experimental data on the compressive strength of self-compacting concrete using Metakaolin and wood ash content, particle parking method of mix design was adopted for experimental compressive strength data while partial least square method of regression analysis was adopted for predictive compressive strength. The mechanical test were carried out to determine the compressive strength while SPSS statistical tools were carried out to predict compressive strength data. The following results were obtained from predictive compressive strength (53.35, 48.50, 41.52, 36.63, 31.98) MPa at 1:1.60:1.73:0.25 mix proportion and (49.04, 44.44, 39.41, 35.07, 29.03) MPa at 1:1.7.4:1.88:0.30 mix proportion while the following results were also obtained from experimental compressive strength (52, 50, 43, 36, 31) MPa at 1:1.60:1.73:0.25 mix proportion and (47, 46, 41, 34, 29) MPa at 1:1.7.4:1.88:0.30 mix proportion. The difference is not significant hence the experimental values obtained are well predicted using partial least square method of regression analysis.
KEYWORDS: Self-Compacting Concrete, Metakaolin, Wood ash, Compressive Strength and predictive model.

I.INTRODUCTION

Self-compacting concrete also known as self-consolidating concrete SCC is concrete considered to be flowable, which can be placed with minimal or no vibration and compacted under its self-weight. SCC was first developed in Japan in the late nineteen eighties to be used in the construction of skyscrapers (Ozawa et al. 1990). It is used in the construction of high-rise buildings and it allows the construction of complicated structures and slender building elements (Holton, 2004). When properly proportioned and placed, it results in both economic and technological benefits for the end user.

Also, absence of theoretical between mixture proportion and measured engineering properties of self-compacting concrete make it more complex. In order to reduce the time and cost involved in it, data driven solution were generated for predicting compressive strength of SCC (Bharathiet al. 2017).

Partial least squares analysis is a multivariate statistical technique that allows comparison between multiple response variables and multiple explanatory variables. Partial least squares is one of a number of covariance-based statistical methods which are often referred to as structural equation modeling (Abdi & Williams, 2013). It was designed to deal with multiple regression analysis when data has small sample, missing values, or multi-collinearity. Partial least squares regression has been demonstrated on both data and in simulations (Garthwaite, 1994, Tennenhaus, 1998).Regression analysis is a statistical tools that are used to predict the relationship between a dependent variable and one or more independent variables which are referred as predictors (Chithra& Kumar, 2016). Therefore this paper is geared towards comparing results from predictive model to experimental data on the compressive strength of SCC using metakaolin and wood ash.

Aim and Objectives of the Study

The aim of this study is to compare experimental and Predictive model data for compressive strength of self-compacting concrete

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using metakaolin and wood ash as partial replacement for cement

The aim will be achieved using the following objectives:

i. To develop predictive model using partial least squares method usingMetakaolin and wood ash as partial replacement of cement for compressive strength of self-compacting concrete.
ii. To comparepredictive model with experimental resultsfor compressive strength of self-compacting concrete using metakaolin and wood ash as partial replacement of cement

II. LITERATURE REVIEW

Metakaolin which is obtained from kaolin, is one of the most natural abundant minerals, which is discovered in Kogi state, Edo state and other Northern parts of Nigeria by Raw Materials Research Development Council of Nigerial (RMRDC). The following literature review below were observed in extent of pasts work.

Ubojiekereet al. (2018) studied the workability and mechanical properties of highstrength self-compacting concrete blended with Metakaolin. Metakaolin was partially replaced cement in the range 5 to 15% at different water/binder ratios of 0.25, 0.30, 0.35 & 0.40. PPM was adopted in the mix design. After various tests for both workability and mechanical properties, the results show that 15% of Metakaolin for 28 days fresh water curing, and 0.25 water/binder ratio and mix ratio of 1:1.33:1.44:0.25 gave optimum compressive strength of 69.6MPa.

Akobo et al. (2021) studied the mechanical properties and workability of self-compacting concrete using Metakaolin and wood ash as partial replacement for cement.It was reported thattarget strength of 42MPa was achieved using particle parking method with mix proportion of 1:1.60:1.73:0.25for self-compacting concrete.

Prema-Kumar et al. (2015) studied effect of partial replacement of cement in SCC by fly ash and Metakaolin. It was observed that the use of mineral admixture such as fly ash and Metakaolin as partial replacement of cement in SCC can bring down the cost of concrete production. It also observed that the combination of fly ash and Metakaolin in the range of 8 to 34% incorporation has no adverse effect on the workability properties of SCC, but inclusion of (15%MK and 9%FA) combination gave optimum compressive strength of 48.76Mpa at 28 days curing age.

Partial least square method was designed to deal with multiple regression analysis when data has small sample, missing values, or multi-collinearity. Partial least squares regression has been demonstrated on both data and in simulations (Garthwaite, 1994, Tennenhaus, 1998).

Dhiviya et al (2017). Studied theprediction of compressive strength for self- compacting concrete (SCC) using artificial intelligence and regression analysis. It reported that the results from both the models were compared and artificial neural network models have predicted better results than Regression Analysis models.

III. MATERIALS AND METHODS

MATERIALS

The following experimental materials were used in this study;

i. Grade 42.5N Portland limestone cement (PLC) manufactured by Dangote cement PLC conforming to NIS 444-1:2003.
ii. Fine aggregate (River Sand) conforming to EN 12620.
iii. Coarse aggregate (Granite) with a maximum size of 10mm (conforming to EN 12620).
iv. The water used throughout the study was obtained from Civil Engineering Laboratory of Rivers State University water mains and it is also fit for drinking and in accordance with BS 3148:1980
v. Metakaolin conforming to (EN 934-2:1995), manufactured by Beijing Toodudu E-commerce Company Limited.
vi. Wood Ash.
vii. Superplasticizer (SP) Poly Carboxylate Ether (PCE) was used.

MEHODFOR PREDICTIVE MODEL

Regression analysis is a statistical/mathematical operation implemented to develop mathematical models for the prediction/estimation of response variables (dependent variables). The operation is done to fit the data of the variables. Several methodologies are employed in regression analysis, however the Partial Least Square method is adopted in this study.

The general multivariate linear model is given in the Equation 3.1

$$Y = \underbrace{\beta^0 + \beta^1X^1 + \beta^2X^2 + \cdots + \beta_n X_n}_{\text{model}} + \underbrace{\varepsilon}_{\text{residual}} \qquad 3.1$$

Where Y = Dependent variable, $X_{1,2,n}$= Independent variables, β_0 = Value of dependent variable when the independent variables are zeros,

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$\beta_{1,2,n}$= Coefficients of independent variables and ε = error in estimate.
In this study, the partial least square regression analysis was employed to develop strength models for the compressive strength results obtained from the laboratory after 28 days of wet curing.
The multivariate linear regression models was developed using the SPSS computational statistical tools. Also, vital statistical parameters are assessed from the develop models to determine their accuracies and significant levels.

The multivariate linear model developed using SPSS computational statistical tools are shown in Equation 3.2.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 \ldots + \beta_n X_n \quad 3.2$$

Were;
Y= Dependent variable,β_0 = Constant term, $\beta_1 \beta_2 \beta_3$ β_n = Coefficients of input parameters
$X_1 X_2 X_3 X_n$ = Independent variable
The Equation 3.2 was usedto predict compressive strength tests results of self-compacting concrete.

IV. RESLTS AND DISCUSSIONS

4.1 Laboratory results for the combination of Metakaolin and Wood Ash percentages for the compressive strength of concrete is presented as Table 4.1

Table 4.1: Compressive Strength Results for Combination ofMetakaolin and Wood Ash

Water/Binder Ratios	MK+WA % combination	Compressive Strength
	0.00	52
	7.50	50
0.25	15.00	43
	22.50	36
	30.00	31
	0.00	47
	7.50	46
0.30	15.00	41
	22.50	34
	30.00	29

4.2 Regression of Compressive Strength Results

Compressive strength results obtained from the compressive strength tests carried out in the laboratory on the concrete samples after 28 days of curing was regressed against the weights of constituent materials and water-binder ratios as independent variables. However vital statistical output are presented and discussed in this section.

Table 4.2: Coefficient for Compressive Strength Regression Analysis

Model	Unstandardized Coefficient	Standardized Coefficient	T	Sig	Zero-order Correlation
CONSTANT	62.702		0.457	0.671	
CEMENT CONTENT	1.659	0.379	0.573	0.598	0.963
FINE AGGREGATE	0.660	0.252	0.217	0.839	-0.390
COARSE AGGREGATE	-1.431	-0.268	-0.267	0.803	-0.196
METAKAOLIN AND WOOD ASH	-2.287	-0.671	-1.405	0.233	-0.951
WATER-BINDER RATIO	-1.842	-0.095	-0.156	0.883	-0.128

From Table 4.2, multivariate linear model for estimation of compressive strength is given by Equation 4.1.

$$CS = 62.702 + 1.659 * X_1 + 0.660 * X_2 - 1.431 * X_3 - 2.287 * X_4 - 1.842 * X_5 \quad (4.1)$$

Where CS = Compressive strength, X_1 = Cement content, X_2 = fine aggregate, X_3 = coarse aggregate, X_4 = Metakaolin and wood ash and X_5 = water-binder ratio.

Equation 4.1 becomes the predictive model for the estimation of compressive strength cured after 28 days. The standardized coefficient indicate the level of influence of individual variable on the estimated model by their absolute values. The highest value is for Metakaolin and wood ash content indicating that the variable with the highest level of influence is Metakaolin and wood ash. To determine the statistical viability the above model, parameters in the regression (model) summary are presented in Table 4.3.

Table 4.3: Regression Summary for Compressive Strength

R	R-square	R-square Change	Standard error of estimate	F	Sig	Durbin-Watson
0.985	0.969	0.931	2.11609	25.324	0.004	1.954

The coefficient of determination, R^2 from Table 4.3, 0.969 indicate that the independent variables contribute to 96.9% which shows high contribution by the independent variables. The error in the estimate is shown by the standard error of estimate which is 2.11609. The F – statistics is statistically significant (sig = 0.004) as the regression was carried out at confidence interval of 95%. The Durbin-Watson value of 1.954 indicates positive autocorrelation of errors. However, the regression statistics shows that the model is of high degree of accuracy and is statistically significant. From Equation 4.1, a set of values for the estimation of the predicted compressive strength based on the Regression Model is generated and are compared with the experimental values. The residual with the above information are presented in Table 4.4.

Table 4.4: Comparison between Predictive dataand ExperimentalCompressive Strength Results

Water/Binder Ratios	Predicted Compressive Strength	Experimental Compressive Strength	Residual
	53.35	52	1.35
	48.50	50	-1.50
0.25	41.52	43	-1.48
	36.63	36	0.63
	31.98	31	0.98
	49.04	47	2.04
	44.44	46	-1.56
0.30	39.41	41	-1.59
	35.07	34	1.07
	29.03	29	0.03

From Table 4.4, show the different between predicted data and experimental compressive strength results of self-compacting concrete, the residual (deviation from experimental values) are small indicating that the model is of high accuracy.

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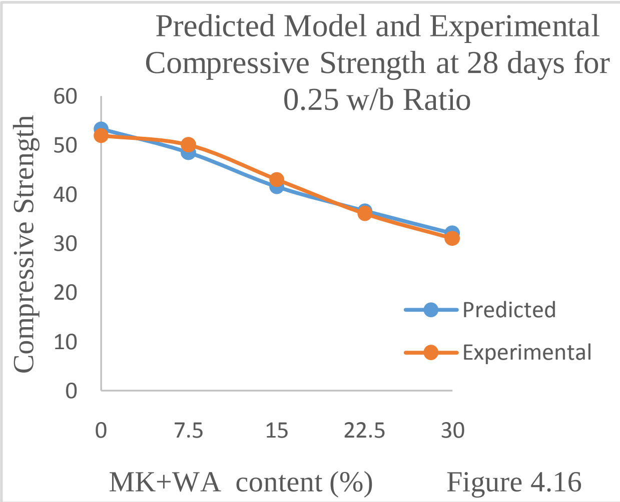
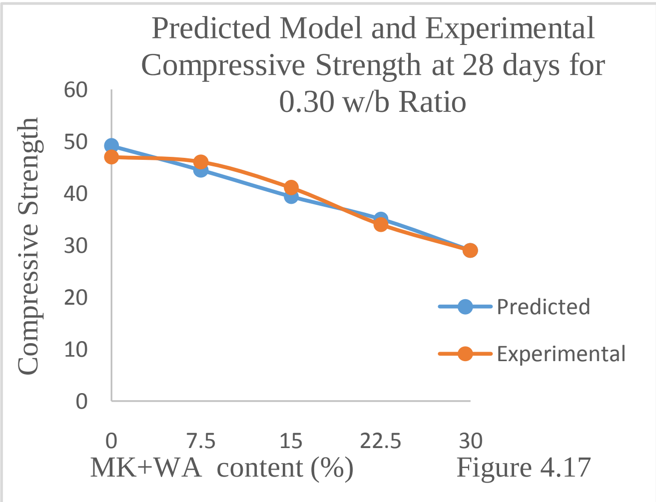
Graphs for the predicted and experimental values based on Table 4.3 are presented in figures 4.1 and 4.2.for water binder ratios of 0.25 and 0.30 respectively.

Figures 4.1 Graph of Predicted Model against Experimental Compressive Strength for water binder ratio of 0.25





Figures 4.2 Graph of Predicted Model against Experimental Compressive Strength for water binder ratio of 0.30

From Table 4.4, Figure 4.1 and Figure 4.2 shows the difference in values ranged from -1.50 to 1.35 for water/binder ratio 0.25 and -1.59 to 2.04 for water/binder ratio 0.30.
This difference is not significant hence the experimental values obtained are well predictedby using partial least square method.

V. CONCLUSION

From the Tests Results, Discussion and Analysis of the Results based on Reviewed Literature.
The following conclusions are drawn from the predictive model and the experimental results.

1. The partial least squares methodwas excellent for predicting compressive strength of self-compacting concrete using metakaolin and wood ash as partial replacement for cement.
2. The results ofpredicted model compared with experimental results was very minimal and the differences is not significant hence the experimental values obtained are well predicted. .

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