International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 7 July 2021, pp: 2476-2481 www.ijaem.net ISSN: 2395-5252

Predictive model for splittensile strength of self-compacting concrete using metakaolin and wood ash as partial replacement for cement

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Submitted: 05-07-2021 Revised: 17-07-2021 Accepted: 20-07-2021

ABSTRACT: This paper is compared results of data from predictive model to experimental data on the split tensile strength of self-compacting concrete using additives such as;Metakaolin and wood ash content. Particle parking method of concrete mix designwas adopted for experimental split tensile strength data while multivariate linear regression models was adopted for predictive split tensile strength. The mechanical tests were carried out to determine the split tensilestrength while SPSS statistical tools were carried out to predictsplit tensilestrength data. The following results were obtained from predictive split tensilestrength (2.28, 2.00,1.75,1.9 &1.45)MPa at 1:1.60:1.73:0.25 mix proportion and (2.09, 1.70, 1.68, 1.55 & 1.45)MPa at 1:1.7.4:1.88:0.30 mix proportion while the following results were also obtained from experimental split tensile strength (2.30, 2.12, 1.98, 1.84 & 1.61)MPa at 1:1.60:1.73:0.25 mix proportion and (2.12, 1.89, 1.79, 1.65 & 1.56)MPa at 1:1.7.4:1.88:0.30 mix proportion. The results of regression model variance is not significant hence the experimental values obtained are well predicted. Also showed high R^2 value of 0.995 and Durbin-Watson statistic value of 0.1850. Strength model developedcan be applied to predict split tensile strengths of self-compacting concrete blended with Metakaolin and wood ash under similar testing methodologies.

KEYWORDS: Self-Compacting Concrete, Metakaolin, Wood ash, Split Tensile Strength and predictive model.

I.INTRODUCTION

Self-Compacting Concrete is a flowable concrete that can fill formwork without any mechanicalvibration, so that it can be easily placed, in complicated formwork, congested reinforced structural elements and hard to reach area (EFNARC, 2005). For SCC, the use of super plasticizers is necessary in order to ensure adequate filling ability, passing ability and segregation resistance. However the use of chemical admixtures are expensive and results in increased material cost. But the use of mineral admixtures without increasing its cost could increase the slump of the concrete. These supplementary materials enhance the rheological properties and reduce the cracking of concrete due to the heat of hydration. Thus it improves the durability.

Excellent adaptability, availability and economy aspects, make concrete the world's most broadly used construction material. Despite all benefits related to the use of concrete, considerable self-weight of concrete compared to other construction materials and workability problems limit its use in some structures. (Kimet al, 2010) Dense concrete increases the mass of the structures and consequently the related forces and hazards.

In recent decades, utilizing the mineral and chemical admixtures in concrete technology has introduced several changes in formulation and mix design to make the concrete workable, stronger and durable.

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 reported thattarget strength of 42MPa was achieved using particle parking method with mix proportion of 1:1.60:1.73:0.25 for self-compacting concrete.

Superplasticizers are chemical admixtures that are added to the concrete to improve their flowing ability. In other sense, they can also help to reduce the amount of water in the concrete (for same slump and workability) and thus help to improve the strength and durability byTacumma&Bharath (2017).Therefore this paper is geared towards comparing results data from predictive model to experimental data on the split

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tensile strength of SCC using metakaolin and wood ash contents.

Aim and Objectives of the Study

The aim of this study is to develop Predictive model for split tensile strength of self-compacting concrete 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 SPSS statistical tools for self-compacting concrete using metakaolin and wood ash.
ii. To compared predictive model with experimental results for split tensile strength of self-compacting concrete.

II. LITERATURE REVIEW

Dhiviyaet al (2017). Studied theprediction of split tensile 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.

Wan-Ibrahim &Hamzah (2015) studied the effect of coal bottom ash on the replacement level of coal bottom ash as partial replacement of fine aggregate in SCC and to investigate the effect of coal bottom ash on the split tensile strength. The study involved designation of 0%, 10%, 20% and 30% of coal bottom ash (CBA) as a partial replacement of fine aggregate with variation of water cement ratios of 0.35, 0.40 and 0.45. The results showed that slump flow, L-box ratio and sieve segregation resistance of SCC mixtures with CBA are decreased, while T50cm slump flow time increased with the increase of CBA replacement level. The highest tensile strength of SCC is 4.25 MPa achieved by control sample with the water cement ratio of 0.35 at the age of 28 days. The increment of CBA replacement levels resulted in the reduction of split tensile strength and density of SCC. Meanwhile, the increment of water cement ratio reduced the split tensile strength of SCC.

Salim et al. (2015) reported that the properties of concrete having Metakaolin at 0, 5, 10 and 15% by weight of cement were investigated for compressive strength, sorptivity and carbonation resistance at two different water–cement ratios. It was observed that 10% of the cement replacement level with Metakaolin enhanced the sorptivity and carbonation resistance of concrete. Analytical techniques (XRD and MIP) were used to evaluate the microstructure properties of the concrete. It was also observed from Nano indentation studies carried out on cement paste samples that the addition of Metakaolin amended the cement paste.

Partial least squared 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).

III. MATERIALS AND METHODS

3.1 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.

3.2 MEHOD FOR PREDICTIVE SPLIT TENSILE STRENGTH MODEL

The multivariate linear regression model was developed using the SPSS computational statistical tools for the prediction/estimation of dependent variables. Also, vital statistical parameters are assessed from the developed model to determine their accuracies and significant levels. 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.

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The general multivariate linear model is given in the Equation 3.1

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

Where Y = Dependent variable, $X_{1,2,n}$= Independent variables, β_0 = Value of dependent variable when the independent variables are zeros, $\beta_{1,2,n}$= 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 split tensile strength results obtained from the laboratory after 28 days of curing.

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

$\beta_1 \beta_2\ \beta_3\ \beta_n$= Coefficients of inputj parameters

$X_1 X_2 X_3 X_n$ = Independent variable

The Equation 3.2 was usedto predict split tensile 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 split tensile strength of concrete is presented as Table 4.1

Table 4.1: Split Tensile Strength Results for Combination of Metakaolin and Wood Ash

Water/Binder Ratios	MK+WA % combination	Split Tensile Strength
	0.00	2.3
	7.50	2.12
0.25	15.00	1.98
	22.50	1.84
	30.00	1.61
	0.00	2.12
	7.50	1.89
0.30	15.00	1.79
	22.50	1.65
	30.00	2.3

4.2 Regression of Split Tensile Strength

Split tensile strength results obtained from the laboratory on the concrete samples after 28 days of curing was regressed against the weightsj of constituent materials and water-binder ratios as independent variables. However vital statisticalj outputshows the coefficients for the predicted model in Table 4.2.

Table 4.2: Coefficient for Spjlit Tensile Strength Regression

Model	Ujnstandardized Coefficient	Standardized Coefficient	T	Sig	Zero-order Correlation
CONSTANT	7.442		4.439	0.011	
WATER-BINDER RATIO	0.331	0.564	2.294	0.083	-0.299
CEMENT CONTENT	-0.105	-0.788	-2.957	0.042	0.950
FINE AGGREGATE	-0.063	-0.790	-1.689	0.167	-0.540
COARSE	-0.075	-0.461	-1.143	0.317	-0.362

AGGREGATE					
METAKAOLIN + WOOD ASH	-0.151	-1.459	-7.586	0.002	-0.903

From Table 4.2, the linear model for estimation of split tensile strength is given by Equation 4.2.

$$STS = 7.442 + 0.331 * X_1 - 0.105 * X_2 - 0.063 * X_3 - 0.075 * X_4 - 0.151 * X_5 \quad (4.2)$$

Where STS = Splitting Tensile Strength, X_1 = Water Binder Ratio, X_2 = Cement Content, X_3 = Fine aggregate, X_4 = Coarse aggregate and X_5 = Metakaolin + wood ash.

The Equation 4.2 is the predicted model for split tensile strength after 28 days curing. 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 variables with the highest level of influence is metakaolin + 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 Split Tensile Strength

R	R-square	R-square Change	Standard error of estimate	F	Sig	Durbin-Watson
0.998	0.995	0.989	0.02588	160.165	0.000	1.850

The coefficient of determination, R^2 from the Table 4.3, 0.995 indicate that the independent variables contribute to 99.5% which indicates a very high contribution by the independent variables. The error in the estimate is shown by the standard error of estimate which is 0.02588, a much reduced error. The F – statistics is statistically significant (sig = 0.000) as the regression was carried out at confidence interval of 95%. The Durbin-Watson value of 1.850 is greater than 2 hence, shows positive autocorrelation of errors. Generally, the regression model is highly significant and of high degree of accuracy.

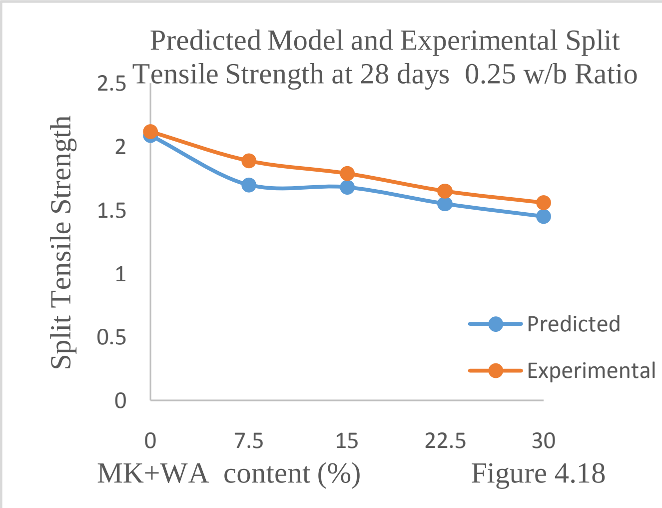
From equation 4.2 a set of values for the estimation of the predicted split tensile strength based on the Regression Model is generated and are compared with the experimental values. The residual with the above information are presented in Table 4.4.

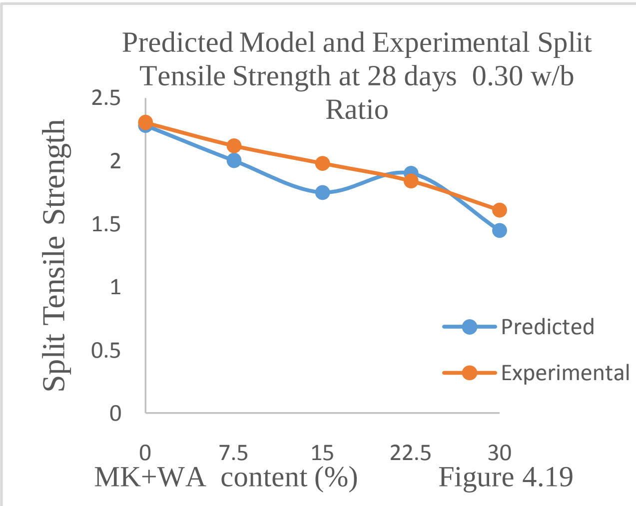
Table 4.4: Comparism between Predictive data and Experimental Split Tensile Strength

Water/Binder Ratios	Predicted Split Tensile Strength	Experimental Split Tensile Strength	Residual
	2.28	2.3	-0.02
	2.00	2.12	-0.12
0.25	1.75	1.98	-0.23
	1.9	1.84	0.06
	1.45	1.61	-0.16
	2.09	2.12	-0.03
	1.70	1.89	-0.19
0.30	1.68	1.79	-0.11
	1.55	1.65	-0.10
	1.45	1.56	-0.11

Graphs for the predicted and experimental values based on Table 4.3 appear as Figures 4.1 and 4.2for water binder ratios of 0.25 and 0.30 respectively.

Figures 4.1: Graphs of Predicted Model against Experimental Split Tensile Strengthfor water binder ratio of 0.25





Figures 4.2: Graphs of Predicted Model against Experimental Split Tensile Strengthfor water binder ratio of 0.30

From Table 4.4, Figure 4.1 and Figure 4.2 shows the difference in values ranged from -0.23 to 0.06 for water/binder ratio 0.25 and -0.19 to -0.03 for water/binder ratio 0.30. This difference is not significant hence the experimental values obtained are well predicted.

V. CONCLUSION

The following conclusions are drawn from the predictive model and the experimental results.

1. The partial least squares method was excellent for predicting split tensile 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 negligible and the differences is not significant hence the experimental values obtained are well predicted. .

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International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 7 July 2021, pp: 2476-2481 www.ijaem.net ISSN: 2395-5252

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