ISSN 2286-4822
www.euacademic.org

EUROPEAN ACADEMIC RESEARCH
Vol. XII, Issue 10/ January 2025

Impact Factor: 3.4546 (UIF)
DRJI Value: 5.9 (B+)

Development of Predictive Models for Compressive and Split Tensile Strengths of Roller-compacted Concrete Containing Micro silica

BARISUA EBENEZER NGEKPE[1]
CHIGOZIE MICHAEL ONYEGBADUE
Department of Civil Engineering, Rivers State University, Port Harcourt, Nigeria

Abstract

The continued effort aims at reducing carbon foot print associated with cement production has necessitated an alternate use of other finer cementitious material such as micro silica in the development of Roller-compacted concrete (RCC). This study examines the role of micro-silica to the evolution of compressive and tensile strengths of RCC. Micro-silica was used to replace cement at 10%, 15% and 20% at varying water/binder ratios of 0.35, 0.40, 0.45 and 0.50. A nonlinear regression analysis was formulated to investigate the functional relationship between the response and independent variables/curing ages. Superplasticizer was exempted from the analysis due the problem of collinearity with cement content. The nonlinear model was achieved by logarithmic transformation of a multiple linear regression model. Results showed that at 15% cement replacement with micro-silica and water/binder ratio of 0,35, maximum value of compressive strength of 64.89 Mpa was achieved. The predictive models for both compressive and tensile strengths showed excellent correlation with test data as depicted in the model performance metrics.

Keywords: Roller-compacted concrete, compressive, Tensile, regression, cement, water/binder ratio, curing ages

1.0 INTRODUCTION

The construction industry is striving to move away from conventional concrete methods to green concrete by reducing the use of cement in concrete, which will lead to a reduction in cement production. However, cement reduction is compensated by the application of other supplementary cementitious materials including silica fume, rice husk ash, fly ash and ground granulated blast furnace slag (GGBS) as partial replacements for cement in concrete mix design (Juenger and Siddique, 2015).

Roller-compacted concrete (RCC) is defined as a zero-slump concrete which is transported, placed and compacted using equipment used in earth and rock fill operations. Roller compacted concrete (RCC) has similar basic ingredients such as conventional concrete (Ouellet, 1998). However, RCC is slightly different from conventional concrete (CC). It is a drier mix-stiff enough to be compacted by vibratory rollers (Burns and Saucier, 1978).

RCC if properly designed does not require joints during construction and form work. For design of RCC, early strength of 40 N/mm^2 for cement content of 300 kg/m^3

[1] Corresponding author: ebenezer.ngekpe@ust.edu.ng

and a w/c ratio of 0.35. In addition, RCC is less sensitive to cracking in relation with drying shrinkage. The RCC is basically used in the design of low volume roads, ports and dams. For instance, RCC pavement was used in Intermodal Yard Paving Projects at the Port of Tacoma, Washington (Pittman and Anderton, 2009).

Several studies aimed at enhance the strengths, durability and performance of roller-compacted concrete have been reported as such:

LaHucik et al (2017) investigated into the benefits of the application of macro-fibers on the mechanical properties of roller-compacted concrete (RCC) designed for pavement. At two dosages, 0.2% and 0.4% by volume, six fiber types of which four were synthetic and two were steel were added into roller-compacted concrete mixtures. Mechanical properties of the concrete were measured and compared with conventional fiber-reinforced concrete (FRC). Results showed that the maximum dry density (MDD) and compressive strength of the macro-synthetic fiber roller-compacted concrete increased more than the control roller-compacted concrete. And also, the steel fiber increased the split tensile strength of the control roller compacted concrete than the macro-synthetic fibre.

The flexural strength and fiber efficiency of steel-fiber-reinforced, roller-compacted, polymer-modified concrete (SFR-RC-PMC) were investigated by Karadelis and Lin (2015). Result revealed that steel-fiber-reinforced, roller-compacted, polymer-modified concrete developed greater flexural strengths than traditional steel-fiber-reinforced concrete. Additionally, compared to traditional steel-fiber-reinforced concrete, the fibers in SFR-RC-PMC demonstrated greater efficiency.

Lin et al. (2013) formulated a mix design methodology for steel-fibre-reinforced, roller-compacted concrete, targeting enhanced bond strength and roller compatibility it was observed that for optimal water content, the modified light compaction method was recommended for steel fiber reinforced, roller-compacted, polymer modified, bond concrete overlays. Approximately 3% of air content was found for mixes with optimal water content determined by modified proctor method.

Atis (2005) carried out a laboratory study to investigate the strength properties of high-volume fly ash (HVFA) roller compacted concrete and superplasticiser workable concrete which were cured at moist and dry curing conditions. With water-cementitious ratio range from 0.28 to 0.43 and partial replacement of Portland cement with good and low quality low-lime class F fly ashes, the compressive, flexural tensile and cylinder splitting tensile strengths were tested and recorded. Results revealed that High-volume fly ash concrete showed high strengths than the normal Portland cement concrete.

Adamu et al (2018) studied the mechanical properties and performance characteristics of a high-volume fly ash roller compacted concrete with crumb rubber and nano silica. The concrete was produced with high volume fly ash used as partial replacement for cement, crumb rubber as partial replacement for sand and nano silica as a cementitious additive material. Statistical models which showed high correlation between variables and responses were developed using response surface methodology. These responses include compressive, splitting tensile and flexural strengths.

The predicting models for compressive, splitting tensile and flexural strength developed using the response surface methodology showed high degree of correlation and predictability and error less than 5%, indicating that the models have high degree of accuracy. By partial replacement of sand with 10% crumb rubber, replacement of cement with 53.72% fly ash and an addition of 1.22% by weight of cementitious material of nano-silica, an optimized roller compacted concrete was achieved. An increased replacement of sand with crumb rubber decreased the compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and abrasion resistance of the high-volume fly ash roller compacted concrete. However, the addition of nano-silica improved the aforementioned mechanical properties.

Fakhri and Fashard (2016) investigated the effect of waste rubber and silica fume on the mechanical properties of roller compacted concrete pavement. The concrete designed and studied was aimed at improving its performance and reducing its environmental impact. In the design, used tyres were used as partial replacement for fine aggregate at varying percentages of 0, 5, 10, 15, 20, 25, 30 and 35. Silica fume was employed as a partial replacement for cement in the eight mixes. To achieve a homogenous mixture, fresh concretes were compacted by harmer rather than a vibrator. From the study, it was observed that the compressive and flexural strengths of the pavement were improved; the addition of tyres as partial replacement of sand increased the concrete strength and the incorporation of silica fume further improved the strengths of the mixtures. Also, the addition of tyres reduced the water absorption of the pavement and increased its rigidity which enhances its flexibility needed for impact resistance against load vehicles when applied in road construction.

Lam et al (2017) examined the feasibility of Electric Arc Furnace (EAF) slag aggregate mix design in the production of roller-compacted concrete pavement. The mechanical properties of the concrete were investigated. Electric arc furnace was used as partial replacement of coarse aggregate at three proportions (0%, 50% and 100%) and fly ash was used as replacement constituent for cement at varying proportions too (0%, 20% and 40%).

Result showed that the expansion due to hydration action and alkali-silica reaction were stable indicating that the design mixture was good for pavement application. There was an increment in the unit weight of the roller compacted concrete pavement due to higher unit weight of electric arc furnace incorporated into the concrete mixture.

However, there were reductions in the compressive strength, splitting tensile strength and modulus of elasticity caused by bad interfacial transition between electric arc furnace and cementitious matrix.

Mohammed and Adamu (2018) developed roller compacted rubbercrete (RCR) by partial replacement of sand by volume with crumb rubber in varying percentages and replacement by weight of cement with nano-silica at varying percentages. The crumb rubber was incorporated into the concrete mixture to improve the flexural strength and nano silica to compensate for loss of strength in the concrete. Result showed that From above 10% replacement of sand with crumb rubber, the compressive strength and splitting tensile strength of roller compacted rubbercrete decreased while that of flexural strength increased up to 20% replacement.

Ali Ahmad et al (2017) examined the feasibility of the applicability of Lumachelle as fine aggregate in roller-compacted concrete containing pozzolan. In the study, three mixtures based on dimension reduction prediction method were designed with different water/cement ratios, pozzolan content and Lumachelle as replacement of fine aggregate. Tests were carried out to examine the mechanical properties of the concrete mixture. Also, probabilistic performance evaluation and sensitivity analysis were carried out based on the Monte Carlo simulation, the score function approach and the dimension reduction prediction method.

Results showed that the compressive strengths of the concrete mixtures were reduced. Pozzolan reduced the strength in the early ages of curing but with increasing age, the strengths were improved though, with over 20% of pozzolan content, the strengths were reduced.

Incorporation of Lumachelle into the concrete mixture did not show any significant difference in strength compared to normal roller compacted concrete with sand as fine aggregate. The use of Lumachelle reduces cost and performs optimally as other fine aggregate used in the design of roller compacted concrete.

Courard et al (2010) examined the use of concrete road recycled aggregate as replacement of natural aggregate in the production of roller compacted concrete. Result from study showed that incorporation of recycled aggregate in the design of roller compacted concrete yield good performance. Also, roller compacted concrete with recycled aggregate showed similar solid compactness as natural aggregate roller compacted concrete but has lower compressive strength.

Ramezanianpour et al (2017) investigated the mechanical and durability properties of roller compacted concrete pavement in cold regions. In the study, trass was used as partial replacement for cement. Mechanical and durability tests and salt scaling with air void analysis were carried out on the concrete mixtures to examine effect of ordinary/trass mixtures with/without air entraining agents.

Result showed that the compressive and tensile strengths of the concrete were reduced by the air entraining agents due to high porosity they generated in the mixtures. But the water absorption and water permeability of the concrete mixtures were increased by the air entraining agent.

However, it was concluded that the usage of air entraining agent like trass may not be a very good replacement material for cement in the design of roller compacted concrete as cement paste is limited in roller compacted concrete.

Dareyni et al (2018) studied the effect of cationic asphalt emulsion (CAE) on the durability of roller compacted concrete. The design used for the study employed the incorporation of CAE as admixture of weight of cement (0%, 2%, 4%, 6%, 8%, 10%) using the maximum density method according to ASTM D1557. Cubic and cylindrical mixtures were prepared using vibratory harmer. Test conducted to determine the durability of concrete include water absorption, sorptivity, electricity resistance and water penetration depth.

From the study, it was observed that the transport characteristics of roller compacted concrete pavement were improved with the addition of cationic asphalt emulsion. Also, the capillary pores of the asphalt produced were reduced by the addition of CAE thereby increasing the strength and improving the durability of the concrete mixture. The penetration property of the asphalt produced was improved by the addition of CAE as well. It was recommended that 4% by weight of cement or more should be incorporated into roller compacted concrete pavements to improve transport properties.

Ngekpe et al. (2020) investigated the roles of metakaolin and micro-silica on the compressive strength of self -compacting concrete. Results showed at 15% cement replacement were optimum in each case.

Abubakr et al. (2022) examined the effects of metakaolin (MK) and steel fiber inclusion on mechanical and durability properties of roller-compacted concrete using experimental methods. Results revealed that a combination of 15% metakaolin and 45 kg/m^3steel fibre produced the optimum compressive strength and durability. However, there is no study on the functional relationship between the response and independent variables.

Sunbul and Tortum (2024) studied the incorporation of basalt fibres and nano powder on the mechanical properties of RCC using Taguchi method for optimising mix design. The reliability of the results obtained was verified using regression analysis. Results showed that the nano material, Tin oxide did not exhibit any significant effect on the mechanical properties of the RCC. However, the microstructural interactions of nano powders and the fibers within the RCC matrix was not analysed.

Ngekpe et al. (2021) carried out experimental investigation on the mechanical properties of high strength recycled aggregate concrete containing micro silica as partial substitute for cement. Results revealed that the maximum compressive strength of 105 Mpa at water/binder ratio of 0.20 at 15% cement replacement with micro-silica.

From the various literatures reviewed, it is observed that the physical and mechanical properties of roller compacted concrete have been examined with varying cementitious materials as admixtures or partial replacement for conventional Portland cement. However, there are few studies done with micro-silica as a cementitious admixture or partial replacement.

Also, from the available literatures reviewed, the influences of the additional cementitious materials and the constituent materials in concrete mixtures on the mechanical and physical properties of concretes have been significantly examined. However, there exists limited study that captured this dependability using predictive regression models. The few studies done in this area had used linear regression models which do not adequately predict mathematical relationships between strengths and mixture constituents and curing age.

Therefore, this study is aimed at addressing this gap identified. To do this, concrete specimens were prepared at water-cement ratio of 0.35, 0.40, 0.45 and 0.50 and at partial replacement of cement with micro-silica at 0%, 10%, 15% and 20%. Thereafter, statistical assessment of the effect of principal variables on the strengths of the concrete mixtures using non-linear regression analysis will be carried out.

2.0 MATERIALS AND METHODS

This section provides detail of method employed in this study, the concrete constituent comprises of cement, fine aggregate, coarse aggregate, water, superplastiser and micro-silica. Detail of these is presented in Ngekpe et al. (2019). Consequenty, the mix proportion presented herein is obtained as well.

2.1 Mix Proportion

The mix design was carried out as per ACI 211 guidelines. The mix proportion is presented as such:

Table 3.2 Mix Proportion

W/C	Percentage replacement	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Microsilica (kg/m^3)	Water (kg/m^3)	Superplasticizer (% of cement)
0.35	0%	371.43	654.72	1159.20	0	140.4	1
	10%	334.29	654.72	1159.20	37.14	140.4	1
	15%	431.01	654.72	1159.20	55.72	140.4	1
	20%	297.14	654.72	1159.20	74.29	140.4	1
0.40	0%	312.5	768.24	1108.80	0	135.9	1
	10%	281.25	768.24	1108.8	31.25	135.9	1
	15%	265.63	768.24	1108.8	46.88	135.9	1
	20%	250	768.24	1108.8	62.5	135.9	1

0.45	0%	277.8	910.8	1008	0	132	1
	10%	247.95	910.8	1008	29.85	132	1
	15%	218.12	910.8	1008	59.69	132	1
	20%	188.26	910.8	1008	89.54	132	1
0.50	0%	230	958	1101	0	127	1
	10%	198.86	958	1101	31.14	127	1
	15%	167.71	958	1101	62.29	127	1
	20%	136.57	958	1101	93.43	127	1

Extracted from Ngekpe et al. (2019).

2.2 Non-linear Regressioin Analysis

Regression analysis will be adopted to establish mathematical relationship between input sparameters and dependent variables. To establish these predictive models and obtain statistical information that show the degree of accuracies, errors of estimates, correlation of variables, regression analysis is done using computer aided application (SPSS).

For more accurate predictive models, the non-linear regression method is applied. This is because concretes exhibit non-linear characteristics when analysed mathematically. To establish, the non-linear regression models to predict the dependent variables, the logarithmic transformation of the multiple linear regression model is used. The principle is explained thus;

The multiple linear regression model is of the form;

$$\mathrm{Y} = \sigma_0 + \sigma_1 \mathrm{X}_1 + \sigma_2 \mathrm{X}_2 + \sigma_3 \mathrm{X}_3 + \cdots + \sigma_n \mathrm{X}_n \quad (1)$$

Taking the natural logarithm of Equation 1 above, we have;

$$\ln \mathrm{Y} = \mathrm{In}\sigma_0 + \sigma_1 \mathrm{InX}_1 + \sigma_2 \mathrm{InX}_2 + \sigma_3 \mathrm{InX}_3 + \cdots + \sigma_n \mathrm{InX}_n \quad (2)$$

Applying laws of logarithm, the above equation transforms into;

$$\ln \mathrm{Y} = \mathrm{In}(\sigma_0 * X_1{}^{\sigma_1} * X_2{}^{\sigma_2} * X_3{}^{\sigma_3} * \ldots * X_n{}^{\sigma_n}) \quad (3)$$

Taking the antilogarithm of Equation 3 yields;

$$\mathrm{Y} = \sigma_0 * X_1{}^{\sigma_1} * X_2{}^{\sigma_2} * X_3{}^{\sigma_3} * \ldots * X_n{}^{\sigma_n} \quad (4)$$

Where Y = Dependent variable, X_i = Independent variables, σ_0= constant of regression and $\sigma_{i=1,n}$= coefficients of independent variables.

3.0 RESULTS AND DISCUSSION

4.2 Compressive Strength

The results of the compressive strength tests on concrete after 7, 14 and 28 are presented in Table 4.2 below. The variations of the compressive strength with the Micro-silica content after 7, 14 and 28 days are plotted and presented below as well.

Table 3.1: Compressive Strength Result

Water-cement ratio	% Replacement with Microsilica	Compressive Strength (MPa)		
		7 Days	14 Days	28 Days
0.35	0	34.96	43.55	44.15
	10	41.78	62.07	63.41
	15	53.33	59.55	64.89
	20	44.74	49.19	61.63
0.40	0	35.55	39.41	40.28
	10	42.96	45.18	45.92
	15	36.28	48	41.18
	20	36.44	39.41	45.63
0.45	0	30.37	35.41	33.78
	10	40	48.67	48.89
	15	31.70	40.89	43.41
	20	36.74	44.74	47.41
0.50	0	30.22	36.00	25.83
	10	29.48	33.18	29.02
	15	40.15	48.44	54.81
	20	44.74	48.44	51.82

From Table 3.1above, it is seen that the maximum compressive strength is recorded for the mixture with 15% incorporation of microsilica and 0.35 water-cement ratio. This is due to high cement content and low water content making available more fine particles and binder that help reduce pores in the concrete. From the result, it is observed that the compressive strength of the concrete increases on increasing amount microsilica and cement content. Also, at same water-cement ratios and percentage incorporation of microsilica, the compressive strength of the concrete increases as the curing age of the concrete.

3.2 Split Tensile Strength

The tensile strength of the concrete cylinders prepared and cured after 28 days were tested and results for the different mixes are presented in Table 4.3 below.

Table 3.2: Split Tensile Strength Result for 28 Days Cured Concrete

Water-cement ratio	% Microsilica Content	Split Tensile Strength (MPa)
0.35	0	2.26
	10	2.50
	15	2.88
	20	3.39
0.40	0	2.36
	10	3.02
	15	3.49
	20	4.10
0.45	0	2.55
	10	3.06
	15	3.77
	20	4.10
0.50	0	2.92
	10	3.20
	15	3.54
	20	4.05

From the results above, the highest value of split tensile strength is 4.10 MPa observed for 20% Microsilica content at 0.40 and 0.45 water-cement ratio respectively.

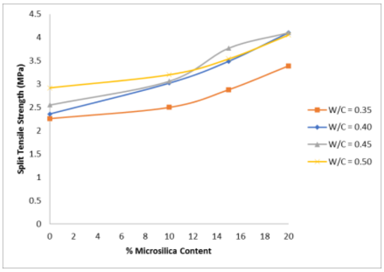

Figure 3.1: 28 Days Split Tensile Strength

From figure 3.1, at 0.35 water cement ratio, the highest increment of strength, 50% is observed for 20% Microsilica content. Similarly, 10.62% and 27.43% increment were observed for 10% and 15% Microsilica content respectively. At 0.40 water-cement ratio, increments of 27.97%, 47.88% and 73.73% were observed for 10%, 15% and 20% Microsilica content respectively. At 0.45 water-cement ratio, 20%, 47.84% and 60.78% were the increment of strength observed at 10%, 15% and 20% Microsilica content respectively. Similarly, at 0.50 water-cement ratio, 9.59%, 21.23% and 38.70%

increment in strength were observed for 10%, 15% and 20% Microsilica content respectively.

From the result above, the most significant effect of Microsilica on the split tensile strength of the concrete is observed for water-cement ratio of 0.40.

3.3 Regression Analysis

The results from the strength tests carried out were regressed using the SPSS computer software with the densities of constituent materials and curing age as input variables and the compressive and split tensile strength as response variables. The superplasticizer content was excluded from the regression analysis due to multicollinearity as it has linear relationship with the cement content which is also an input variable.

3.3.1 Compressive Strength Regression

The compressive strength was regressed as response (dependent) variable and cement content, fine aggregate, coarse aggregate, microsilica, water-cement ratio and curing age as input (independent) variables. Due to multicollinearity, superplasticizer was excluded from the regression. The result of the regression done with SPSS is attached to this work in Appendix E. Vital statistical outputs from the result are presented and discussed below.

Table 3.3: Coefficients for Compressive Strength Regression

Model	Unstandardized coefficients	Standardized coefficients	t	Sig	Zero-order correlation
(Constant)	31.199		3.291	0.003	
CEMENT CONTENT (X1)	-1.941	-2.516	-2.833	0.008	0.313
FINE AGGREGATE (X2)	-1.932	-0.592	-2.328	0.027	-0.578
COARSE AGGREGATE (X3)	-0.774	-0.196	-1.098	0.281	0.382
MICROSILICA CONTENT (X4)	-0.395	-0.765	-2.160	0.039	0.196
WATER-CEMENT RATIO (X5)	-3.468	-2.299	-2.574	0.015	-0.500
CURING AGE (X6)	0.154	0.435	4.061	0.000	0.435

From the above table, the predictive model for compressive strength of the concrete according to Equation 3.3 is given by

$$Y = e^{31.199} \times X_1^{-1.941} \times X_2^{-1.932} \times X_3^{-0.774} \times X_4^{-0.395} \times X_5^{-3.468} \times X_6^{0.154} \quad 3.1$$

Where Y = Compressive Strength, X_1 = Cement Content, X_2 = Fine aggregate content, X_3 = Coarse Aggregate content, X_4 = Microsilica content, X_5 = water-cement ratio and X_6 = curing age.

From Table 3.3 above, the zero-order correlation values show the values of Pearson correlation coefficients while the standardized coefficients show the degree of influence of the input variables. The variable with the most absolute value of standardized coefficient is the variable with the most influence on the prediction of the dependent variable. From the table above, cement content has the highest absolute value of 2.516, hence, cement content has the most influence on the prediction of compressive strength.

3.3.2 Accuracy and Significance of Regression Model

The accuracy of the predicting model (Equation 3.1) in the estimation of compressive strength model summary table of Appendix E from which some statistical values are presented in Table 4.5 below.

Table 3.4: Model Summary of Regression of Compressive Strength

R	R-Square	Adjusted R-Squared	Standard Error of Estimate	F	Sig	Durbin-Watson
0.817	0.667	0.598	0.128922945934	9.688	0.000	2.487

R-squared value 0.667 indicates that the independent variable can only predict 66.7% of the predicted strength. This means there are other factors that account to the prediction of the compressive strength of the concrete. The standard error of estimate is small indicating that there is small error in the regression. Hence, the accuracy of the regression is high. The Durbin-Watson value of 2.487 is greater than 2 and indicates negative autocorrelation of errors. This means errors of opposite signs succeeds each other on a scatter plot.

The regression analysis was done under a confidence interval of 95%. For a predictive model to be significant under this condition, the significance of F must be less than 0.05. From Table 3.4, the significance of F is 0.000 which is less than 0.5 hence, the model is statistically significant.

3.4.3 Predicted Compressive Strength and Experimental Compressive Strength

The predicted model in Equation 3.1 is employed to generate values of compressive strength (predicted compressive strength). These values are compared with their corresponding experimental compressive strength. This is done through a linear regression of the predicted compressive strength and the experimental compressive strength. The result is attached to this work in Appendix F. Some information from the result is presented below.

Table 3.5: Coefficient for Predicted and Experimental Compressive Strength Regression

Model	Understandized coefficient	Standardized coefficient	T	Sig
Constant	13.257		3.639	0.001
Experimental Compressive Strength	0.699	0.837	8.932	0.000

From Table 3.5 above, the relationship between predicted and experimental compressive strength is given by the equation below.

$$Y = 13.257 + 0.699 * X4 \qquad 3.2$$

Where Y = Predicted Compressive Strength and X = Experimental Compressive Strength.

The coefficient of the dependent variable is less than and not very close to 1 indicating the variation of predicted and experimental compressive strength. The Pearson coefficient, R is same with the standardized coefficient which is 0.837 as shown in the above table. The variation of predicted compressive strength from the experimental compressive strength can be observed from the variation of the data points from the trendline of the plot in Figure 4.10 below.

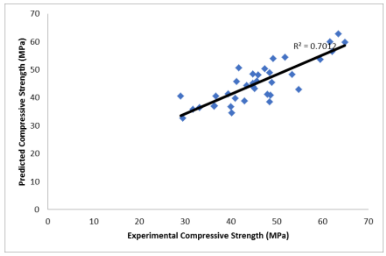

Figure 3.2: Scatter plot of predicted and experimental compressive strength

From the figure above, it is seen that the variation of the data points from the trendline are wide. This accounts for the low value coefficient of regression shown on the plot.

3.3.4 Regression of 28 Days Compressive Strength

Concrete cubes cured after 28 days were tested and the result for the compressive strength for the different mix proportions obtained were regressed using non-linear regression. The regression output is attached to this work in Appendix G. Vital statistics from the result are presented below and discussed.

Table 3.6: Coefficient for 28 Days Compressive Strength Regression

Model	Unstandardized coefficients	Standardized coefficients	t	Sig	Zero-order correlation
(Constant)	36.513		1.691	0.142	
CEMENT CONTENT (X1)	-1.744	-2.131	-1.118	0.306	0.340
FINE AGGREGATE (X2)	-2.739	-0.791	-1.449	0.197	-0.702
COARSE AGGREGATE (X3)	-0.844	-0.201	-0.526	0.618	0.392
MICROSILICA CONTENT (X4)	-0.262	-0.479	-0.630	0.552	0.344
WATER-CEMENT RATIO (X5)	-3.010	-1.881	-0.981	0.365	-0.582

From Table 3.6 above, the compressive strength model predicted could be written as

$$Y = e^{36.513} \times X_1^{-1.744} \times X_2^{-2.739} \times X_3^{-0.844} \times X_4^{-0.262} \times X_5^{-3.010} \qquad 3.3$$

Where Y = Compressive Strength, X_1 = Cement content, X_2 = Fine aggregate content, X_3 = Coarse aggregate content, X_4 = Microsilica content, X_5 = Water-cement ratio.

The standardized coefficient shows the input variable with the most influence on the prediction of the compressive strength. From Table 3.6, the cement content has the most absolute value hence, the cement content has the highest influence on the model. The Pearson correlation coefficient of the various input variables is shown by the zero-order correlation in the table.

The goodness of fit and significance of the predicted model can be deduced from the regression statistics table shown in Table 4.8 below.

Table 3.7: Model Summary for 28 Days Compressive Strength Regression

R	R-Square	Adjusted R-Squared	Standard Error of Estimate	F	Sig	Durbin-Watson
0.826	0.682	0.418	0.169535802354	2.579	0.000	2.679

The regression coefficient, R^2 value of 0.682 means the independent variables could predict the compressive strength to 68.2%. Errors account for the remaining 31.8%. This means there are other factors that determined the strength obtained. However, the standard error of estimate is small indicating that the regression has minimal error. Hence, the accuracy of the regression analysis is high. Durbin-Watson value of 2.679 indicates negative autocorrelation of regression error.

The significance of F 0.000 is less than 0.05. Since the regression was done at confidence interval of 95%. This means the regression output is statistically significant. Values of compressive strength generated using Equation 3.3 are compared with the experimental compressive strength to check the variation between the predicted strength and the experimental strength. The predicted values of compressive strength were regressed with experimental values using a linear regression. The output is attached to this work in Appendix H. Below are some key parameters from the regression done.

Table 3.8: Coefficient of Predicted and Experimental 28 Days Compressive Strength Regression

Model	Unstandardized coefficient	Standardized coefficient	T	Sig
Constant	11.027		1.438	0.181
Experimental Compressive Strength	0.776	0.852	5.139	0.000

From the above table, the linear relationship between predicted and experimental compressive strength is given by

$$Y = 11.027 + 0.776 * X \qquad 3.4$$

Where Y = Predicted compressive strength and X = Experimental compressive strength. The coefficient of experimental compressive strength being 0.776 indicates that the variation of predicted compressive strength from the experimental compressive strength is small. The Pearson correlation coefficient, R is the same as the standardized coefficient value of experimental strength which is 0.852.

However, the variation of the data points of a scatter plot of predicted and experimental strength is shown in Figure 3.3

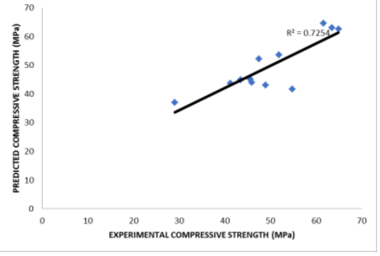

Figure 3.3: Scatter plot of Predicted and Experimental 28 Days Compressive strength

From Figure 3.3 above, the regression coefficient of the plot is 0.7254 (72.54%). The remaining percentage accounts for the error in the fitting which is caused by the data points that are some distances away from the trendline. This accounts for the variation of the predicted compressive strength from the experimental compressive strength. However, the variation is minimal indicating high degree of accuracy in the predicted model in Equation 4.3.

3.3.2 Split Tensile Strength Regression

The result obtained from the experimental test on cylindrical specimens cured for 28 days were regressed against cement content, fine aggregate content, coarse aggregate content, microsilica content and water-cement ratio and the result presented in Appendix I attached to this work in the appendices. Key statistical outputs from the result are discussed below.

Table 3.9: Coefficient for Split Tensile Strength Regression

Model	Unstandardized coefficients	Standardized coefficients	t	Sig
(Constant)	-17.897		-3.049	0.023
CEMENT CONTENT (X1)	0.675	1.182	1.591	0.163
FINE AGGREGATE (X2)	2.357	0.976	4.587	0.004
COARSE AGGREGATE (X3)	-0.290	-0.099	-0.665	0.531
MICROSILICA CONTENT (X4)	0.465	1.217	4.106	0.006
WATER-CEMENT RATIO (X5)	0.603	0.540	0.723	0.497

From the table above, the predicted model for split tensile strength is presented as below

$$S = e^{-17.897} \times X_1^{0.675} \times X_2^{2.357} \times X_3^{-0.290} \times X_4^{0.465} \times X_5^{0.603} \qquad 3.5$$

Where S = Split Tensile Strength, X_1 = cement content, X_2 = Fine aggregate content, X_3 = Coarse aggregate content, X_4 = Microsilica content and X_5 = Water-cement ratio.

Equation 3.4 becomes the predicted model for estimating split tensile strength of concrete cured for 28 days. The standardized coefficient from Table 4.9 shows the independent variable with the most influence on the prediction of the split tensile strength (dependent variable). Microsilica has the most absolute value hence, it has the highest influence on the prediction of split tensile strength.

The goodness and significance of the model predicted above (Equation 4.5) can be ascertained from the regression statistics (model summary) table from which key parameters are drawn and presented in Table 4.11 below.

Table 3.10: Model Summary for 28 Split Tensile Strength Regression

R	R-Square	Adjusted R-Squared	Standard Error of Estimate	F	Sig	Durbin-Watson
0.976	0.952	0.912	0.046087299197	23.702	0.001	2.870

From the table above, the regression coefficient of 0.952 indicates that that the independent variables contributes 95.2% to the prediction of the split tensile strength. The standard error of estimate is far less than one indicating small error in estimation of the split tensile strength. Therefore, the regression output or the model predicted in Equation 3.5 is having high degree of accuracy. The Durbin-Watson's value of 2.870 which is greater than 2 indicates negative autocorrelation of errors in the fitting of values.

The significance of the predicted model is shown by the significance of F statistic. From Table 3.10, the significance of F is 0.001. The regression was done at a confidence interval of 95% and under this condition, a predicted model is significant when the significance of F is less than 0.05. From the above table, the significance of F is less than 0.05 hence, the predicted model is statistically significant.

Equation 3.5 being used to generate values of split tensile strength (predicted split tensile strength), these values are being compared with the experimental split tensile strength through a linear regression in order to check for the variation of the predicted split tensile strength from the experimental split tensile strength. The output of the regression is attached to this work in Appendix J. Vital statistical output from the work are presented below.

Table 3.11: Coefficient for Predicted and Experimental Split Tensile Strength Regression

Model	Unstandardized coefficient	Standardized coefficient	T	Sig
Constant	0.167		0.674	0.516
Experimental Compressive Strength	0.956	0.973	13.318	0.000

From the above table, the linear relationship between the predicted split tensile strength and experimental split tensile strength is given below.

$$Y = 0.167 + 0.956 * X \qquad 3.6$$

Where Y = Predicted split tensile strength and X = Experimental split tensile strength.

The coefficient of Experimental split tensile strength being 0.956 is very close to 1 indicating that the predicted split tensile strength is very close to their corresponding experimental values. This further proves that the accuracy of predicted model in Equation 3.5 is very high.

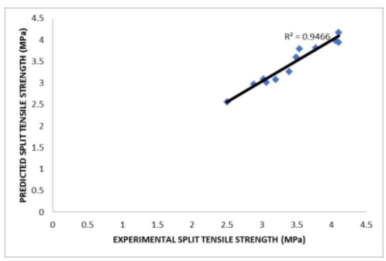

Figure 4.11: Scatter Plot of Predicted and Experimental Split Tensile Strength

From the figure above, the data points are observed to be very close to the trendline which accounts for the high value of regression statistics. This further proves diagrammatically that the predicted split tensile strength values are very close to the experimental split tensile strength.

4.0 CONCLUSION

This study examines the reliability of an experimental data on the compressive and tensile strengths of roller-compacted concrete containing micro-silica as partial substitute of cement. Salient findings are highlighted as follows:

- Test data revealed that a maximum compressive strength of 64.89 Mpa was measured at 28 days of wet-curing; this occurred at 15% cement replacement with micro-silica and for water/binder ratio of 0.35. Hence, it demonstrated micro-silica significant role in enhancing strengths of RCC.
- The hydration kinetics of micro-silica was most significant at 15 % cement replacement level.
- The gradual increase in strength is attributed to the reduced void content by micro-silica, which ehances hydration and microstructural properties of the roller-compacted concrete.

- Comparison between tests data and predictive models showed excellent correlation as depicted these higher values of the model performance metrics.

REFERENCES

1. Abu Bakr, M., Mahmood,H.F. & Mohammed, A.A. (2022). Investigation on metakaolin and steel fiber addition on some mechanical and durability properties of roller compacted concrete. Case studies in construction materials. 16, e01136.
2. Atis, C. D. (2005). "Strength properties of high-volume fly ash roller compacted and workable concrete, and influence of curing condition." Journal of Cement and Concrete Research. Vol. 35. Pp 1112-1121.
3. Ali Akbar Ramezanianpour, Ahmad Mohammadi, Erfan Riahi Dehkordi and Qasem Bagheri Chenar (2017). Mechanical properties and durability of roller compacted concrete pavement in cold regions." Journal of Construction and Building Materials. Vol. 146. Pp 260-266.
4. Bashar S. Mohammed and Musa Adamu (2018). "Mechanical performance of roller compacted concrete pavement containing crumb rubber and nano silica." Journal of Construction and Building Materials. Vol. 159. Pp 234-251.
5. Burns Cecil D, Saucier Kenneth I. Vibratory compaction study of zero-slump concrete. ACI J 1978: 75(3): 86-90
6. Chamroeun Chhorn, Seong Jae Hong, Seung Woo Lee (2018). Relationship between compressive and tensile strengths of roller-compacted concrete." *Journal of Traffic and Transportation Engineering (English Edition)*. Vol. 5(3): 215-223
7. Krishna Rao S., Sravana P. and Chandrasekhar Rao T. (2016). "Abrasion resistance and mechanical properties of roller compacted concrete with GGBS." Journal of Construction and Building Material. Vol. 114. Pp 925-933.
8. Juenger, M. C. and Siddique, R. (2015). "Recent advances in understanding the role of supplementary cementitious materials in concrete." *Journal of Cemennt and Concrete Research*. Vol 78.
9. LaHucik, J., Dahal, S., Roesler, J and Amirkhanian, A, N. (2017). "Mechanical properties of roller-compacted concrete with macro-fibers". *Journals of Construction and Building Materials.* Vol 135. pp 440- 446.
10. Lin, Y., Karadelis, J. N. and Xu, Y. (2013). "A new mix design method for steel fiber-reinforced, roller compacted, polymer modified bonded concrete overlays." Journal of Construction and Building Materials. Vol. 48. Pp 333-341.
11. Mansour Fakhri and Farshad Saberi. K. (2016). "The effects of waste rubber particles and silica fume on the mechanical properties of roller compacted pavement." Journal of Cleaner Production. Vol 129. Pp 521-530.
12. Mohammad Dareyni, Abolfadi Mohammadzadeh Moghaddam and Aref Delarami (2018). "Effect of cationic asphalt emulsion as an admixture on transport properties of roller-compacted concrete." Journal of Construction and Building Materials. Vol 163. Pp 724-733.
13. Mostafa AliAhmad, Mahmoud Miri and Mohsen Rashki (2017). "Probabilistic and experimental investigating the effect of pozzolan and Lumachelle fine aggregates on roller compacted concrete properties." Journal of Construction and Building Materials. Vol. 151. Pp 755-766.
14. Musa Adamu, Bashar S. Mohammed and Mohd Shahir Liew (2018). "Mechanical properties and performance of high-volume fly ash roller compacted concrete containing crumb rubber and nano silica." Journal of Construction and Building Materials. Vol. 171. Pp 521-538.
15. Ngekpe,B.E, Akobo IZ.S , Onwuama, K.U & Obunwo, U.E. (2020). Comparative study on compressive strength of self-compacting concrete blended with metakaolin and micro-silica. *Journal of mechanical and civil Engineering*. 6(6), pp.13-26.
16. Ngekpe, B.E., Akobo, I.Z.S & Elenga, E.D. (2021). Tensile strength of high strength concrete using micro-silica and recycled aggregate concrete. International Journal of advances in engineering and management.3 (8). pp. 373-383.
17. Ngekpe, B.E., Akobo, I.Z.S & Onyegbadue, C.M. (2019). The mechanical properties of roller-compacted concrete blended with micro-silica. SSRG international journal of civil Engineering (SSRG-IJCE). 6(6), 1-6.
18. Ouellet E. (1998). Design and study of the mechanical behaviour of roller compacted concrete. Master Thesis 1998, Universite' Laval (QC), Canada.
19. Sunbul,S. & Tortum, A. (2024). Investigation of the use of nano powder on roller compressible fibrous concrete roads. Case studies in construction and building materials. 21, e03572.