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Predictive Model of Compressive Strength of Concrete Made Withmswi Ash Blended With Micro-Silica Based Om Experimental Data

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ABSTRACT-This Study is to developa predictive model for the compressive strength of concrete made withMSWI ash blended with micro-silica to partially replace cement for medium strength concrete mix at replacement level of 5%, 10%, 15%, 20%, and 25% of cement with W/C of 0.35, 0.40, 0.45 and 0.50 respectively. Four mix ratios of G25 (1:1.67:2.57:0.5), G30 (1:1.9:2.1:0.45), G35 (1:1.47:2.26:0.40) and G40 (1:1.37:2.10:0.35) were used to investigate the compressive strength results for 7 days, 21days and 28 days were obtained for optimum strength and model was validated based on Durbin Watson auto correlation.

Key words: Compressive Strength, Municipal Solid Waste Incinerator Ash (MSWI Ash), Micro-Silica and predictive model

I. INTRODUCTION

In recent time challenges associated with environmental problems including wastes disposal and management had attracted it collectionfor other purpose.Municipal solid waste (MSW) which constitutes a reasonable amount of waste generated to ensure wellness and to improve the economy of the Nation by converting waste to wealth if manage or used for other purposes. This research work is to combine municipal solid waste incinerator (MSWI) ash blended with micro-silica to produce concrete that can be used to build infrastructural elements made with reinforced concrete and to develop a predictive model of compressive strength of concrete made withMSWI ash and micro-silica based on experimental data. A little amount of micro-silica can be significant in a concrete mix, a good example being in the range of 5 to 9.8% by weight of the cement. (Akobo el tal, 2020). Therefore, with high rising threat of municipal solid waste effect posed on public health and its negative impact on the entire environment had motivated this research to combine micro-silica and municipal solid waste incinerator (MSWI) ash as partial replacement for cement for concrete grades of G25 to G40 using percentage replacement level of 0, 5, 10, 15, 20, and 25 respectively. And to ease the rigor of some laboratory experiment, predictive model was developed for computation of compressive strength of concrete made with municipal solid waste incinerator (MSWI) ash and micro-silica. This research study is to control or solve the negative impact associated with MSW in our environment. In this country Nigeria, waste recycling programme and good campaign management and disposal method of municipal solid waste (MSW) are ongoing but with little practical implementation, the popular method generally observed here in Nigeria is that of uncontrolled combustion of MSW but there are still adverse effect on public health and the environment. Therefore, a viable solution to the disposal problem would be the use of municipal solid waste incinerator ash (MSWI ash) with combination of micro-silica for Civil Engineering applications such as raw materials in producing concrete, concrete blocks, pavement blocks, kerb's stone and for other usage.

Aim and objectives of the study

The aim of this study is to determine the variation in compressive strengths of concrete using MSWI Ash and micro-silica as a partial replacement of cement for medium concrete grades (G25 to G40)

i. Determine the characteristic compressive strength of medium strength concrete made

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with MSWI ash and micro-silica as partial replacement for cement.

ii. To develop a predictive model which used compute compressive strengths of concrete made with MSWI ash and micro-silica as partial replacement for cement.

II. LITERATURE REVIEW

Incinerator ash is one of the major by-products of the mass burn facility. Studies have confirmed the feasibility of using municipal solid waste incinerator (MSWI) ash as a replacement for fine aggregates in concrete mixes to produce useful concrete products (Gines, 2009; Van der, 2013).

Verma (2012) found that silica dust increases the strength of concrete by 25%. Silica dust is much cheaper than cement therefore it is very important from economical point of view.

Also Pandit (2014) concluded that the addition of micro-silica to concrete increases the strength more than 17% due to their pozzolanic properties and reduce the permeability of concrete.

Ghutke (2011) found that silica dust has been recognized as a pozzolanic admixture that is it effective in enhancing mechanical properties to a great extent. An addition of silica dust to concrete improves the durability of the concrete and also protects the embedded steel from corrosion.

III. MATERIALS AND METHODS

The materials used for this research work are MSWI ash, Micro-silica, cement, Fine aggregate (sharp river sand), coarse aggregate (chippings) and water

i. **Municipal solid waste incinerator ash (MSWI ASH);**

MSWI ash was obtained from incineration of municipal solid waste sourced from central waste dump of Aluu, Ikwerre LGA in Port Harcourt and incinerated in the Kiln of Rivers State University (RSU) Civil Engineering Laboratory and used in this work.

ii. **Micro-silica;**

Micro-silica also known as Silica fume, was bought from MrOgbuwaUche ORIENTAL TREXIM PVT Ltd a dealer of the material in Lagos.

iii. **Cement;** Portland limestoneCement (Plc) grade 42.5N produced by DangotePlc bought from the Mile 3, Building material market Diobu Port Harcourt was used for this research work

iv. **Coarse aggregate**; Coarse aggregate (chippings) were obtained from a quarry at Akamkpa in Cross-River State but sourced at Mile 3, Building materials market Diobu Port Harcourt.

v. **Fine aggregate**; Sharp River sand were obtained from Imo River at Oyegbo L.G A but sourced at mile 3, market Diobu Port Harcourt.

vi. **Water** Potable drinkable water sourced in RSU water main obtained in the Civil Engineering Laboratory was used for this research work

3.2 Statistical Analysis (Non-Linear Regression).

Regression analysis was carried out to investigate the functional relationship between concrete constituent materials (Cement, MSWI Ash, Micro-silica, sand, gravel, water/Cement ratio) for compressive and flexural strengths. Therefore, experimental data on compressive and flexural strengths at various water cement ratios and different replacement levels of cement with MSWI Ash was used as the output variable in the regression analysis while the concrete constituents were treated as the input variables. For detail see section 4.2.3 and section 4.2.4 of this work.

3.3 Multiple Linear Regression Analysis

Multiple linear regression analysis is commonly used as statistical tool for measuring a relationship between multiple independent variables and dependent variables. (Oyeleke, 2010). The method adopted in this work is partial least square using Statistical product and service solution (SPSS) statistical computation software. Hence, exponential power regression model in Equations (3.1) were used for the fitting of input variables in Table 4.3 for estimation of the compressive strength of concrete. First, multivariable linear regression model was obtained for the general expression for multiple linear regression analysis models and presented as Equation 3.1

$$Y = \gamma_0 + \gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 + \cdots + \gamma_n X_n + \varepsilon \quad (3.1)$$

For non-linear dependencies, we transformed Equation (3.12) by taking the logarithm of both sides of the Equation 3.12 to none linear parameter of Equation (3.13) was formed for exponential power regression model of Equation (3.14)

$$\ln Y = \ln(\gamma_0 \times \gamma_1 X_1 \times \gamma_2 X_2 \times \gamma_3 X_3 \times \ldots \times \gamma_n X_n) \quad (3.2)$$

Where;

Y = Dependent Variable

γ_0= Constant term of model equation

$\gamma_1 \gamma_2 \gamma_n$ Coefficients of input parameters or independent variables

X_1, X_2.... X_n= Input parameters or dependent variables

ξ = random error

However, in most representation of models, the error is neglected, which makes the equation to appear in the form.

$$CS\ (Y) = e^{-\gamma} \times \frac{X_1^{\gamma} \times X_2^{\gamma} \times X_4^{\gamma} \times X_5^{\gamma}}{X_3^{\gamma} \times X_6^{\gamma}} \qquad (3.3)$$

This is the Exponential power Regression Model used for the regression analysis.

3.4 Model Validation

To determine the basic fact of this exponential power regression model in Equation (2.3), some of the significant values are included as follows: coefficient of regression determinant (r^2), coefficient of correlation (r), standard error, model error (ξ=residual), the significance level, the T-test, the F-test and the residual. According to Oyeleke (2010) only the value of determinant coefficient cannot guarantee the validity of a model. Therefore, further validation of results via P-value, F-test and Durbin-Watson statistic, need to be carried out or employed.

$$R^2 = 1 - \frac{\text{Sum of squares of residuals}}{\text{Sum of square of predicted values}} \qquad (3.4)$$

The maximum determinant coefficient is expected to be 1 which indicates a perfect fit.

The coefficients of the regression equation were computed considering 95% confidence level, this implies that the allowable error level is limited to 5%. Input variable with P-value less than 0.05 can only be considered to be significant. In this study, the multi linear regression analyses were carried out using the SPSS computational software.

For all regressions outputs seeAkobo el tal, (2020) Appendices B and relevant statistical results presented and discussed in Section (4.1 and 4.2) of this work.

3.4 Compressive Strength Test (ASTM C 293:1987)

The compressive strength of concrete were obtained after the cubes (150mm x 150mm x 150mm) had achieved the required age in accordance with BS EN12390-3-2016 for test procedure, the load was applied steadily till failure and highest load reached was recorded.

The compressive strength is calculated from the equation 3.5.

$$f_c = \frac{\text{faiure load}}{\text{cross sectional area}} = \frac{P}{A} \qquad (3.5)$$

Where: f_c = compressive strength

P = failure load P

A = cross sectional area of cube

IV. RESULTS AND DISCUSSION

This chapter presents the analysis and discussion of the results obtained from experimental tests carried analyzed with the help of graphs, tables and compared with the predictive model data.

4.1 Regression Analysis of Compressive Strength of Concrete made with MSWI Ash + Micro-silica as Partial Replacement at 28 days

The compressive strengths result obtained from the experimental data carried out on the concrete mix grade of G25 to G40 were regressed against constituent materials using a multi variable linear regression analysis of Table 4.1

Table 4.1: Development of the Mix Design Multi-Linear Regression Model

CONCRETE MIX DESIGN FOR GRADE 25, 30, 35 AND 40.

% replaced	Concrete Grades	WC	Free water	Cement	Micro-silica	MSWI Ash	Fine Aggr	Coarse Aggr	28 days comp. Strength (N/mm^2)
0	Grade 25	0.5	208.25	416.5	0	0	696.46	1068.43	40.14
5	1:1.67:2.57			395.68	10.4125	10.4125			46.97
10				374.85	20.825	20.825			47.17
15				354.025	31.238	31.238			41.64
20				333.2	41.65	41.65			38.81
25				312.375	52.063	52.063			35.85
0	Grade 30	0.45	199.64	443.64	0	0	696.46	1068.44	40.11

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5	1:1.9:2.1			421.458	22.182	11.091			42.07
10				399.276	44.364	22.182			45.48
15				377.094	66.546	33.273			41.48
20				354.912	88.728	44.364			38.74
25				332.73	110.91	55.455			38.97
0	Grade 35	0.4	189.82	474.55	0	0	697.03	1070.33	47.76
5	1:1.47:2.26			450.823	11.864	11.864			48.76
10				427.095	23.728	23.728			50.30
15				403.368	35.592	35.592			43.44
20				379.64	47.455	47.455			41.33
25				355.913	59.319	59.319			35.41
0	Grade 40	0.35	178.54	510.1	0	0	704.36	1068.42	53.77
5	1:1.37:2.10			484.595	12.753	12.753			56.36
10				459.09	25.505	25.505			60.52
15				433.585	38.258	38.258			50.74
20				408.08	51.01	51.01			48.66
25				382.575	63.763	63.763			44.44

4.2Predictive Model Application and Model Validation

In this section, the results of the non-linear regression analysis carried out using SPSS statistical computational software were discussed. Some key statistical information is presented in the discussion. However, detailed results of the analysis are presented in the Appendices A attached to this work. A multivariate non-linear regression analysis was employed using the Partial Least Square method of regression. Exponential power models are obtained for the estimation of compressive strengths of micro-silica and MSWI ash – blended concrete prepared at various water cement ratios and partial replacement of cement. Table 4.2 presents the correlation coefficients of the variables with compressive strength.

Table 4.2: Regression Coefficients for Compressive Strength Model

Variable	Unstandardized Coefficients	Standardized Coefficients	T	Sig	Pearson Correlation Coefficients
(Constant)	-32.411		-0.563	0.581	
CEMENT CONTENT	2.308	1.997	3.427	0.003	0.787
WATER CONTENT	0.244	0.122	0.100	0.921	-0.616

FINE AGGREGATE	-4.441	-0.372	-0.117	0.908	-0.340
COARSE AGGREGATE	9.420	0.818	0.197	0.846	-0.423
MICRO SILICA CONTENT	0.778	4.088	1.639	0.120	-0.387
MSWI ASH	-0.554	-2.902	-1.151	0.266	-0.391

From Table 4.2 the exponential predictive model is given in Equation (4.1) as shown

$$CS = e^{-32.411} \times \frac{X_1^{2.308} \times X_2^{0.244} \times X_4^{9.420} \times X_5^{0.778}}{X_3^{4.441} \times X_6^{0.554}} \qquad (4.1)$$

Where CS = Predicted compressive strength, X_1= Cement content, X_2=Water content, X_3=Fine aggregate, X_4 = Coarse Aggregate, X_5=Micro-silica content and X_6=MSWI ash content.

The T-statistics of the variables and the constant term and their significant values are presented in the Table 4.2 as well as the Pearson correlation coefficients of the independent variables. Table 4.3 shows the regression summary of the predicted model in Equation 4.1

Table 4.3: Regression Summary for Compressive Strength Model

R	R-Square	R-Square Change	Standard Error of Estimate	F	Sig	Durbin-Watson
0.911	0.831	0.771	0.066279	13.902	0.000	1.838

The coefficient of determination, R^2, 0.831 indicates 83.1% contribution of the estimation of the model from the independent variables. An estimated error of 0.066279 shows a significantly reduced error in estimation, indicating a more accurate estimation of compressive strength. The model is statistically significant from the significant value of F-statistics which is less than 0.05 for an estimation carried out under 95% confidence interval. The Durbin-Watson shows a positive autocorrelation of errors.

4.3 Comparing Experimental Compressive Strength Data with Predictive Model Data

Applying Equation 4.1 to the variable contents in the mix proportion yields values of compressive strength (predicted compressive strength) shown in the Table 4.4 presents the predicted strength, experimental compressive strength obtained and the difference which is called compressive residual

Table 4.4: Predicted Compressive Strength Vs. Experimental Compressive Strength.

Predicted Compressive Strength [MPa]	Experimental Compressive Strength [MPa]	Compressive Residual [MPa]
42.22	40.14	2.0757
44.08970274	46.97	-2.8803
43.50547468	47.17	-3.66453
43.1666533	41.64	1.526653
38.08071607	38.81	-0.72928
35.55162505	35.85	-0.29837
41.12	40.11	1.01
40.88738135	42.07	-1.18262
44.58818635	45.48	-0.89181

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41.79643617	41.48	0.316436
39.31782812	38.74	0.577828
35.191088	38.97	-3.77891
45.76	47.75	-1.99
46.98499991	48.76	-2.775
47.5010314	50.3	-2.79897
44.27989307	43.33	0.949893
41.9738853	41.33	0.643885
38.07407144	35.41	2.664071
52.77	54.00	-1.23
53.5086262	56.36	-2.85137
56.37379949	60.52	-4.1462
53.12422552	50.74	2.384226
50.07307441	48.66	1.413074
45.59132489	44.44	1.151325

The residual of predicted and experimental compressive strength as shown in Table 4.4 show little difference indicating slight variation of predicted compressive strengths from experimental compressive strength. A line plot of the predicted and experimental compressive strengths is shown in the Figure 4.1(a to d).

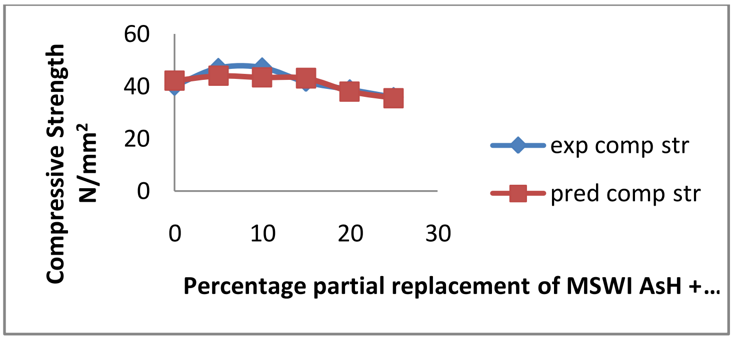

Figure 4.1a: Graph of Predicted Compressive vs Experimental Compressive Strength

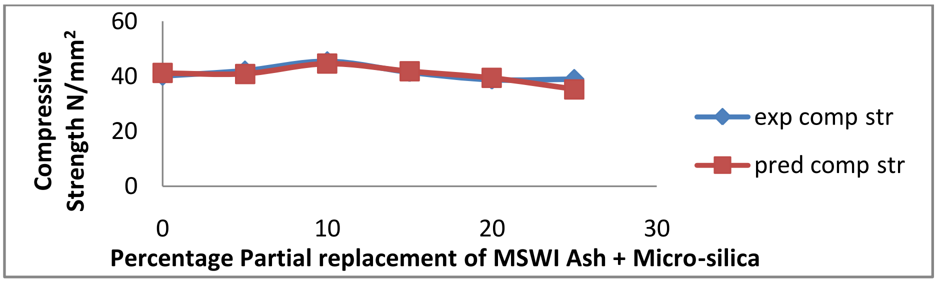

Figure 4.1b: Graph of Predicted Compressive vs Experimental Compressive Strength

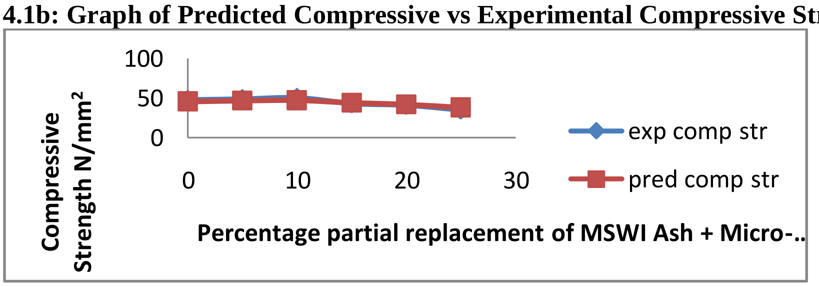

Figure 4.1c: Graph of Predicted Compressive vs Experimental Compressive Strength

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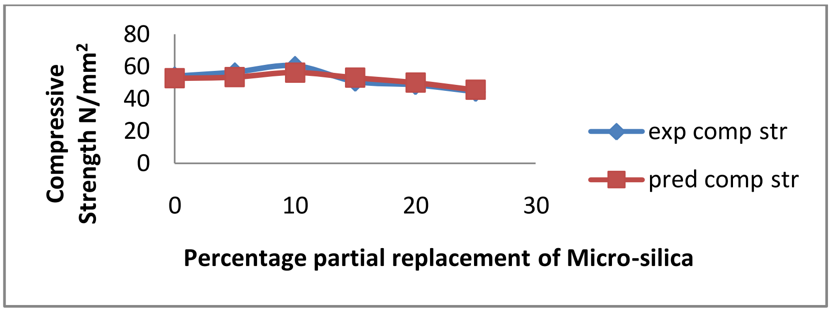

Figure 4.1d Graph of Predicted Compressive vs Experimental Compressive Strength

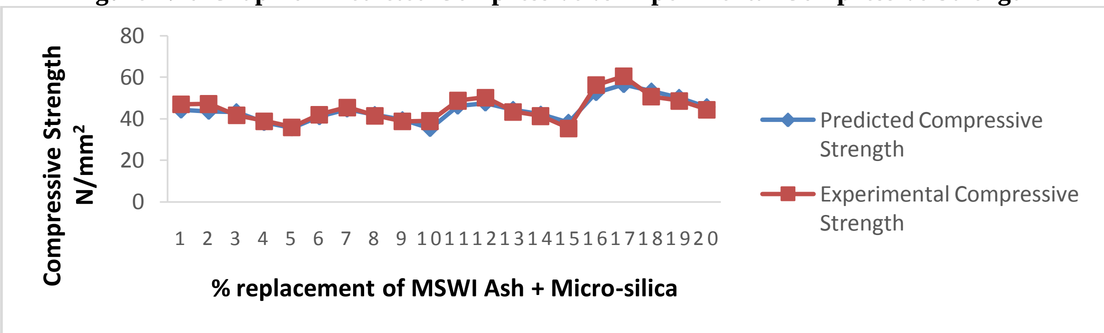

Figure 4.2: Summary Graphs of Predicted Compressive vs Experimental Compressive Strength

Figure 4.2 shows graphically the variation between the predicted compressive strength and the experimental compressive strength at each mix proportion. The closeness of the points shows the high degree of prediction of compressive strength by the independent variables, from Figure 4.1(a - d) and Table 4.4shows that the Compressive Strength experimental data carried out using universal compression test machine under constant stress until failure shows similar pattern with thepredictive model compressive Strengths data begins to increases with in partial replacement of MSWI Ash and Micro-silica content from 5 to 10%, then start decreases gradually in strength due to increase of MSWI Ash blended with Micro-silica. Based on the result of this work 5 and 10% partial replacement of (MSWI Ash and Micro-silica) would be encourage for medium Strength in accordance to BS 8110; 1997.

V. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Compressive and Flexural Strength of Concrete mix with MSWI Ash and Micro-silica as partial replacement of cement had been examined in this research study. From the results analysis and discussion of the results in this work the following conclusions are drawn

i. The compressive strength test results show that, the compressive strength improves when MSWI Ash plus Micro silica are replaced in less or equal to 10% of cement in comparison to the control mixes (0% cement partial replacement) and the compressive strength of 42.07N/mm^2, 47.17N/mm^2, 50.30N/mm^2 and 60.52N/mm^{2}and predictive model data of 44.0897N/mm^2, 44.09N/mm^2, 44.588N/mm^2, 47.501N/mm^2 and 56.373N/mm^{2}were respectively reported for mix ratio G25 (1:1.67:2.57:0.5), G30 (1:1.9:2.1:0.45), G35 (1:1.47:2.26:0.40) and G40 (1:1.37:2.10:0.35) respectively at 28days maturity of medium strength.

ii. The predictive model developed can be used to determine compressive strength of concrete made with MSWI Ash + microsilica due to relative their similarity

5.2 Recommendations

From the findings of this research work 5 to 10% of partial replacement of MSWI Ash combined with Micro-silica are recommended to be utilized for concrete works of grade G25, to G40 of the concrete used in this study. This is premised on the compressive strengths of 44.0897 N/mm^2, 44.09 N/mm^2, 44.588 N/mm^2, 47.501 N/mm^2 and 56.373 N/mm^{2}at 28days respectively. Further studies are recommended to be carried out in this research area to find out durability and splitting Tensile strength of MSWI ash and Micro-silica concrete.

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