Sustainable Structure and Materials, *Vol. 3, No .2, (2021) 025-35*
DOI: https://doi.org/10.26392/SSM.2021.04.01.025

Regression Models for the Prediction of Strength Properties of Waste Tyre Ash (WTA) - Mortar

Aliyu Muhammad Magana,*, Musa Adamu*, G. H. Yunusa

[1]*Department of Civil Engineering, Bayero University Kano, P.M.B 3011, Kano State, Nigeria*
*Corresponding author/ E-mail: maganaaliyu@gmail.com. Madamu.civ@buk.edu.ng.

ABSTRACT. *Sustainable development is an emerging political and social issue of global significance, Environmental scientists are generally of the view that Portland cement is not particularly environmentally friendly. Thus, the challenges of producing and using concrete, is aggravated by the high need and consumption of cement which is causing the using concrete, is aggravated by the high need and consumption of cement which is causing the environmental threats as outlined by the environmentalists. The background of this study emanates from this development and forms the basis for conducting the research. Waste Tyre Ash (WTA) is the ash residue that is obtained after slices of waste or scrap tyres are burnt at a temperature of 5000C for a period of 5 hrs. Therefore, the aim of this study is to determine the effect of using WTA as a partial replacement of cement in WTA-Mortar and to develop models for the prediction of strength properties. Cement was partially replaced with WTA at 0%, 5%, 10%, 15%, 20%, 25% and 30% by weight. The findings showed that WTA decelerates setting time of cement and strength development in mortar. Compressive strength and flexural strength of mortar increases with increase in WTA up to 20% and 15% replacement of cement respectively. Strength predictive models for WTA-Mortar have good correlations with experimental data with average of R2 of 0.91, RMSE of 0.57 and COE of 0.66. Statistical models drawn from the results of this research will also provide a means to predict WTA mortar strengths and behavior.*

Keywords: Waste Tyre Ash, Mortar, Compressive Strength, Flexural Strength, Statistical Models

1. INTRODUCTION

Sustainable development is an emerging political and social issue of global significance. The increasing need for the concrete industry to comply with the fundamental goals of sustainable development and to reduce its impact on the environment, has led scientists and researchers to improve upon the properties of concrete products and at the same time to develop materials and technologies that can recycle the various wastes for their effective and economical use in cement-based products and thus ultimately making these materials as commodity products. Over the years, many waste materials like fly ash, ashes produced from various agricultural wastes such as palm oil waste, rice husk ash, wheat straw ash, have been tried as pozzolana or alternate cementitious materials in cement-based products (1, 2).

Environmental scientists are generally of the view that Portland cement is not particularly environmentally friendly (3-5). Thus, the challenges of producing and using concrete, is aggravated by the high need and consumption of cement which is causing the environmental threats as outlined by the environmentalists (4). This situation can thus be stated in the following simple terms: use as much concrete, but with as little Portland cement as possible, and this means to replace as much Portland cement as possible by supplementary cementitious materials, especially those that are by-products or wastes of industrial processes, and to use recycled materials in place of natural resources. Also, other researchers have opined that the best way for the construction industry to become sustainable is by using wastes from other industries as building materials (6-8). One such waste material considered in this study is the waste (scrap) tyre ash (WTA). The background of this study emanates from this development and forms the basis for conducting the research

The ever-increasing volume of rubber waste in landfills from the disposal of used tyre has grown into a serious environmental problem (9). Also, that scrap tyre is composed of ingredients that are non – degradable in nature at ambient conditions and that they usually produce environmental effects. Scrap Tyres (ST) or used vehicle tyres are therefore products whose generation and disposal have continued to raise a lot of concern to environmentalists. It is reported that more than 4.13 million tons of recycled rubber (or used tyre) is generated annually in the United States, 320,000 tons in Canada and 1,000,000 tons in Japan (10).

Although no known statistical data on used tyre generation is found for Nigeria (11), some researchers have all the same attempted to give this statistics. They also all agree that used tyres constitute a disposal challenge. Aisien, Amenaghawon (12) have opined that increased vehicle ownership and traffic volume has led to an increase in the quantity of waste tyres in Nigeria. That as the country's population and economy grow, so does the amount and type of scrap tyres generate. Accordingly, it is estimated that with an annual generation rate of 15% between 700,000 and 850,000 scrap tyres are added to the scrap tyre waste stream in Nigeria each year (13). Oba, Onungwe (14) have also reported that every year an estimated eight hundred and fifty thousand (850, 000) scrap tyres are carelessly discarded in Nigeria.

Ganjian, Khorami (9) have suggested that one of the methods for utilization of these materials is their use in concrete and other building products. And this is of interest to this research hence it borders on the expected savings that may be achieved in the constituent materials used to make concrete, such as cement, by substituting it with tyre (ash).

Strength is a primary criterion in concrete application. The effect of any supplementary cementitious material on the strength of concrete depends on the pozzolana content and pozzolanic activity of the material during hydration.

Supplementary cementitious materials (SCM) as mineral admixtures have been identified in literature as being essential towards achieving low-cost construction materials with the main benefits of saving natural resources and energy as well as protecting the environment (15). Generally, mortar and concrete are known to gain strength over a long period of time after casting.

Waste Tyre Ash (WTA) is the ash residue that is obtained after slices of waste or scrap tyres are burnt at a temperature of 500ºC for a period of 5 hrs according to Aliyu (1). WTA in this study is thus used as a pozzalana (or supplementary cementitious material (SCM) for the partial replacement of cement in mortar. According to (16) the burning of tyre usually produces a dark heavy smoke, burning at high temperature furnaces with proper chimney filtering achieves a complete burning without similar smoke. Perhaps this explains the burning of tyre to get tyre-rubber ash (TRA) mortar where tyre rubber chips were obtained and burned at a controlled temperature of 8500C for 72 hours to obtain the residue (ash) in the work of Al-Akhras and Smadi (17) as reported by Rafat (18).

This work studied the properties of tyre-rubber ash (TRA) mortar, using the TRA as a partial replacement of sand in five percentages ranging from 0 to 10% with an increment of 2.5% by weight of sand, it was concluded that as the TRA content increased, workability of the fresh mortar decreased. This behavior was adduced to the increase in the cementitious materials in the mortar mix, particularly due to the large surface area of the TRA. It was also concluded that both initial and final setting times increased with the increase in TRA content, acting here as a retarder, thus. Initial setting time was found to have increase from 145 minutes for the control paste mix to 220 minutes at 10% TRA paste mix. The final setting time increase from 270 minutes for control mix to 390 minutes for 10% TRA paste mix. These findings may be seen to agree with the views of Illston and Domone (4) which demonstrate that admixtures in concrete and mortar are better explained by their mode of action rather than their constituent chemical composition.

Another very interesting finding of this study by Al-Akhras and Smadi (17) in Rafat (18) was that TRA specimens showed higher compressive strengths at various curing period up to 90 days compared with those of the control specimens. Also, that the tensile and flexural strengths of the TRA mortar specimens were higher than those of the control specimens. Al-Akhras and Smadi (19) reported the effect of TRA replacement on the flexural strength of mortar at 7 and 28 days, respectively. Similarly, the flexural strength increased with increasing TRA content from 2.26 MPA for control mortar to 2.91 MPA for mortar containing 10% TRA at 7 days and from 3.48MPA for control mortar to 5 MPA for mortar containing 10% TRA at 28 days. Percentage increase of 12%, 27%, 32% and 43% were given at TRA content of 2.5%, 5%, 7.5% and 10%, respectively at 28 days compared to control mortar. Al-Akhras and Smadi (19) also studied the durability aspects of mortar to accelerated cycles of freezing and thawing damage using mortar containing 5% and 10% TRA replacement. The freezing and thawing damage was assessed using the relative dynamic modulus of elasticity and durability factor, respectively. To accelerate these tests, mortar specimens were subjected to freezing and thawing cycling after 7 days of moist curing. Their results indicated that mortar specimens containing 5% and 10% TRA showed higher durability to freezing and thawing damage. Their finding on the durability of mortar to chloride ion penetration was also encouraging using mortar containing 5% and 10% TRA replacement. In this study, the control mortar showed the highest value of electrical charge of 3200 coulombs at 28 days (indicating low resistance to chloride-ion penetration) when compared to the mortar containing 5% and 10% TRA which were 870 and 420 coulombs, respectively. This indicated higher resistance to chloride-ion penetration than the control mortar. After 10 days of moist curing, the electrical change passed through all three types of mortar was reduced for the control mortar it was reduced to 1875 coulombs. This was significantly higher than that of the mortar containing 5% TRA (at 520 coulombs) and mortar containing 10% TRA (at 350 coulombs).

According to ASTM C 1202 (20), when the electrical charge passed through mortar is below 1000 coulombs, the mortar has high resistance to chloride-ion penetration. This according to Al-Akhras and Smadi (19) may be attributed to the effect of TRA filler packing, which reduces the air content of mortar and consequently increases the resistance of mortar to chloride-ion penetration. Rangaraju and Gadkar (21) reported reductions in compressive strength and flexural strength when either the coarse or fine aggregates were replaced by crumb rubber (waste tyre). Also observed was increase in air content and reduction of workability of rubberized concrete. Also, that when tyre rubber ash (TRA) was used to replace the fine aggregate in mortar mixes, workability decreased with increasing TRA content. Initial and final setting time of TRA paste mixes increased with increase TRA content. That the compressive strength, tensile strength, and flexural strength also increased with increasing TRA content. The research also indicated that the reduction in compressive strength was more due to replacement with coarse aggregates than replacement with fine aggregate. Thus, the ability to reliably predict the strength of concrete and mortar especially one produced by the use of a supplementary cementitious material becomes important as it will provide a chance to adjust beforehand the mix proportion used to avoid a situation where concrete does not reach the required design strength or for more economic use of raw materials and fewer construction failures, hence reducing construction cost.

Researchers have worked on areas of predicting mortar strength for quite some time as in the works of Ogork, Uche (22), Ogork, Uche (23), Ogork (2) and FM Zain and M Abd (24) have both worked on and reported that statistical models which are mathematically rigorous can be used to perform prediction faster and provide insight into the key factors influencing strength of concrete.

Therefore, the aim of this study is to determine the effect of using WTA as a partial replacement of cement in WTA-Mortar and to develop models for the prediction of strength properties. Strength types interested in this study include the flexural and compressive strengths. Of WTA-Mortar, respectively. Statistical models drawn from the results of this research will also provide a means to predict WTA mortar strengths and behavior. This will be another contribution to the on-going researches on waste or by-products for use as partial replacements of cement.

2. MATERIALS AND METHODS

2.1 Materials

Ordinary Portland cement manufactured in Nigeria as Dangote 3X, Grade 42.5N brand, having specific gravity of 3.15, fineness (% passing 90 m sieve) of 97% and loss on ignition of 1.3 was used. The oxide composition of the cement is shown in Table 1.

Sharp sand from river Challawa, Kano, Nigeria, with specific gravity of 2.80, bulk density of 1898.75 kg/m^3 with a moisture content of 2.60% and classified as zone 1 was used. Crushed granite coarse aggregate of 20 mm nominal diameter and 2.85 specific gravity, bulk density of 1500 kg/m3 and average impact value of 20.87% was used. The particle size distribution curve for the fine aggregate, coarse aggregate and Waste Tyre Ash (WTA) is shown in Fig 1.

The WTA was obtained by burning sliced pieces of waste tyres to ash through heating to a temperature of about 5000C in open burning for about five (5hrs) hours, at the local open burning site off the Eastern bye-pass ring road adjacent to Unguwa uku Ward in Tarauni Local Government Area of Kano – Nigeria. The ash was allowed to cool and sieved through 75µm sieve.

Table -1: Sample Table format

Elemental Oxide	Ordinary Portland Cement (OPC) (%)	Waste Tyre Ash (WTA) (%)
Al_2O_3	2.10	3.41
SiO_2	18.69	30.40
Cao	65.23	2.13
Fe_2O_3	3.96	6.39
K_2O	0.48	0.54
MnO	0.09	0.05
MgO	1.96	1.20
SO_3	2.33	10.71
Na_2O	2.32	4.32
P_2O_5	-	1.64
TiO_2	0.31	0.37
Cr_2O_3	0.03	0.01
BaO	0.07	-
CuO	0.03	-
ZnO_2	0.03	22.39

CL	-	0.38
LOI	1.3	14.6

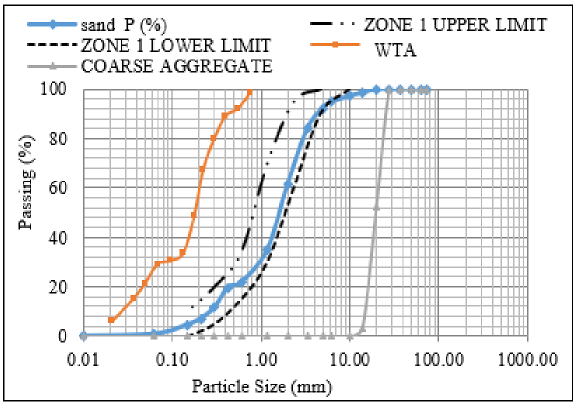

Figure -1: Particle size distribution of WTA, fine & coarse aggregates

2.2 Methods

A chemical oxide composition analysis of the cement and WTA used in this study was obtained using X – Ray fluorescence (XRF) analytical method using X – Ray spectrometer at the Multi-User Research Laboratory at Ahmadu Bello University, Zaria, Kaduna State, Nigeria. The specific gravity of the cement was determined in accordance with BS EN 197-1:2000 using the glass jar method. The specific gravity and bulk density of both the fine and coarse aggregates was determined according to BS EN 1075-5:1999; 1097-3:1998, while the moisture content was determined according to BS EN 1097-5:1999, respectively.

The fine aggregate used was sieved and analyzed in accordance with BS 812-103: 1989. The sand zone classification was based on BS 882 (1992) of rating limits for fine aggregate. The average impact value test for the aggregate was done in accordance with BS812-112:1990.

The mortar mix proportions presented in Table 2 were used to prepare 40mm X 40mm X 160mm prison specimens to determine the flexural strength of WTA- cement mortar cured in water for 3, 7, 28, 56 and 90 days, respectively. The flexural strength test was conducted in accordance with BS EN 196 – 1 :2005. A total of one Hundred and five (105) prisms were cast and three prisms tested for an average for each curing regime using the Avery – Denison Universal Testing Machine of 600 KN load capacity.

Cube samples of 40mm X 40mm X 40mm cross-sections were used for the compressive strength tests in accordance with BS EN 196-1: 2005. The Avery-Denison Universal Testing Machine of 600KN load capacity loaded at a rate of increase of 0.5kN/s. The samples were cured in water for 3, 7, 28, 56 and 90 days before testing.

Table -2: Mix Proportion of WTA – Mortar

Mix No	WTA (%)	Cement (kg/m^3)	WTA (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)
FSM-00	0	529.1	0	1587.3	264.6
FSM-01	5	502.6	26.5	1587.3	264.6
FSM-02	10	476.2	52.9	1587.3	264.6
FSM-03	15	449.7	79.4	1587.3	264.6
FSM-04	20	423.3	105.8	1587.3	264.6
FSM-05	25	396.8	132.3	1587.3	264.6
FSM-06	30	370.4	158.7	1587.3	264.6

2.3 Regression Models of Strength of Mortar

Statistical models were developed from experimental data using the `R` statistical software to predict strength of WTA-Mortar. The models were then used to analyze the sensitivities of pozzolanic activity of WTA. In doing this, two predictors were considered: (i) influence of ash content and (ii) influence of curing age on strength. These two factors were then used to model the strength properties of the pozzolanic mortar. Three modelling techniques including the Multiple Linear Regression (MLR), the Polynomial and the ANN were used to determine the best technique that would best predict the response against the given set of predictors as stated.

Of the many variants of the ANN model available, the multilayer perception network (MLP) was selected for this work because of its popularity and availability on various commercial and open-source software platforms.

The training data set was used to train the supervised back propagation algorithm. In this training two major processes are involved that is the forward and backward passes. In the forward pass, the input variables e.g WTA % content and Age of curing expressed as X1, X2, X3 etc. are received by the input neurons and passed through connecting links of various weights with which the inputs are weighted. The weighted inputs are then summed up using a linear combiner as shown in Equation 1:

$$U_k = \sum_{j=1}^{m} W_{kj} X_{jj} = 1,2,3 \qquad (1)$$

Where Uk represents Linear Combiner; K represents a neuron; X1, X3 …….., Xm are the input signals; wk1, wk2…….., wkm are the synaptic weights
This is then transmitted forward to the hidden layer neurons. The outputs of the hidden layers are estimated using its activation function as given in Equation 2.

$$f(x) = \frac{1}{1+e^{-x}} \qquad (2)$$

Where f(x) = the activation function
Subsequently these outputs estimated using Equation 3 are then passed to the output layer where the final output of the network will then be estimated using the output layer activation function given in Equation 3.

$$Y_k = f(U_k + b_k) \qquad (3)$$

Where, Yk = Output signal of the network, K; bk = the bias

The essence of the activation function is to limit the amplitudes of the outputs to certain critical values to reduce the computational loads of the network and to maintain the output values within an acceptable margin of the target variables say the strength in this study. The network outputs are then compared with the target output (observed data) and their difference is considered as the network error which is then propagated backward through the network to update various weights within the network. This iteration continues until the minimum error is obtained (25).

In this study, the ANN training was done using the Caret packages applying the R software for statistical analysis (Development Core Team, `R` l 2013). Also, several ANN models were trained with three weight decay factors (0.001,0.01 and 0.1) while incrementing the number of hidden neurons up to a predetermined number of hidden neurons (50 in this study). The function then selects the ANN model with the minimum mean squared error (MSE) as the final model.

The data so obtained from these experiments were used in the `R` software for the modeling. The software generates model equations and graphs that would best fit the experiment data. The prediction performance for each of the modeling techniques stated above was evaluated based on the R^2, RMSE and COE values, accordingly. An Anova Table was subsequently used to compare and identify the best of the three models for each of the strength properties.

The models generated are;

a. Regression models for WTA- mortar including;

i. Multiple Linear Regression models (MLR) for Flexural and Compressive Strengths of WTA – mortar, respectively.

ii. Polynomial Regression Models for Flexural and Compressive Strengths of WTA- mortar, respectively.

Artificial Neural Network (ANN) models for Flexural and Compressive Strengths of WTA –mortar, respectively.

3. RESULTS AND DISCUSSIONS

3.1 Flexural Strength of WTA-Mortar

The results for the flexural strength of Waste Tyre Ash (WTA) – mortar is presented in Table 3 and Fig 2. It can be seen that the flexural strength of the mortar with increase in the WTA content from 5% - 20% and decreases thereafter with increase of the WTA content.

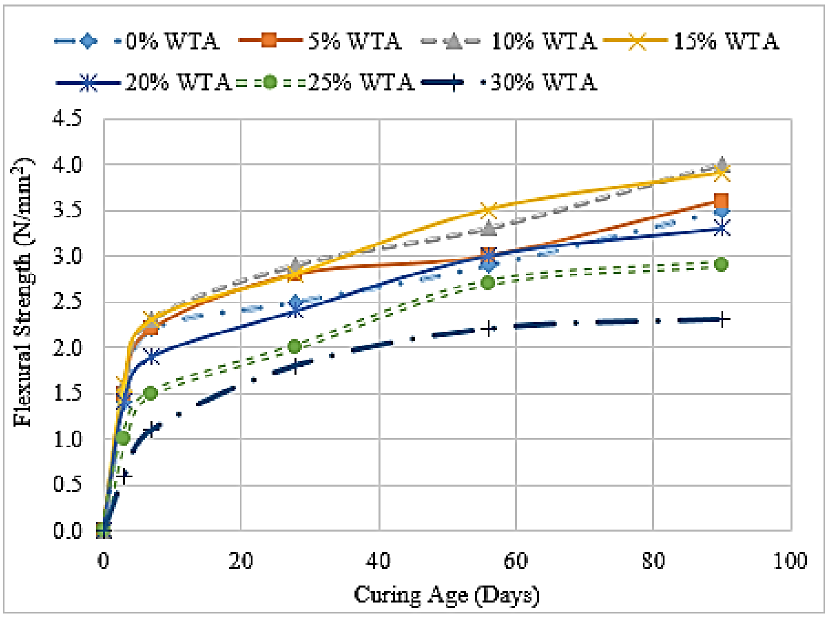

Figure -2: Flexural Strength Development of WTA – Mortar

Table -3: Flexural Strength of WTA – Mortar

Mix No	WTA (%)	Mean Flexural Strength (N/mm2)				
		3 Days	7 Days	28 Days	56 Days	90 Days
FSM-00	0	1.0	1.7	2.2	2.9	3.0
FSM-01	5	1.2	1.8	2.3	2.9	3.2
FSM-02	10	1.5	2.1	2.5	3.2	3.6
FSM-03	15	1.6	2.3	2.8	3.5	3.9
FSM-04	20	1.4	1.9	2.4	3.0	3.3
FSM-05	25	1.0	1.5	2.0	2.7	2.9
FSM-06	30	0.6	1.1	1.8	2.2	2.3

To generate the model for this, the ‘R’ statistical software was used to generate the parameters for the model for predicting strength and is presented in Equation 4. Multiple linear regression (MLR) model was considered, and the data are categorized into two splits of training (80%) and test (20%) pattern. The resulting statistical result is shown in Table 4 for the model.

$$f_{fm} = 1.73 - 0.02\ WTA + 0.02\ AGE \ldots\ldots\ldots\ldots\ldots 4$$

Where, f_{fm} = flexural strength of WTA – Mortar, WTA = WTA Content at 0, 5, 10, 15, 20, 25 and 30% replacement of cement, AGE = Curing Age of 3, 7, 28, 56 and 90 days, respectively.

Table -4: Statistical Analysis of Flexural Strength of WTA – Mortar Model

Predictors	Estimate	Std. Error	t-Value	Pr(> 1 t 1)
Coefficients: (Intercept)	1.733	0.116	14.986	< 2e-16***
WTA	-0.0168	0.0057	-2.955	0.0041**
AGE	0.0219	0.0018	12.370	< 2e-16***
Significant Codes	0 ‘***’	0.001 ‘**’	0.01 ‘*’	0.05, ‘0.1’ 1

The model has a Residual standard error: 0.5264 on 81 degrees of freedom, Multiple R – squared: 0.6623, Adjusted R-squared: 0.654, F – statistic: 79.43 on 2 and 81 DF, P-value: < 2.2e – 16. The predicted versus actual plot for the flexural strength model is shown in Fig 3, and it can be seen the model has a good degree of correlation graphically.

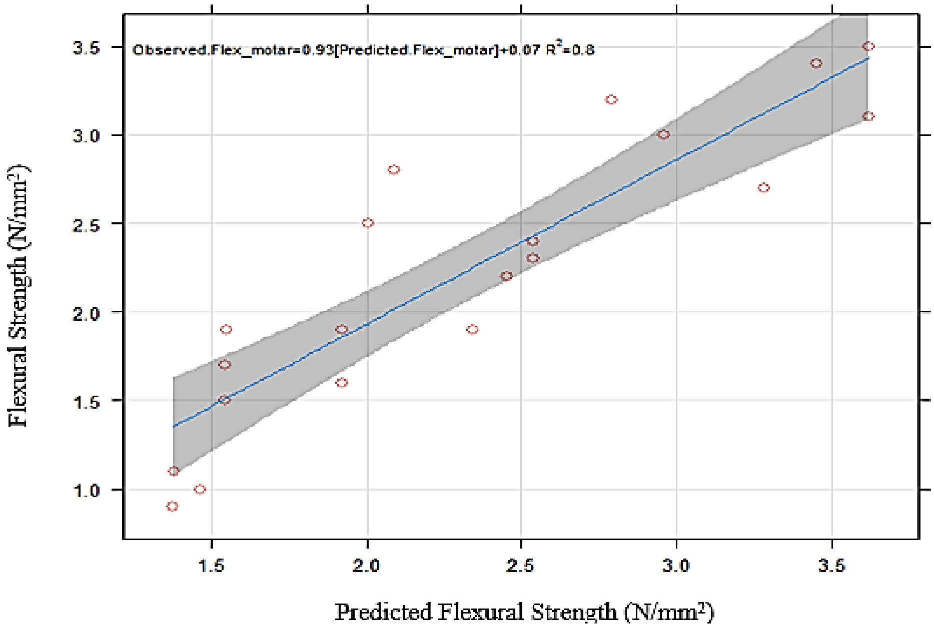

Figure 3: Predicted Versus Observed Values for Flexural Strength of WTA – Mortar

In this regression modeling situation, the predictors are two being the % WTA content and the Age of curing of the WTA – Mortar in days. The response is the flexural strength. The shaded region shows the points that lie within the level of significance for a 95% confidence level. The MLR equation generated and shown in Equation 4 seem to be in contrast to what was observed as stated above therefore it is an indication that the relationship between WTA and Flexural strength is not linear or the correlation between the predictor variables might affect the interpretation of the results. Hence the need for considering nonlinear models. Consequently the 2nd and higher degree polynomial model and the Artificial Neural Network (ANN) were considered.

For the polynomial model the regression equation generated is given in Equation 5 as:

$$f_{fm} = 2.264 - 1.518\ WTA - 2.855\ WTA^2 + 6.522\ AGE - 1.937\ AGE^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Where, f_{fm} = Flexural Strength of WTA – Mortar, WTA = WTA content at 0, 5, 10, 15, 20, 25 and 30% replacement of cement, AGE = Curing Age of 3,7, 28, 56 and 90 days, respectively.

This is again seen to be in contrast to what was observed of the flexural strength data as earlier described. And apparently the polynomial model cannot therefore be used to predict the correlation between WTA and the flexural strength. The need to try another model to which, the ANN was considered. The ANN result gives R^2 as 0.90, RMSE as 0.29 and COE as 0.65. To analyze the performance of each of the models, an Anova table was used to compare the R2, RMSE and COE of each model and presented in Table 5.

Table -4: ANOVA for the Flexural strength of WTA – Mortar Model

Model	R^2	RMSE	COE
MLR	0.65	0.36	0.54
Polynomial	0.85	0.29	0.62
ANN	0.90	0.29	0.65

From statistical literature, if a proposed model gives R2> 0.8, there is a well – built correlation between predicted and measured values for the data available in the dataset (Palika, Sharma and Kumar, 2016). Also, the RMSE indicate the measure of error between the predicted and observed values. It is given usually using the same units of measurement as the observed data. The lower and closer to zero it is, the more authentic the prediction will be (Sulaiman, 2016; Palika, Sharma and Kumar, 2016; Sulaiman, Tight and Quinn, 2016).

The Coefficient of Efficiency (COE) have also been suggested for measuring model performance for some time. A perfect model has a COE = 1 and a value of 0.0 implies that the model is no more able to predict the observed values than does the observed mean (Legates and McCabe, 1994; 2012). Meaning since the model can explain no more of the variation in the observed values than can the observed mean, such as model can have no predictive advantage. Negative values of COE imply that the model is less effective than the observed mean in predicting the variation in the observations (Legates and McCabe, 1999). Also, according to Legates and McCabe (1999), COE has no lower bound. Thus, the ANN model is seen to have the best R^2, RMSE and COE values of the three and is thus considered to be the best model for prediction of WTA – mortar flexural strength.

3.2 Compressive Strength of WTA-Mortar

The results for the compressive strength of Waste Tyre Ash (WTA) – Mortar is shown in Table 5 and Fig 4, respectively. The strength of WTA - mortar is seen to increase with increase in the WTA content up to 20% and thereafter decreases with increase of the WTA –content (i.e., for 25% - 30%). Also, the strength is seen to increase with increase in the age of curing for all WTA percentage replacement.

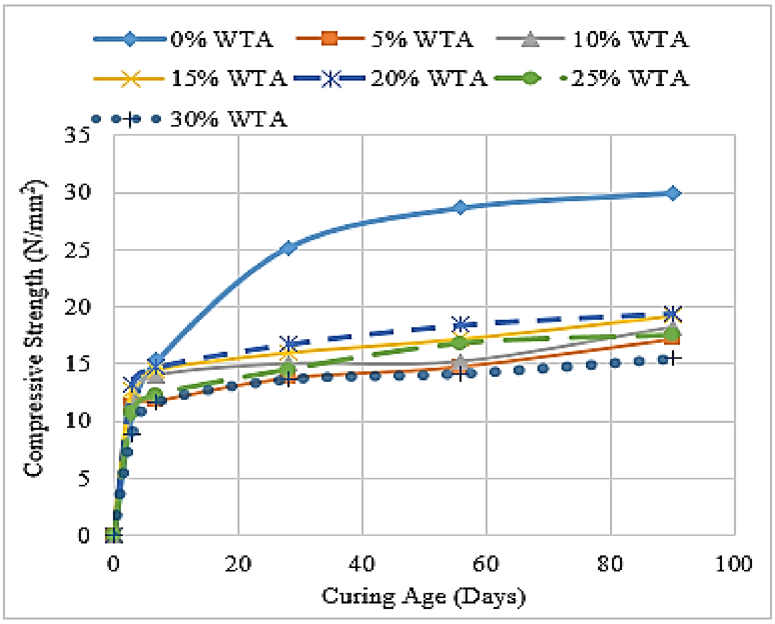

Figure 4: Compressive Strength of WTA- Mortar

Table -5: Compressive Strength of WTA – Mortar

Mix No	WTA (%)	Mean Flexural Strength (N/mm2)				
		3 Days	7 Days	28 Days	56 Days	90 Days
FSM-00	0	10.0	10.5	11.3	12.7	15.8
FSM-01	5	11.3	11.8	13.8	14.8	17.2
FSM-02	10	11.8	14.0	15.0	15.2	18.2
FSM-03	15	12.8	14.5	16.0	17.2	19.2
FSM-04	20	13.2	14.7	16.7	18.4	19.4
FSM-05	25	10.8	12.3	14.5	16.8	17.5
FSM-06	30	8.8	11.7	13.7	14.2	15.5

The MLR regression equation generated for the model is presented in Equation 6 The resulting statistical analysis is shown in Table 6 for the model.

$$Fcm = 11.21 + 0.04WTA + 0.07\ AGE \quad (6)$$

Where, f cm = The mortar compressive strength, WTA = replacement of cement at 0, 5, 10, 15, 20, 25 and 30%, respectively. AGE=Curing age of WTA – Mortar samples in days

Table -6: Statistical Analysis of Compressive Strength of WTA – Mortar Model

Predictors	Estimate	Std. Error	t-Value	Pr(> 1 t 1)
Coefficients: (Intercept)	11.209	0.420	26.668	< 2e-16***
WTA	0.040	0.0195	2.062	0.0424*
AGE	0.065	0.0062	10.632	< 2e-16***
Significant Codes	0 '***'	0.001 '**'	0.01 '*'	0.05, '0.1' 1

Residual standard error = 1.82 on 82 degrees of freedom Multiple R – squared: 0.5882, Adjusted R – squared: 0.5782 F – statistic: 58.57 on 2 and 82 DF, P – value: <2.2e – 1. The predicted versus actual plot for the compressive strength model is shown in Fig 5, it can be seen that a good correlation existed between the predicted and actual values of compressive strength, therefore the model can be said to fit graphically.

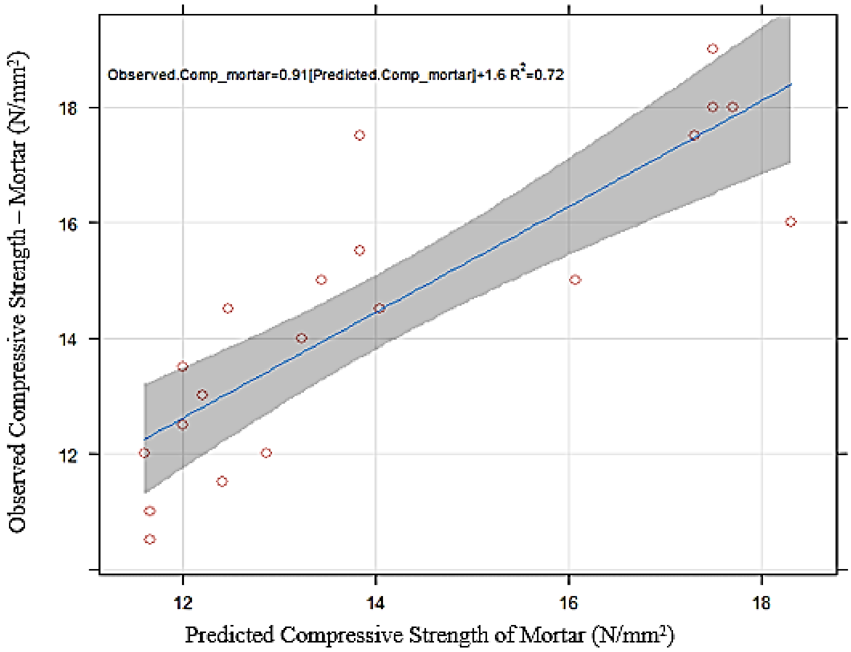

Figure 5: Predicted Versus Observed Values for Compressive Strength of WTA – mortar

In a similar way, the regression modelling situation here has two predictors being the % WTA Content in the WTA Mortar replacing cement described as WTA and the Age of curing of the WTA – Mortar in days. The response here is the compressive strength.

The MLR equation generated and shown in Equation 6 seem to be satisfactory in explaining the correlation between WTA and the compressive strength and could be used for the prediction purpose.

However, the R^2 value of 0.72 as observed in Fig 4 is not considered good enough for this model. This compared to the value of 0.80 as the minimum R^2 value as suggested by Chopra, Sharma (26) call for the need for considering other nonlinear models. The RMSE value of 1.4 as observed for this prediction might also be considered for improvement as it is considered to be the best the closer to 0 it is. Consequently, the polynomial model and the ANN models were, further considered. Using the polynomial model, the regression equation generated is given in equation 7 as:

$$f_{cm} = 14.26 + 3.84\text{ WTA} - 13.51\text{ WTA2} + 19.4\text{ AGE} - 2.45\text{ AGE2} \quad (7)$$

Where, f_{cm} = The compressive strength of WTA – mortar, WTA = WTA replacement of cement at 5, 10, 15, 20, 25 and 30%, respectively, AGE = Curing of 3, 7, 28, 56 and 90 days respectively, for WTA – Mortar samples.

Again, the regression equation stated here seem to contrast with what was observed and described above for the WTA – mortar compressive strength. It is therefore an indication that the correlation between the predictor variables might affect the interpretation of the results. Or simply the polynomial regression model may not be able to reliably explain the relationship between WTA and the compressive strength of WTA – mortar. This is despite the good R2 value of 0.87 and RMSE value of 0.86 as observed in the computer printout of the compressive strength results. The need to try another higher model like the ANN model becomes necessary. The ANN result gives R2 as 0.91, RMSE as 0.85 and COE as 0.67.

In a similar way an ANOVA Table was constructed as shown in Table 7 to compare the performances of the three models, the MLR, Polynomial and ANN, accordingly.

Table -4: ANOVA for the Compressive strength of WTA – Mortar Model

Model	R^2	RMSE	COE
MLR	0.58	1.39	0.45
Polynomial	0.87	0.86	0.67
ANN	0.91	0.85	0.67

An evaluation of Table 8 indicates that the ANN model has the best of the values of R2, RMSE, COE and thus the ANN model is considered to be the best model here for the prediction purpose of the compressive strength of WTA – Mortar.

4. CONCLUSIONS

In this study, the influence of waste tyre ash (WTA) as a pozzalana in mortar was investigated. Particularly the effect of this on the flexural and compressive strengths. The results of the experimental data obtained were further used for the regression analysis to develop models for the prediction of these strengths. Subsequently, the following conclusions are drawn.

1) The waste tyre ash, made from both open and control burning is a low reactivity pozzolan with combined SiO_2, Al_2O_3 and Fe_2O_3 of about 40 percent.
2) Waste tyre ash decelerates setting time of cement and strength development in mortar.
3) Compressive strength of mortar increases with increase in waste tyre ash up to 20% replacement of cement.
4) Optimum content of waste tyre ash replacement of cement is 20% for compressive strength and 15% for flexural strength with corresponding strength values at 28 days of 16.7 N/mm^2 and 2.8 N/mm^2 for compressive strength and flexural strength of mortar respectively.
5) Strength predictive models for WTA-Mortar have good correlations with experimental data with average of R^2 of 0.91, RMSE of 0.57 and COE of 0.66.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Staff of Concrete and Materials Laboratory, Department of Civil Engineering, Bayero University Kano for their viable support

REFERENCES

1. Aliyu MM. Properties of Waste Tyre Ash (WTA) Mortar and Concrete. . Kano, Nigeria: Bayero University 2019.
2. Ogork EN. Statistical Modelling of Properties of Groundnut Husk Ash (GHA) Mortor and Concrete and Groundnut Husk Ash (GHA)- Rice Husk Ash (RHA) Concrete. Kano, Nigeria: Baero University; 2014.
3. Aïtcin P-C, Mindess S. Sustainability of concrete: CRC Press; 2011.
4. Illston JM, Domone P. Construction materials: their nature and behaviour: CRC press; 2001.
5. Safiuddin M, Jumaat MZ, Salam M, Islam M, Hashim R. Utilization of solid wastes in construction materials. International journal of physical sciences. 2010;5(13):1952-63.
6. Tavakoli D, Heidari A, Karimian M. Properties of concretes produced with waste ceramic tile aggregate. Asian Journal of Civil Engineering. 2013;14(3):369-82.
7. Meyer C. The greening of the concrete industry. Cement and concrete composites. 2009;31(8):601-5.
8. MEHTA PK. Rice Hush Ash-A unique supplementary cementing material. Advances in concrete technology. 1992.
9. Ganjian E, Khorami M, Maghsoudi AA. Scrap-tyre-rubber replacement for aggregate and filler in concrete. Construction and building materials. 2009;23(5):1828-36.
10. Dragica J., S A. The Incorporation of Recycled Rubber Aggregate in Cement Based Composites. 2013.
11. Oriaku E, Agulanna C, Odenigbo J, Nnoruka N. Waste to wealth through the incineration of waste tyres and recovery of carbon black. International Journal of Multidisciplinary Sciences and Engineering. 2013;4(7):30-6.
12. Aisien FA, Amenaghawon N, Adeboyejo AR, Eng B. Application of recycled rubber from scrap tire in the removal of phenol from aqueous solution. Pacific Journal of Science and Technology. 2013;14(2):330-41.
13. Aisien F. A., Amenaghawon N. A., A AS. Adsorption of fethylbenzene from Aqueous solution using recycled rubber four scrap tyre. Journal of Scientific Research of Reports. 2013;2(2):497-512.
14. Oba A, Onungwe I, George A, Amgbara T, Akpan P. Waste to Wealth; The Utilization of Scrap Tyre as Aggregate in Bituminous Mixes for Road Construction. Int J of Engg Res and Apps. 2015;5(11):6-11.
15. Elinwa AU, Mahmood YA. Ash from timber waste as cement replacement material. Cement and Concrete Composites. 2002;24(2):219-22.
16. Turer A. Recycling of scrap tires. Material Recycling-Trends and Perspectives. 2012:195-212.

17. Al-Akhras N, Smadi M, editors. Properties of tyre rubber ash mortar. Dhir RK et al. Proceedings of the International Conference on Sustainable Concrete Construction University of Dundee, Scotland, UK; 2002.
18. Rafat S. Waste materials and by-products in concrete. Berlin: Springer, Verlag; 2008.
19. Al-Akhras NM, Smadi MM. Properties of tire rubber ash mortar. Cement and concrete composites. 2004;26(7):821-6.
20. ASTM C 1202. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. American Society for Testing Materials. 1997.
21. Rangaraju P, Gadkar S. Durability evaluation of crumb rubber addition rate on Portland cement concrete. Department of Civil Engineering, Clemson University, Clemson. 2012:1-126.
22. Ogork E, Uche OA, Elinwa AU. Performance of groundnut husk ash (GHA)-rice husk ash (RHA) modified concrete in acidic environment. International Journal of Engineering Research and Applications. 2014;4(11):71-7.
23. Ogork ENN, Uche OA, Elinwa AU, editors. Characterization of Groundnut husk ash (Gha) admixed with Rice husk ash (Rha) in cement paste and concrete. Advanced Materials Research; 2015: Trans Tech Publ.
24. FM Zain M, M Abd S. Multiple regression model for compressive strength prediction of high performance concrete. Journal of applied sciences. 2009;9(1):155-60.
25. Chakraverty S, Mall S. Artificial neural networks for engineers and scientists: solving ordinary differential equations: CRC Press; 2017.
26. Chopra P, Sharma RK, Kumar M, Chopra T. Comparison of machine learning techniques for the prediction of compressive strength of concrete. Advances in Civil Engineering. 2018;2018.