Model For Predicting Compressive Strength Of Interlocking Tiles Using Recycled Plastic Bottles

Lewechi Anyaogu, Chinenye Elizabeth Okere, Nnanna Obiabuchi Martin

Abstract: This work presents the model for predicting the compressive strength of interlocking tiles made with recycled plastic bottles. The use of recycled plastic bottles in making interlocking tile is an approach to eliminating plastic from the environment. The interlocking tiles were produced with sand, granite dust, and recycled plastic bottles. Scheffe's and Osadebe's models are statistical methods used in this study to design mix and formulate the model. The melting of the plastic mixed with sand and granite dust was regulated at an average temperature of 194.41°c. The hot mixtures were cast and air-cured for 28days. A total of thirty-six (36) interlocking tiles were cast, comprising of three cubes for each mix-ratio of a total of twelve (12) mix ratios. The first six (6) mix ratios were used to determine the coefficients of the response function, while the other six were used to validate the response function. The highest and lowest experimental compressive strengths recorded in this work are 22.00 Nmm^{-2} and 20.33Nmm^{-2} respectively at observation points. The maximum and least experimental compressive strengths recorded in this work are 24.33 Nmm^{-2} and 21.00Nmm^{-2} respectively at control points. The results from the response function were compared favorably with the experimental results. The response functions were tested with the statistical student's t-test and found to be adequate at a 95% confidence level. With the response function developed in this work; any desired compressive strength of interlocking tiles made from the mixture of sand, granite dust, and recycled plastic bottle can be predicted from known mix proportions and vice versa.

Index Terms: Compressive strength, Granite dust, Interlocking tile, Osadebe's models, Polyethylene terephthalate, Sand

1 Introduction

Interlocking tile is one of the construction materials made for pavements. It is usually made from a mixture of water, cement, aggregates (fine and coarse aggregates or aggregates like sand, quarry dust). The use of recycled plastic bottles in making interlocking tile is a new approach to eliminating plastic from the environment. The incessant rise in flood has been directly linked to drainage blockage, and also aquatic lives are spayed. Also, the price of the constituent materials used in making conventional interlocking tiles contributes to the overall cost. Cement being the costliest material. Its major production activities cause carbon emission, the release of harmful dust particles in the air, and many more factors that result in unexpected climate changes and major environmental health hazards. These negative impacts from the frequent demand of this conventional pavement material motivated this research, however, to bring about sustainable development. Models for predicting Compressive Strength and Elastic Modulus of interlocking tiles made from recycled plastic bottles using Osadebe's regression method will be formulated. Shannmagavalli et al.[6], stated that sustainable development for construction involves the use of innovative materials and recycling of waste materials to compensate for the lack of natural resources and find alternative ways of conserving the environment. According to the research done at the Massachusetts Institute of Technology [3] by students on a way to make stronger concrete with plastic bottles, the students discovered a method to produce concrete that is up to 20 percent stronger than conventional concrete. The procedure involved incorporating in the concrete, the pulverized plastic flakes that were exposed to small amounts of harmless gamma radiation. The finding was helpful as concrete is the second most widely used material on Earth after water. MIT News also report that approximately 4.5 percent of the world's human-induced carbon emissions are generated by producing concrete. The use of recycled plastic as a partial or complete replacement of cement in making concrete will reduce negative environmental impact.

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2 MATERIALS AND METHODS

2.1 Materials

The materials used for the laboratory test included:

i. Granite Dust: Granite is a common type of igneous rock which are form molten magma with high content of silica and alkali metal oxide. Granites can be predominantly white, pink, or grey in color, depending on their mineralogy. The granite dust for this research was obtained from the quarry site at Eziama, Lokpaukwu, Umunneochi Local Government Area in the Abia State of Nigeria. The granite dust was sun-dried for seven days to remove the water present before use. Granite dust that was free from deleterious matters and clay that conforms to BS 882 (1992) [1] was used. It was well graded in the size range of 0.075mm to 2.36mm.

ii. Recycled Plastic Bottle: According to Encyclopedia Britannica (2016) [2], Polyethylene Terephthalate (PET or PETE) is a strong, stiff synthetic fibre and resin, and a member of the polyester family of polymers. PET is spun into fibres for permanent-press fabrics, blow-molded into disposable. The waste plastic bottles were gathered from the refuse waste bin, inhabited vicinities, waste dump sites, although mostly contaminated with unfinished content, sands, insects, etc. the waste plastic bottles were washed from materials that might alter chemical composition during the melting stage. Because of space coverage of the empty plastic bottles were shredded into smaller pieces at a crushing plant in Afam, Oyigbo Rivers State for easy haulage.

iii. Rivers Sand: The fine aggregate used for this project experiment was river sand obtained from the Otamiri River. Otamiri is the name given to a river located in a community in the Federal University of Technology Owerri. The river sand was obtained wet as it was freshly dredged and then dried before use. The fine aggregate is sharp river sand, which is free from clay, silt, and organic matter. It has a specific gravity of 2.575, compacted bulk density of 1820.39 kg/m^3, and was well graded in the size range of 0.075mm to 2.36mm. The sand was free from debris and all form of external impurities. Sieve analysis was done and the result is as presented in chapter four of this work

2.2 Methods

2.2.1 Production of the Interlocking Tile made from Recycle PET bottles

The components of the interlocking tiles were recycled plastic bottles, sharp sand, and granite dust. The plastic bottles were shredded into flakes for easy and fast melting, then mixed with dried sharp sand and dried granite dust in the correct proportions. The batching of constituent materials was done by mass using the sensitive electronic weighing balance based on the design mix ratio that was designed by the simplex method. The melting and mixing of the material were regulated using the Infra-ray temperature measuring devices. The heating was done with locally sourced cooking utensils which are an aluminum tower pot, wooden spatula, scoop, float trowel, and camp gas cooker. The batched dried sand, PET flakes, and granite were transferred into the pot and heated to a regulated temperature. The mixture was stirred thoroughly to obtain a homogenous mix until the heating temperature recorded about 200°C.

The hot mix was transferred to steel moulds that were already lubricated to ensure easy was removal from the moulds.

The placing of the hot mix was tampered with, to reduce the voids using the float trowel. The moulds were filled, leveled, and compressed. It was left for about 5minutes and then removed from the moulds to make steel moulds ready for another mix. This same process was repeated for all the mix ratios. However, it is recommended to equip the personnel with fume masks.

The produced interlocks were arranged, labeled according to mix ratio descriptions. Eventually, the interlocks were properly kept to air-dry.

The curing was carried out in an open air secluded environment to allow for the interlocking tile to cool and prevent damage. The duration of the curing was twenty eight (28) days.

The cubes were air-cured for 28 days after which they were tested for impulse velocity and compressive strength values using the Pundit Lab and Schmitt Hammer machine. The pulse velocities for interlocking tile were measured. The rebound values were taken and converted to compressive strength values.

2.2.2 Osadebe Model for predicting the Compressive Strength

In this research work, Osadebe model was used to formulate a mathematical model to predict the compressive strength of the interlocking tiles.

According to Osadebe (2003) [5], the regression model for prediction of compressive strength of the interlocking tiles is formulated as follow;

The mix component is three. It comprises of recycled plastic bottled, sand and granite dust. You must have 6 observation points.

2.2.3 Determination of Mix Proportions of the Pseudo Components

Scheffe's Simplex lattice was applied to design the mix ratios when shown in an imaginary space will give 6 points on the three-dimensional factor space [7]. In Scheffe's mixture design, the pseudo components have a relationship with the actual components, that the actual components can be derived from the pseudo components and vice versa [7]. According to Scheffe (1958) [7], pseudo components are designated as X while the actual components are designated as S. Hence the relationship between X and S as expressed by Scheffe is given Equation (1) The normal mix ratios such as 1:2:4 will not be used directly, because the simplex requirement stipulates that the sum of all components must be unity i.e. $\sum X_1 = 1$. However, it is imperative to carry out a transformation from actual to pseudo components using Table 1 and equation (1). The chosen mix proportions were based on past experience and literature.

Table 1: Actual and Pseudo Components

N	Actual Components			Response	Pseudo Components		
	Recycled Plastic Bottle	Sand	Granite Dust		X_1	X_2	X_3
	S_1	S_2	S_3				
N_1	1.55	2.15	3.30	Y_1	1	0	0
N_2	1.80	2.20	3.00	Y_2	0	1	0
N_3	2.00	2.25	2.75	Y_3	0	0	1

Where N= any point on the factor space
Y=response

a. Determination of Actual Components of the binary Mixture

The Actual components of the binary mixture are determined by multiplying matrix [A] with values of matrix[X]expressed thus:

$$[s] = [A]*[X] \quad (1)$$

This approach was used to obtain the mix proportions of the individual ingredients of the mixture for both observation points and control points which are shown in Table 2

b. Mix ratios for the Osadebe's models

Again, six observation points are needed to formulate the models. Out of the 12 points of the (3, 2) design simplex lattice, the first 6 was used for the model formulation. The remaining 6 points will be used to validate the model. The chosen six mix ratios for model formulation and their fractional proportions are shown along with the other six required for model validation in Table 3.

Table 2: Mix-proportions, S, and their Corresponding Fractional Portions, X, Based on Osadebe's Second-Degree Polynomial

OP	MIX PROPORTION S, S_i			FRACTIONAL PORTIONS, X_i		
	S_1	S_2	S_3	X_1	X_2	X_3
N_1	1.5500	2.1500	3.3000	0.2214	0.3071	0.4714
N_2	1.8000	2.2000	3.0000	0.2571	0.3143	0.4286
N_3	2.0000	2.2500	2.7500	0.2857	0.3214	0.3929
N_{12}	1.6750	2.1750	3.1500	0.2393	0.3107	0.4500
N_{13}	1.7750	2.2000	3.0250	0.2536	0.3143	0.4321
N_{23}	1.9000	2.2250	2.8750	0.2714	0.3179	0.4107
CONTROL MIX						
C_1	1.7810	2.1995	3.0195	0.2544	0.3142	0.4314
C_2	1.7250	2.1875	3.0875	0.2464	0.3125	0.4411
C_3	1.7775	2.1985	3.0240	0.2539	0.3141	0.4320
C_{12}	1.8175	2.2075	2.9750	0.2596	0.3154	0.4250
C_{13}	1.7950	2.2025	3.0025	0.2564	0.3146	0.4289
C_{23}	1.8200	2.2075	2.9725	0.2600	0.3154	0.4246

2.2.4 Formulation of Osadebe Model

The response function to be adopted herein is a polynomial equation of the component proportions given as:

$$Y = a_1x_1 + a_2x_2 + a_3x_3 + a_4x_1x_2 + a_5x_1x_3 + a_6x_2x_3 \quad (2)$$

$$Y_1 = [x_i]_1 \cdot [a_i]_1 \quad (3)$$

$$Y_2 = [x_i]_2 \cdot [a_i]_2 \quad (4)$$

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$$Y_6 = [x_i]_6 \cdot [a_i]_6 \quad (5)$$

Expanding Equations (4) to (5) yields;

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} & x_{56} \\ x_{61} & x_{62} & x_{63} & x_{64} & x_{65} & x_{66} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} \quad (6)$$

That is:

$$Y = [x_i]\,[a]_i \quad (7)$$

Equation (7) was used to obtain the array response equation for the set of mix ratios used in the formulation as:

$$[Y^k] = [x_i][a_i]$$

(8)

The numbers of coefficients of the polynomial were derived using Equation (9)

According to Osadebe and Ibearugbulem (2009) [4],

The numbers of coefficients,

$$K = \frac{(q+m-1)!}{[(q-1)! \times m!]} \quad (9)$$

Where, m = the degree of polynomial of the response function; q = the number of components of the mixture; q=3, m=2

Thus,

$$K = \frac{(3+2-1)!}{[(3-1)! \times 2!]} = 6$$

∴k = 6.

For the 3 components mixture of second degrees the number of coefficients is 6.

Where k denotes the mix number (or observation point number); $[a_i]$ is the coefficient vector, and $[x_i]$ is the shape function vector. They are;

$$[a_i] = [a_1 \quad a_2 \quad a_3 \quad a_4 \quad a_5 \quad a_6]^T \quad (10)$$

$$[x_i] = [x_1 \quad x_2 \quad x_3 \quad x_1x_2 \quad x_1x_3 \quad x_2x_3] \quad (11)$$

$$[Y] = [x_1 \quad x_2 \quad x_3 \quad x_1x_2 \quad x_1x_3 \quad x_2x_3] \cdot [a_1 \quad a_2 \quad a_3 \quad a_4 \quad a_5 \quad a_6]^T \quad (12)$$

The actual mix proportions s_i^k and the corresponding fractional portions x_i^k are shown in Table 2. And the values of the constant coefficient $[a_i]$ in Equation (12), are determined with the values of $[Y^k]$ and $[x_i]$.

Rearranging Equation (8) yields

$$[a_i] = [x_i]^{-1}[Y^k] \quad (13)$$

Expressing Equation (13) in expanded form yields:

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & x_{36} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & x_{46} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} & x_{56} \\ x_{61} & x_{62} & x_{63} & x_{64} & x_{65} & x_{66} \end{bmatrix}^{-1} \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \end{bmatrix} \quad (14)$$

The values of a_1 to a_6 are obtained from Equation (14) and substituted into Equation (`2) to obtain the regression equation. The values of $[x_i]$ matrix is shown in Table 3a and the values of the inverse of $[x_i]$ matrix is presented in Table 3b; while the values of $[Y^k]$ matrix is obtained from the experimental investigation. The X matrix and its inverse areas given in Tables 3a and 3b respectively.

Table 3: X-Matrix for the Interlocking Mixes for Observation Point and control

OP	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
N1	0.2214	0.3071	0.4714	0.06799194	0.104368	0.14476694
N2	0.2571	0.3143	0.4286	0.08080653	0.1101931	0.13470898
N3	0.2857	0.3214	0.3929	0.09182398	0.1122515	0.12627806
N12	0.2393	0.3107	0.4500	0.07435051	0.107685	0.139815
N13	0.2536	0.3143	0.4321	0.07970648	0.1095806	0.13580903
N23	0.2714	0.3179	0.4107	0.08627806	0.111464	0.13056153
CONTROL MIX						
C1	0.2544	0.3142	0.4314	0.07993248	0.1097482	0.13554588
C2	0.2464	0.3125	0.4411	0.077	0.108687	0.13784375
C3	0.2539	0.3141	0.4320	0.07974999	0.1096848	0.1356912
C12	0.2596	0.3154	0.4250	0.08187784	0.11033	0.134045
C13	0.2564	0.3146	0.4289	0.08066344	0.10997	0.13493194
C23	0.2600	0.3154	0.4246	0.082004	0.110396	0.13391884

Table 3b: X-Matrix for the Interlocking Mixes

OP	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
N1	0.2214	0.3071	0.4714	0.06799194	0.104368	0.14476694
N2	0.2571	0.3143	0.4286	0.08080653	0.1101931	0.13470898
N3	0.2857	0.3214	0.3929	0.09182398	0.1122515	0.12627806
N12	0.2393	0.3107	0.4500	0.07435051	0.107685	0.139815
N13	0.2536	0.3143	0.4321	0.07970648	0.1095806	0.13580903
N23	0.2714	0.3179	0.4107	0.08627806	0.111464	0.13056153

Table 3b: X -Inverse Matrix

OP	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
N1	8693.54201	-4774.273202	-14765.86412	-15370.49447	-4755.990739	30974.94988
N2	19545. 9754	133469.6912	52854.20365	-107384.6174	74030.77846	-172513.0767
N3	2241.61979	35666.84253	18019.22073	-21915.92552	19066.93626	-53077.46963
N12	-54285.596	-208923.5861	-49655.72233	217000.2959	-110975.9864	206835.1664
N13	-2153.0092	35088.53557	22787.79349	-13508.47134	20523.22157	-62738.28541
N23	-35003.347	-319146.4436	-141321.9615	230491.701	-174532.3688	439508.9193

Legend: OP is Observation Point

Substituting the values of the inverse X- matrix into Equation (14), it will yield the Equation (15) for determination of coefficients of the models for prediction Compressive Strength.

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} = \begin{bmatrix} 8693.54201 & -4774.273202 & -14765.86412 & -15370.49447 & -4755.990739 & 30974.94988 \\ 19545.9754 & 133469.6912 & 52854.20365 & -107384.6174 & 74030.77846 & -172513.0767 \\ 2241.61979 & 35666.84253 & 18019.22073 & -21915.92552 & 19066.93626 & -53077.46963 \\ -54285.596 & -208923.5861 & -49655.72233 & 217000.2959 & -110975.9864 & 206835.1664 \\ -2153.0092 & 35088.53557 & 22787.79349 & -13508.47134 & 20523.22157 & -62738.28541 \\ -35003.347 & -319146.4436 & -141321.9615 & 230491.701 & -174532.3688 & 439508.9193 \end{bmatrix}^{-1} * \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \end{bmatrix} \quad (15)$$

Consequently, the Equation (15) is modified by replacing the experimental strength values Y in Table 4. The resulting Equation (15) is used in determination of coefficients of the models for prediction of compressive strength.

Table 4: Compressive Strength Test of the Interlocking Tile

Observation Points	N_1	N_2	N_3	N_{12}	N_{13}	N_{23}
$Y_{laboratory}(N/mm^2)$	20.33	22.00	21.83	21.00	21.00	21.00
Control Point	C_1	C_2	C_3	C_{12}	C_{13}	C_{23}
$Y_{laboratory}(N/mm^2)$	24.33	23.00	22.33	21.00	21.00	21.00

Table 5: Compressive strength (Y) from laboratory and Model

Table 5a: Mixes for Observation Points

S/N	N_1	N_2	N_3	N_{12}	N_{13}	N_{23}
$Y_{laboratory}(N/mm^2)$	20.33	22.00	21.83	21.00	21.00	21.00
$Y_{model}(N/mm^2)$	20.35	22.00	21.83	21.00	21.00	21.00

Table 5b: Mixes for Control

S/N	C_1	C_2	C_3	C_{12}	C_{13}	C_{23}
$Y_{laboratory}(N/mm^2)$	24.33	23.00	22.33	21.00	21.00	21.00
$Y_{model}(N/mm^2)$	21.46	20.59	21.42	21.60	28.26	21.60

3 Result

3.1 Regression Model Results

After multiplying Matrix inverse of X by experimental value of compressive strengths, Y, in the Table 3a, equation (15) yields the unknown coefficients of the regression equation as in equation (16).

$$\begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{bmatrix} = \begin{bmatrix} -22835.5982 \\ 164546.2572 \\ 49214.1540 \\ -214226.9572 \\ 55509.1816 \\ -413652.6875 \end{bmatrix} \quad (16)$$

By substituting the coefficients of region equation (values of α) in equation (16) into equation (2) the equation for prediction of compressive strength of interlocking tile is obtained. This is given in equation (17) below:

$$Y = -22835.5982x_1 + 164546.2572x_2 + 49214.15401x_3 - 214226.9572x_1x_2 + 55509.1816x_1x_3 - 413652.6875x_2x_3 \quad (17)$$

The equation (17) is the final response function for the predicting of the compressive strength of interlocking tile from recycled plastic bottles as binder based on Osadebe's regression function.

3.2 Test of Adequacy of the Osadebe's Response Function

The test for adequacy of the model was done with a two-tailed statistical student's t-test at 95% accuracy level. The compressive strengths and elastic modulus at the control points (i.e. C_1, C_2, C_3, C_{13}, C_{13}, C_{23}) were used for the test. Hence, it gives the risk that 5% or below of the mixture will be inaccurate. Before one proceeds in the check, two hypothetical hypotheses will be stated thus:

- Null Hypothesis (H0): There is no significant difference between the model results and the experimental results at an α- level of 0.5.
- Alternative Hypothesis (H1): There is a significant difference between the model results and the experimental results at an α- level of 0.5.

Table 6: Statistical Student's t-test for Osadebe's response function

OP	Y_E	Y_M	$D_i=Y_E-Y_M$	D_A-D_i	$(D_A-D_i)^2$
C1	24.33	21.46	2.87	3.25	10.55
C2	23.00	20.59	2.41	2.79	7.77
C3	22.33	21.42	0.91	1.29	1.67
C12	21.00	21.60	-0.60	-0.22	0.05
C13	21.00	28.26	-7.26	-6.88	47.27
C23	21.00	21.60	-0.60	-0.22	0.05
			$\sum D_i$ = -2.26		$\sum(D_A-D_i)^2$ =67.36

$$\sum D_i = -2.26$$

$$D_A = \frac{\sum D_i}{N} = \frac{-2.26}{6} = -0.38$$

$$S^2 = \frac{\sum(D_A-D_i)^2}{(N-1)} = \frac{67.36}{5} = 13.472$$

$$S = \sqrt{S^2} = \sqrt{13.472} = 3.6704$$

The actual value of the total variation in t-test is given by

$$t = \frac{D_A * N^{0.5}}{S} = \frac{-0.38 * 6^{0.5}}{3.6704} = -0.2536$$

and the allowable value of the total variation in t-test is obtained as follows
Degree of freedom = N-1 = 6-1 = 5
5% significance for Two-Tailed Test = 2.5 %
1 - 2.5% = 97.5% = 0.975.
Therefore, allowable total variation in the t-test is given by
$t_{(0.975,\ N-1)}$ = $t_{(0.975,\ 5)}$ = 2.571 (Obtained from standard statistical table).

From table 6, the calculated $t_{\text{calculated}} = -0.2536$.
Thus, $t_{(\text{table})} > t_{(\text{calculated})}$.
This implied that the difference between the two set of interlocking tiles compressive strength is less than the allowable difference. Hence null hypothesis is accepted and alternative hypothesis rejected. Hence, Osadebe's regression model is adequate.

4. Conclusions

i. The physical properties of the sharp sand, granite dust, and recycled plastic bottle (Polyethylene Terephthalate) were determined.
ii. The tiles were produced with the PET bottles and compressive strength determined
iii. Comparison of the experimental compressive strength and model-predicted compressive strength was made and the maximum percentage difference between was absolute 34.55%.
iv. The model was tested at a 95% accuracy level using statistical student's t-test and found to be adequate.

5. REFERENCES

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