ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 10, Issue 1, pp: (1-9), Month: April 2023 – September 2023, Available at: www.paperpublications.org

APPLICATION OF IBEARUGBULEM'S MODEL FOR OPTIMSING SPLITTING TENSILE STRENGTH OF BASALT CONCRETE MIX

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DOI: https://doi.org/10.5281/zenodo.7863126

Published Date: 25-April-2023

***Abstract*: The search for new raw materials that will compete favourably with existing ones is necessary to prevent the depletion of existing raw materials. This work investigates the suitability of basalt as coarse aggregate for the production of concrete and the application of Ibearugbulem's model for predicting the splitting tensile strength of concrete. A total of 24 concrete cylinders for basalt and granite samples of diameter 100mm and length 200mm were casted and demoulded after 24 hours. The samples were cured and tested for splitting tensile strength after 28 days. The laboratory results were used in formulating a model which predicts the 28 days splitting tensile strength. From the analysis, it was established that the difference between the laboratory results of splitting tensile strength and predicted values of splitting tensile strength are not significant.**

***Keywords:* Splitting tensile strength, Concrete, Basalt, Granite, Coarse aggregate, Model.**

1. INTRODUCTION

The construction industry is faced with the challenge of sourcing for new raw materials that will prevent over reliance on the existing ones. Intensive research is required to discover raw materials that can perform in similar capacity or an improvement on the performance of existing materials.

The demand for coarse aggregates is rising from time to time as a result of increased construction as a result of township expansion and infrastructural upgrades such as hospitals, residential and public buildings, airports, schools and highways [1]. The Federal and State governments in contributing to solving housing deficits are financing several housing and real estate projects. These projects utilize high volume of coarse aggregates.

The discovery of new materials is important to technological improvement thereby solving the problem of overdependence on the conventional materials. Mix design is based on critical technical principles to achieve desired output. To predict the behavior of concrete under all loading and exposure conditions require a deep knowledge of the type, size and aggregate content which can be made possible through laboratory testing and observations [2].

ISSN 2393-8471

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Basalt is usually dark, fine grained and columnar structure usually formed from fast cooling of magnesium – rich and iron – rich lava rising to the top [2]. Basalt rock are useful in the making of various products such as basalt reinforcement bars, basalt fabrics, continuous basalt filament wires and basalt mesh and grids. These basalt composites are applicable in soil strengthening, construction of bridges and highways, industrial floors, plastic polymer reinforcement, retrofitting and rehabilitation of engineering structures [3].

2. LITERATURE REVIEW

Ibearugbulem et al [4] observed that the Scheffe's model and Osadebe's model have predetermined number of experiments to be performed to enable their formulation. This is because the predetermined observation points will decide the mix ratios that can be used in the experiment. Their limitation is that they cannot be used to predict or optimize laboratory tests that are already performed. This limitation led to a search for a new regression model called Ibearugbulem's regression model which has been found to be a satisfactory option.

Ibearugbulem et al [4] assumed that the origin Z_0 is zero and that since the products and quotients of constants are equal to constants, the Osadebe's model equation can be simplified as:

$$F(Z) = \sum b_m . Z_i^m \qquad (2.1)$$

$0 \leq m \leq \infty, 2 \leq m \leq \infty$

From equation 2.1, Ibearugbulem et al [5] deduced that:

For $m = 0, b_m = 0$ (2.2)

For $m = 2, b_m = b_{ii}$ $(for\ Z_i^2 term)$

$b_m = b_{ii}$ $(for\ Z_i^2 term)$ (2.3)

For $m = 3,\ b_m = b_{iii}$ $(for\ Z_i^3 term)$

$b_m = b_{ijk}$ $(for\ Z_i Z_j Z_k\ term)$

$b_m = b_{iij}$ $(for\ Z_i^2 Z_j term)$

$b_m = b_{ijj}$ $(for\ Z_i Z_j^2 term)$

$b_m = b_{iik}$ $(for\ Z_i^2 Z_k term)$

$b_m = b_{ikk}$ $(for\ Z_i Z_k^2 term)$

$b_m = b_{jjk}$ $(for\ Z_j^2 Z_k term)$

$b_m = b_{jkk}$ $(for\ Z_j Z_k^2 term)$ (2.4)

For a four component mix, the equation becomes:

$$F(Z)= \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_{12} Z_1 Z_2 + \alpha_{13} Z_1 Z_3 + \alpha_{14} Z_1 Z_4 + \alpha_{23} Z_2 Z_3 + \alpha_{24} Z_2 Z_4 + \alpha_{34} Z_3 Z_4 + \alpha_{123} Z_1 Z_2 Z_3 + \alpha_{124} Z_1 Z_2 Z_4 + \alpha_{134} Z_1 Z_3 Z_4 + \alpha_{234} Z_2 Z_3 Z_4 + \alpha_{1234} Z_1 Z_2 Z_3 Z_4 \qquad (2.5)$$

Ibearugbulem and Ajoku [6] illustrated that the relationship between the pseudo variables Z_i and the actual variables S_i are expressed as:

$$Z_i = {}^{S_i}/_{S} \qquad (2.6)$$

$$S = \Sigma_{Si} \qquad (2.7)$$

ISSN 2393-8471

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Vol. 10, Issue 1, pp: (1-9), Month: April 2023 – September 2023, Available at: www.paperpublications.org

Ibearugbulem et al [4] explained further that summing equation 2.6 and equation 2.7 will generate simultaneous equations presented in matrix format whose solution will produce the coefficients of Ibearugbulem's regression equation.

$$\begin{bmatrix} \sum_r Z_1 F(Z) \\ \sum_r Z_2 F(Z) \\ \sum_r Z_3 F(Z) \\ \vdots \\ \sum_r Z_1 Z_2 Z_3 F(Z) \end{bmatrix} = \begin{bmatrix} \sum_r \sum Z_1 . Z_1 & \sum_r \sum Z_2 . Z_1 & \sum_r \sum Z_3 . Z_1 \ldots \\ \sum_r \sum Z_1 . Z_2 & \sum_r \sum Z_2 . Z_2 & \sum_r \sum Z_3 . Z_2 \ldots \\ \sum_r \sum Z_1 . Z_3 & \sum_r \sum Z_2 . Z_3 & \sum_r \sum Z_3 . Z_3 \ldots \\ \vdots & \vdots & \vdots \\ \sum_r \sum Z_1 . Z_1 . Z_2 & \ldots & \sum_r \sum Z_2 . Z_1 . Z_2 \ldots \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_{123} \end{bmatrix} \quad (2.8)$$

Equation 2.8 can be written in a simplified format as:

$$[F(Z).Z] = [CC][\alpha] \quad (2.9)$$

Ibearugbulem et al [4] further stated that the component CC in equation 2.9 is usually a symmetric matrix usually a 7x7 dimension for a mixture of three component as shown in Table 1.

Table 1: Elements of CC for a three component mixture.

ΣΣZ1Z1	ΣΣZ1Z2	ΣΣZ1Z3	ΣΣZ1Z1Z2	ΣΣZ1Z1Z3	ΣΣZ1Z2Z3	ΣΣZ1Z1Z2Z3
ΣΣZ1Z2	ΣΣZ2Z2	ΣΣZ2Z3	ΣΣZ1Z2Z2	ΣΣZ1Z3Z2	ΣΣZ2Z2Z3	ΣΣZ1Z2Z3Z2
ΣΣZ1Z3	ΣΣZ2Z3	ΣΣZ3Z3	ΣΣZ1Z2Z3	ΣΣZ1Z3Z3	ΣΣZ2Z3Z3	ΣΣZ1Z2Z3Z3
ΣΣZ1Z1Z2	ΣΣZ1Z2Z2	ΣΣZ1Z2Z3	ΣΣZ1Z1Z2Z2	ΣΣZ1Z1Z2Z3	ΣΣZ1Z2Z2Z3	ΣΣZ1Z1Z2Z3Z2
ΣΣZ1Z1Z3	ΣΣZ1Z3Z2	ΣΣZ1Z3Z3	ΣΣZ1Z1Z2Z3	ΣΣZ1Z1Z3Z3	ΣΣZ1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3
ΣΣZ1Z2Z3	ΣΣZ1Z2Z3	ΣΣZ2Z3Z3	ΣΣZ1Z2Z2Z3	ΣΣZ1Z2Z3Z3	ΣΣZ2Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3
ΣΣZ1Z1Z2Z3	ΣΣZ1Z2Z3Z2	ΣΣZ1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z2	ΣΣZ1Z1Z2Z3Z3	ΣΣZ1Z1Z2Z3Z3	ΣΣZ1Z1Z2Z2Z3Z3

Source: Ibearugbulem et al [4].

3. RESEARCH METHODOLOGY

Materials constitute the various ingredients required for the production of fresh concrete such as cement, fine aggregates, coarse aggregates and water. The Ordinary Portland Cement Type-I, class 32.5 manufactured by Larfarge was used for the investigation. The Cement factory is located at Mfamosin in Akamkpa LGA of Cross River State. The cement was procured in bags from a retail outlet source in Calabar, Cross River State. Calabar River sand was used as fine aggregate throughout the investigation. The sand was prepared in accordance with the requirements of BS882: 1992 and BS 812: 1975.

The crushed granite aggregate was obtained from a quarry in Akamkpa LGA and labelled G1 and G2 while the crushed basalt was obtained from three locations in Ikom in Cross River State of Nigeria. The basalt from location 1 was labelled B1 and B2, the basalt from location 2 was labelled B3 and B4 while basalt from location 3 was labelled B5 and B6. The splitting tensile strength test was carried out in a compression testing machine. The cylindrical specimen was casted on a steel mould of diameter 100mm and length 200mm. Concrete samples for same compressive strength test were taken for the experiment. Three cylinders each were made from B1, B2, B3, B4, B5, B6, G1 and G2 making a total of 24 cylinders. The cylindrical samples were demoulded after 24 hours and cured in a curing tank for 28 days. The B mix was for basalt while G mix was for granite. The granite mix was used as control.

ISSN 2393-8471

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The summary of mix design showing all the mix ratio is presented in Table 2

Table 2: Summary of mix design.

S/N	Sample No.	Mix ratio	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)
1	B1, B3, and B5	1:1.96:2.81	410	802	1153	205
2	B2, B4, and B6	1:2.25:2.75	394.23	887	1084	205
3	G1	1:1.80:2.75	410	736	1127.5	205
4	G2	1:2.07:2.76	394.23	815	1088	205

Four ingredients were used, these are: water, cement, river sand and basalt coarse aggregates. However, the component mixtures were reduced from four to three for simplification as follows:

Water/cement ratio denoted as S1

Sand/cement ratio denoted as S2

Basalt/cement ratio denoted as S3

Similarly, Granite/cement ratio denoted as S3 for the control mix.

4. RESULTS OF MATHEMATICAL MODELLING OF SPLITTING TENSILE STRENGTH

The CC matrix is reduced from 14 by 14 to 7 by 7 by this transformation. The Ibearugbulem's regression model kept cement constant, thereby reducing the components from 4 to 3. The values of S are presented in Table 3 while the values of Z are presented in Table 4.

Table 3: Values of S

S/N	S1	S2	S3	S
B1	0.50	1.96	2.81	5.27
B2	0.52	2.25	2.75	5.52
G1	0.50	1.80	2.75	5.05
G2	0.52	2.07	2.76	5.35

Table 4: Values of Z

S/N	Z1	Z2	Z3	Z1Z2	Z1Z3	Z2Z3	Z1Z2Z3
B1	0.0948767	0.3719165	0.5332068	0.0352862	0.0505889	0.1983084	0.0188148
B2	0.0942029	0.4076087	0.4981884	0.03839792	0.0469308	0.2030659	0.0191294
G1	0.0990099	0.3564356	0.5445545	0.03529066	0.0539163	0.1940986	0.0192177
G2	0.0971963	0.3869159	0.5158879	0.03760678	0.0501424	0.1996052	0.0194009

The laboratory results for 28 days splitting tensile strength test of all specimen is presented in Table 5

Table 5: Splitting tensile strength test results for all specimen at 28 days.

Specimen	Splitting tensile Strength (N/mm^2)	Average Value	Denotation
B1	11.10	11.36	B1
B3	11.37		
B5	11.60		
B2	10.37	10.25	B2
B4	10.13		
B6	10.25		
G1	11.52	-	G1
G2	10.58	-	G2

ISSN 2393-8471

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Using the values of Zi for B1 and B2 in Table 4 and the laboratory results (R) of splitting tensile strength test in Table 5 as presented in Table 6,

Table 6: Matrix Z and R

Z1	Z2	Z3	Z1Z2	Z1Z3	Z2Z3	Z1Z2Z3		R=
0.0948767	0.3719165	0.533207	0.03529	0.05059	0.19831	0.018815		11.36
0.0942029	0.4076087	0.498188	0.0384	0.04693	0.20307	0.019129		10.25

ZR is a product of matrix Z and R and summation is found as shown in Table 7

Table 7: Summation of ZR

Z1 F(Z)	Z2 F(Z)	Z3 F(Z)	Z1Z2 F(Z)	Z1Z3 F(Z)	Z2Z3 F(Z)	Z1Z2Z3 F(Z)
1.077799	4.224971	6.057229	0.400849	0.574691	2.252779	0.213736
0.96558	4.177989	5.106431	0.39358	0.481043	2.081427	0.196076
2.043379	**8.402961**	**11.16366**	**0.794428**	**1.055734**	**4.334205**	**0.409812**

Substituting [F(Z), Z] and the inverse CC matrix into the equation 2.9, the coefficient $[\alpha]$ is obtained as shown in Table 8

$$[F(Z).Z] = [CC][\alpha]$$

$$[\alpha] = [F(Z).Z][CC]^{-1} \quad (4.1)$$

The multiplication process is shown in Tables 8, 9 and 10

Table 8: Matrix $[CC]^{-1}$

$[CC]^{-1}$						
-11807736.42	-602729.339	-554655.777	-5892962.18	-7756856.2	60.9933272	38.8199987
-602730.5221	-258307.715	159745.8435	3414004.305	-1035685.9	3.82344896	44.4319351
-554655.9986	159746.182	-180523.493	-1046545.52	2498464.54	7.66318872	19.4307277
-5892959.32	3414008.791	-1046543.86	-30586934.9	18314987.9	70.892079	39.9208415
-7756859.207	-1035687.9	2498463.323	18314981.35	-16944527	20.5619537	47.6953936
-57.92732572	2.047186947	8.207684133	86.80594908	11.0329569	0.00024624	-173.42787
-38.81997619	44.43194016	19.43072223	39.92074406	47.6954434	173.427845	0.00100978

Table 9: Matrix F(Z).Z

F(Z).Z
2.043379
8.402961
11.16366
0.794428
1.055734
4.334205
0.409812

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 10, Issue 1, pp: (1-9), Month: April 2023 – September 2023, Available at: www.paperpublications.org

Table 10: Matrix $[F(Z).Z][CC]^{-1}$

21.56666	21.56666	21.56666	21.56666	21.56666	21.56666	21.56666
-1.689	-1.689	-1.689	-1.689	-1.689	-1.689	-1.689
15.6947	15.6947	15.6947	15.6947	15.6947	15.6947	15.6947
-64.8883	-64.8883	-64.8883	-64.8883	-64.8883	-64.8883	-64.8883
76.221	76.221	76.221	76.221	76.221	76.221	76.221
-6.5E-05	-6.5E-05	-6.5E-05	-6.5E-05	-6.5E-05	-6.5E-05	-6.5E-05
-0.0018	-0.0018	-0.0018	-0.0018	-0.0018	-0.0018	-0.0018

Table 11: Values of coefficient $[\alpha]$

$\alpha1$	$\alpha2$	$\alpha3$	$\alpha12$	$\alpha13$	$\alpha23$	$\alpha123$
21.5667	-1.6890	15.6947	-64.8883	76.2210	-0.000065	-0.0018

From the three component equation,

$$F(Z) = \alpha_1 Z1 + \alpha_2 Z2 + \alpha_3 Z3 + \alpha_{12} Z1Z2 + \alpha_{13} Z1Z3 + \alpha_{23} Z2Z3 + \alpha_{123} Z1Z2Z3 \quad (4.2)$$

Therefore, substituting the values of $[\alpha]$ in Table 11 into equation 4.2, the optimization equation for predicting the 28 day splitting tensile strength of basalt concrete is:

$$\mathbf{F(Z) = 21.5667Z1 - 1.689Z2 + 15.695Z3 - 64.883Z1Z2 + 76.221Z1Z3 - 0.000065Z2Z3 - 0.0018Z1Z2Z3} \quad (4.3)$$

The model in equation 4.3 is used in predicting the 28 days splitting tensile strength and the predicted values alongside the laboratory values are presented in Table 13 and the predicted values for the control mix is presented in table 14 as computed in Table 12

Table 12: Computation of predicted model values of splitting tensile strength of beams.

Model	**B1**	**B2**	**G1**	**G2**
21.5667Z1	2.046177326	2.031645683	2.13531681	2.096203443
-1.689Z2	-0.628166969	-0.688451094	-0.602019728	-0.653500955
15.6947Z3	8.368520764	7.818917481	8.546619511	8.096705824
-64.8883Z1Z2	-2.289648554	-2.491580943	-2.289950933	-2.440240023
76.221Z1Z3	3.855944169	3.577127751	4.109554302	3.82190387
-0.000065Z2Z3	-1.289E-05	-1.31993E-05	-1.26164E-05	-1.29743E-05
-0.0018Z1Z2Z3	-3.38666E-05	-3.44329E-05	-3.45919E-05	-3.49216E-05
Σ	**11.35277998**	**10.24761125**	**11.89947275**	**10.92102426**

Table 13: Values of predicted 28 days splitting tensile strength with laboratory values.

S/N	**B1**	**B2**
$C_{Lab}(N/mm^2)$	11.360	10.250
$C_{Model}(N/mm^2)$	11.353	10.248

Table 14: Values of predicted 28 days splitting tensile strength of control mix with laboratory values.

S/N	G1	G2
$C_{Lab}(N/mm^2)$	11.520	10.580
$C_{Model}(N/mm^2)$	11.899	10.921

The Fisher F test was carried out on the control mix to ascertain whether there is significant difference between the values of splitting tensile strength of concrete obtained from the laboratory and the values obtained from the model. The results of the F test is presented in Table 15

Table 15: Fisher F test on splitting tensile strength from model using control mix.

Response Symbol	C_{Lab}	C_{Model}	$(C_{Lab} - M)$	$(C_{Model} - Q)$	$(C_{Lab} - M)^2$	$(C_{Model} - Q)^2$
G1	11.520	11.899	0.47	0.489	0.2209	0.239121
G2	10.580	10.921	-0.47	-0.489	0.2209	0.239121
Total	22.10	22.820	-	-	0.4418	0.478242
Mean	11.05	11.41	-	-	-	-

Legend:

C_{Lab} = Laboratory values of splitting tensile strength

C_{Model} = Splitting tensile strength predicted by model

M = Mean of laboratory values of splitting tensile strength

Q = Mean of splitting tensile strength predicted by model

N = Number of observations = 2

Hence,

$$S_L^2 = \Sigma(C_{Lab} - M)^2 / N - 1 \quad (4.4)$$

$$S_M^2 = \Sigma(C_{Model} - Q)^2 / N - 1 \quad (4.5)$$

$$S_L^2 = \frac{0.4418}{2-1} = 0.4418$$

$$S_M^2 = \frac{0.478242}{2-1} = 0.478242$$

Since the greater value is taken as S_1^2, Hence,

$$S_1^2 = 0.478242$$

$$S_2^2 = 0.4418$$

$$f_{calculated} = \frac{S_1^2}{S_2^2} = \frac{0.478242}{0.4418} = 10.825$$

Hence, $\frac{1}{f} = 0.0924$

From statistical tables,

$f_{0.05}(1,1) = 161.45$

ISSN 2393-8471

International Journal of Recent Research in Civil and Mechanical Engineering (IJRRCME)
Vol. 10, Issue 1, pp: (1-9), Month: April 2023 – September 2023, Available at: www.paperpublications.org

Therefore, the condition $\frac{1}{f} < \frac{S_1^2}{S_2^2} < f$ is satisfied, hence, the difference between the laboratory values of splitting tensile strength and the predicted values from the model is not significant as the calculated value of F is less than the table value of F.

The student T test was carried out on the control mix to ascertain whether there is significant difference between the values of splitting strength of concrete obtained from the laboratory and the values obtained from the model. The results of the T test is presented in Table 16

Table 16: Student T test on splitting tensile strength.

Response Symbol	C_L	C_M	$(C_M - C_L) = X$	$D - X$	$(D - X)^2$
B1	11.36	11.353	-0.007	0.1848	0.03415104
B2	10.25	10.248	-0.002	0.1798	0.03232804
G1	11.52	11.899	0.379	-0.2012	0.04048144
G2	10.58	10.921	0.341	-0.1632	0.02663424
Total	-	-	**0.711**	-	**0.13359476**

Legend:

C_L = Laboratory values of splitting tensile strength

C_M = Splitting tensile strength predicted by model

N = Number of observations = 4

Hence,

$$D = \Sigma \frac{(C_M - C_L)}{N} = \frac{0.711}{4} = 0.1778$$

$$S^2 = \Sigma \frac{(D - X)^2}{N-1} \quad (4.6)$$

$$S^2 = \frac{0.13359476}{4-1} = 0.04453$$

$$S = \sqrt{0.04453}$$

$$S = 0.211$$

$$t = D \frac{\sqrt{N}}{S} \quad (4.7)$$

$$t = 0.1778 \frac{\sqrt{4}}{0.211} = 1.6853$$

t Value from the table is given as $t_{\alpha/N,(V)}$ where $V = N - 1$

Therefore $t_{0.05/4,(3)} = t_{0.0125,(3)}$

From statistical table, $t_{0.0125,(3)} = 5.516$ by interpolation

5. DISCUSSION

The model equation developed is used in predicting the 28 day splitting tensile strength of concrete mix. The Fisher F test was carried out on the control mix to ascertain whether there is significant difference between the values of splitting tensile strength of concrete obtained from the laboratory and the values obtained from the model. The T test was also carried out on the to ascertain whether there is significant difference between the values of splitting tensile strength of concrete obtained from the laboratory and the values obtained from the model. The analysis show clearly that the difference between the predicted values and the laboratory values of splitting tensile strength are not significant. With the model developed, developers do not need to go to the laboratory to carry out rigorous test to obtain results of splitting tensile strength.

6. CONCLUSIONS

From the statistical analysis of Fisher F-test, the condition $\frac{1}{f} < \frac{S_1^2}{S_2^2} < f$ is satisfied, hence, the difference between the laboratory values of splitting tensile strength and the predicted values from the model is not significant as the calculated value of F is less than the table value of F.

Similarly, from the student T-test, since t from the statistical table is greater than the value of calculated t, the difference between the laboratory values of splitting tensile strength and the predicted values from the model is not significant.

ACKNOWLEDGEMENTS

This research is supported by Prof. David Onwuka, Dr. Mrs Chinenye Okere and Mrs Ulari Onwuka.

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