Jurnal Kejuruteraan 34(3) 2022: 401-409
https://doi.org/10.17576/jkukm-2022-34(3)-07

Mathematical Model to Predict Split Tensile Strength of Concretes in Crude Oil Contaminated Environments

J. C. Ezihe[a], O. O. Ugwu[b], F. O. Okafor[a]

[a] *Department of Civil Engineering, Faculty of Engineering, University of Nigeria, Nsukka*
[b] *Department of Civil Engineering, Faculty of Engineering, Alex Ekwueme University, Ndufu Alike*

**Corresponding author: covenant3000@gmail.com*

Received 24 April 2021, Received in revised form 27 August 2021
Accepted 27 September 2021, Available online 30 May 2022

ABSTRACT

Few concrete components used for constructions within the Niger Delta region of Nigeria are contaminated with crude oil to varying ranges. An investigation into the split tensile behaviour of concretes to crude oil when cured in 10% crude oil/water medium is carried out in this work. In this work, crude oil was used as a fifth ingredient of concrete mix which replaced 5% to 20% of the w/c. The four other components were cement, sand, granite, and water. A designed mix ratio of 1:2:4 with w/c of 0.5 was utilized as the initial component mix design. Scheffe's simplex theory was used for the five mix ratios in a {5,2} experimental design. This gave rise to ten additional mix ratios and fifteen other additional mix ratios were generated for control purposes. These thirty concrete mix ratios were subjected to laboratory experiments to determine the 7 and 28 days split tensile strengths. The results of the first fifteen split tensile strengths were used for the calibration of the model constant coefficients, while the results from the second fifteen were used as control. A mathematical regression model was derived from the results, with which the split tensile strengths were developed. The derived model was subjected to a two-tailed t-test with 5% significance, which ascertained the model to be adequate with an R2 value of 0.9616 and 0.9227. The study revealed that crude oil presence in a concrete mix can be harmful as it reduces the split tensile strength of concretes.

Keywords: Crude oil; Scheffe's simplex lattice design; Split Tensile

INTRODUCTION

Crude oil contamination has been one of the global environmental concerns despite the fact that crude oil has remained one of the blessings of nature that act as the source energy for the daily operations of humans, hence a viable source of income to the economy amidst its several other benefits. Amnesty (2018) posited that Niger delta is one of the most polluted places on earth as 17.5m litres of oil have been spilled in 2011. The degree of crude oil contamination on various concrete components and its effects have been explored by various researchers like Ezihe (2019), Ajagbe (2013), Nduka (2011) and Awoyera (2020). Concrete is a substance used for building which is made by mixing cement, sand, granite, and water.

Structural concrete is a special type of concrete that is capable of carrying a structural load or forming an integral part of a structure. According to Gahlot (2016), concrete had been used as an ad hoc construction material until 1919 when Duff Abram found the water-cement ratio law, which led to concrete quality control through scientific procedures. Crude oil contaminated concretes are normal concrete with traces of crude oil in its mix.

Most researchers have discovered that there are traces of crude oil presence found within most of the concrete components especially within crude oil polluted environments. Hence, crude oil interaction with concrete can either be within the concrete mix or external interaction during curing which the practical reality is the submerging of concrete structures within crude contaminated water environments of mild or severe crude oil pollution.

These have generated a lot of concern among researchers to understudy both the internal and external interaction of concretes with crude oil as to whether to completely discard it or to optimize its resourcefulness to concrete production.

Works by Ejeh (2009), Osuji (2015) and Ezihe (2021) indicated that crude oil is aggressive to concrete and that the presence of crude oil in concrete influences the strength properties of the concrete. There is therefore the need to develop models that can predict the strength properties of concretes in interaction with crude oil. Such models can also be used to understudy the component interactions. In this work, mixture experiment models for predicting the flexural strength of crude oil contaminated concrete cured in crude oil contaminated environment were developed using Scheffe's augmented simplex lattice design Scheffes (1958).

METHODOLOGY

MIXTURE EXPERIMENTS AND SCHEFFE'S MODEL EQUATION

Cornell (2011) explained a mixture experiment to be one in which the response is assumed to be dependent on the relative proportions of the constituent materials and not on their total amount. For such experiments, Anya (2015) opined that there are two basic requirements that must be satisfied namely; the sum of the proportions of the constituents must add up to one and none of the constituents will have a negative value. Scheffe's simplex lattice design is actually one of the many mixture experiment model forms that exist. Scheffes (1958) invented an empirical model in form of the polynomial equation. The equation for such designs, which for a second degree polynomial for {*q, m*} is given as:

$$Y = \sum_{1 \le i \le q} \beta_i X_i + \sum_{1 \le i \le j \le q} \beta_{ij} X_i X_j \quad (1)$$

Y is the response function and X_i (i = 1 to q) is the proportion of component i in the mixture. The second degree polynomial is the most commonly used polynomial to fitting mixture experiment data. The component mixture equation (1) is expressed as:

$$Y_{ij} = 4Y_i - 2Y_i - 2Y_j \quad (2)$$

Therefore, for a five component mixture {*5, 2*}, equation (1) is expressed as:

$$Y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{14} x_1 x_4 + \beta_{15} x_1 x_5 + \beta_{23} x_2 x_3 + \beta_{24} x_2 x_4 + \beta_{25} x_2 x_5 + \beta_{34} x_3 x_4 + \beta_{35} x_3 x_5 + \beta_{45} x_4 x_5 \quad (3)$$

The estimated coefficients in equation (1) were determined after a mixture regression analysis of the experimental data. The canonical polynomial has fewer terms than the standard polynomial and is often referred to as the {*q, m*} polynomial; *m* being the degree of the polynomial. Oba (2019), Anya (2015) and Ezihe (2019) are among other researchers that have also worked on Scheffes simplex theory.

MATERIALS

Water, Cement, Sand, granite and crude oil are the materials used for the concrete production. Potable water was used. Dangote brand of Ordinary Portland cement of 42.5 grade which conforms to NIS: 444 (2003) was used. The sand with a specific gravity of 2.68 and coefficient of uniformity of 1.49. The corresponding values for the granite of 10mm size are 2.70 and 1.53. Bonny light Crude oil was gotten from Port-Harcourt, Nigeria.

EXPERIMENTAL DESIGN AND PROCEEDINGS

An augmented {5, 2} Scheffe's simplex lattice design with 15 points was used as represented in figure (I) and (II) below. The number of components is 5 and a second-degree polynomial was used in designing the experiments. That is, q = 5 and n = 2. An initial mix design was done which thereafter, the first five concrete mix ratios derived from different percentages of contaminations (0% - 5%) which represents the main components are presented as:

$$S = \begin{bmatrix} 0.5 & 1 & 0 & 2 & 4 \\ 0.475 & 1 & 0.025 & 2 & 4 \\ 0.45 & 1 & 0.05 & 2 & 4 \\ 0.425 & 1 & 0.075 & 2 & 4 \\ 0.40 & 1 & 0.10 & 2 & 4 \end{bmatrix}$$

Their corresponding pseudo components are given as:

$$X = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

And centre points of the pseudo components are represented as:

$$X_P = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 & 0 \\ 0.5 & 0 & 0.5 & 0 & 0 \\ 0.5 & 0 & 0 & 0.5 & 0 \\ 0.5 & 0 & 0 & 0 & 0.5 \\ 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0.5 & 0 & 0.5 & 0 \\ 0 & 0.5 & 0 & 0 & 0.5 \\ 0 & 0 & 0.5 & 0.5 & 0 \\ 0 & 0 & 0.5 & 0 & 0.5 \\ 0 & 0 & 0 & 0.5 & 0.5 \end{bmatrix}$$

Scheffes (1958) stipulates, $S_{ij} = XS_i$ (4)

Substituting gives the corresponding centre point values for the main components.

Similarly, this process is repeated for an additional 15 (control) points that was used for the verification of the formulated model. All were then subjected to experimental proceedings in order to determine their various responses which were used in the formulation of the model equation. The concrete samples were prepared in cylindrical shapes of 300mmX150mm diameter. The split tensile test which is the most commonly used indirect tensile test was used according to BS 1881:117 in order to determine the tensile strength of the concrete. The specimen was subjected to a compressive load along the vertical diameter at a constant rate. This brought about a tensile split in the specimen. The tensile strengths were then determined by,

$$f_t = \frac{2P}{\pi l d} \quad (5)$$

Where P = the load at failure
d = the diameter of the specimen in millimetres
l = the span length of beam in millimetres
The regular pentagons for the pseudo components and corresponding actual components are given in figures (I) and (II) respectively.

ANALYSIS, RESULTS AND DISCUSION

Table I and Table II shows the pseudo components, results of the compressive strength tests and result from the Scheffes model.

MODEL EQUATION FOR THE SPLIT TENSILE STRENGTHS AT 7 DAYS

The coefficients of polynomial from table (I), (II), eq. (2) are substituted into eq. (3) to give the resultant model equation:

$$Y_{c7}=2.35x_1+2.17x_2+2.00x_3+1.87x_4+1.85x_5-0.71x_1x_3+0.08x_1x_4-0.48x_1x_5+0.18x_2x_3-0.10x_2x_4-0.32x_2x_5-0.21x_3x_5+0.08x_4x_5 \quad (6)$$

Eq. (6) above is the mathematical model to predict the 7 days split tensile strength of concrete contaminated with crude oil and cured at portable water medium.

MODEL EQUATION FOR THE SPLIT TENSILE STRENGTHS AT 28 DAYS

The coefficients of polynomial from table (I), (II), eq. (2) are substituted into eq. (3) to give the resultant model equation:

$$Y_{c28}=2.87x_1+2.85x_2+2.50x_3+2.23x_4+2.04x_5-0.74x_1x_3+0.85x_1x_4+0.05x_1x_5+0.35x_2x_3-0.14x_2x_4-0.32x_2x_5-0.17x_3x_5 \quad (7)$$

Eq. (7) above is the mathematical model to predict the 28 days split tensile strength of concrete contaminated with crude oil and cured at portable water medium.

TEST OF ADEQUACY OF THE MODEL

The coefficients of polynomial from table (IV),
A two-tailed student t-test was carried out at 95% confidence level.

Let D be difference between the experimental and predicted responses
The mean of the difference,

$$D_a = \frac{1}{n}\sum_{i=1}^{n}(D_i) \quad (8)$$

The variance of the difference,

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(D - D_a)_i^2 \quad (9)$$

Where n = number of observations with degree of freedom n – 1.

$$T_{calc}=\frac{D_a\sqrt{n}}{S} \quad (10)$$

From the Table t-test table, $T_{(0.95,14)} = 2.145$. Also, from Table (II) to (III) $T_{calculated} < T_{(0.975,14)} = 1.0634$ and 1.4253, and lies between 2.145, and -2.145, therefore there is no significant difference between the experimental and predicted responses, H_0 is accepted, and Ha is rejected. The model is confirmed to be adequate. Fig. V, VII shows the scatter plot between the experimental and predicted responses. From fig V and VII, the R^2 value of 0.9227 and 0.9616 for 28 days and 7 days respectively indicates that the experimental results are highly correlated to the predicted results which is an additional confirmation that the mode is fit and adequate.

CONCLUSION

A mathematical model for the prediction of the split tensile strengths of concretes to crude oil contaminated water when cured in 10% crude oil/water medium was developed in this work. A two-tailed t-test was carried out at 5% significance level, which confirmed the adequacy of the derived model with an R2 value of 0.9227 and 0.9616 for 28 days and 7 days respectively. The use of these models will greatly help to ensure sustainability in production within crude oil contaminated region.

ACKNOWLEDGEMENT

This work was supported by the Universiti Teknologi MARA (UiTM) Cawangan Sarawak, Malaysia.

DECLARATION OF COMPETING INTEREST

None

TABLE 1. Pseudo components, Split Tensile tests results and Scheffes model results for concretes in 10% Crude oil/ water curing media

Pseudo Components					7 days Split Tensile Strength (N/mm²)		28 days Split Tensile Strength (N/mm²)	
w-c ratio	cement	crude oil	sand	granite	Y_{exp}	Y_{pred}	Y_{exp}	Y_{pred}
X1	X2	X3	X4	X5				
1	0	0	0	0	2.35	2.35	2.87	2.87
0	1	0	0	0	2.17	2.17	2.85	2.85
0	0	1	0	0	2.00	2.00	2.50	2.50
0	0	0	1	0	1.87	1.87	2.23	2.23
0	0	0	0	1	1.85	1.85	2.04	2.04
0.5	0.5	0	0	0	2.26	2.26	2.86	2.86
0.5	0	0.5	0	0	2.00	2.00	2.50	2.50
0.5	0	0	0.5	0	2.13	2.13	2.76	2.76
0.5	0	0	0	0.5	1.98	1.98	2.47	2.47
0	0.5	0.5	0	0	2.13	2.13	2.76	2.76
0	0.5	0	0.5	0	2.00	2.00	2.50	2.50
0	0.5	0	0	0.5	1.93	1.93	2.37	2.37
0	0	0.5	0.5	0	1.93	1.93	2.37	2.37
0	0	0.5	0	0.5	1.87	1.87	2.23	2.23
0	0	0	0.5	0.5	1.88	1.88	2.13	2.13
		Control						
0.49	0.3	0.1	0	0.11	2.18	2.18	2.85	2.70
0.25	0	0.3	0.15	0.3	1.96	1.96	2.43	2.38
0.1	0.15	0.2	0.3	0.25	1.94	1.94	2.38	2.39
0.15	0.21	0	0.15	0.49	1.92	1.92	2.33	2.35
0	0.24	0.11	0.49	0.16	1.92	1.92	2.35	2.35
0.49	0.31	0.09	0.11	0	2.20	2.20	2.85	2.78
0.21	0.32	0.12	0.22	0.13	2.04	2.04	2.47	2.58
0	0.27	0.22	0.17	0.34	1.92	1.92	2.34	2.36
0.27	0.1	0.31	0.29	0.03	2.05	2.05	2.60	2.55
0.49	0.13	0.21	0.17	0	2.16	2.16	2.83	2.68
0	0.19	0.49	0.11	0.21	1.95	1.95	2.41	2.44
0.19	0.09	0.26	0.37	0.09	1.98	1.98	2.48	2.48
0.1	0.21	0.13	0.21	0.35	1.93	1.93	2.37	2.37
0.11	0.2	0	0.2	0.49	1.90	1.90	2.29	2.32
0.15	0.28	0.46	0.06	0.05	2.07	2.07	2.65	2.61

TABLE 2. Statistical t- test for 28 days split tensile strength of crude contaminated concrete in 10% Crude oil/ water curing media

SAMPLE	SPLIT TENSILE		t test	t test	t test
	Yexp	Ypredict	D=Yex-Yp	Da - D	(Da - D)^2
C1	2.85	2.701843	0.15	-0.1306	0.017056
C2	2.43	2.379534	0.05	-0.03565	0.001271
C3	2.38	2.388804	-0.00978	0.028717	0.000825
C4	2.33	2.348425	-0.01623	0.035173	0.001237
C5	2.35	2.354154	-0.00819	0.027127	0.000736
C6	2.85	2.779659	0.074481	-0.05554	0.003085
C7	2.47	2.580252	-0.11513	0.134071	0.017975
C8	2.34	2.364027	-0.02082	0.039756	0.001581
C9	2.60	2.553006	0.050624	-0.03169	0.001004
C10	2.83	2.683713	0.145467	-0.12653	0.016009
C11	2.41	2.439949	-0.03062	0.049558	0.002456
C12	2.48	2.481752	-0.00079	0.019731	0.000389
C13	2.37	2.374596	-0.00935	0.028285	0.0008
C14	2.29	2.315306	-0.02169	0.040625	0.00165
C15	2.65	2.606766	0.041974	-0.02304	0.000531
TOTAL			0.284077		0.066605
AVE, Da			0.018938		
S^2=	0.004757				
S=	0.068975				
Tcalc=	1.063414				
T(0.975,14)		2.145			
TRUE					
Since 1.0634 lies between -2.145 and 2.145, the model is confirmed adequate and certified ok.					

TABLE 3. Statistical t- test for 7 days split tensile strength of crude contaminated concrete in 10% Crude oil/ water curing media

SAMPLE	SPLIT TENSILE		t test	t test	t test
	Yexp	Ypredict	D=Yex-Yp	Da - D	(Da - D)^2
C1	2.18	2.138068	0.05	-0.03585	0.001285
C2	1.96	1.918885	0.04	-0.03492	0.001219
C3	1.94	1.94289	-0.00459	0.01429	0.000204
C4	1.92	1.931477	-0.0146	0.024297	0.00059
C5	1.92	1.93523	-0.01205	0.02175	0.000473
C6	2.20	2.184475	0.020385	-0.01068	0.000114
C7	2.04	2.037493	0.003787	0.005913	3.5E-05
C8	1.92	1.937333	-0.01541	0.025113	0.000631
C9	2.05	2.010591	0.03603	-0.02633	0.000693
C10	2.16	2.106503	0.055817	-0.04612	0.002127
C11	1.95	1.965955	-0.01379	0.023495	0.000552
C12	1.98	1.976459	0.008461	0.001239	1.53E-06
C13	1.93	1.93888	-0.01315	0.022855	0.000522
C14	1.90	1.921162	-0.02192	0.031622	0.001
C15	2.07	2.043385	0.026375	-0.01668	0.000278
TOTAL			0.145499		0.009726
AVE, Da			0.0097		
S^2=	0.000695				
S=	0.026357				
Tcalc=	1.425336				
T(0.975,14)		2.145			
TRUE					

Since 1.4253 lies between -2.145 and 2.145, the model is confirmed adequate and certified ok.

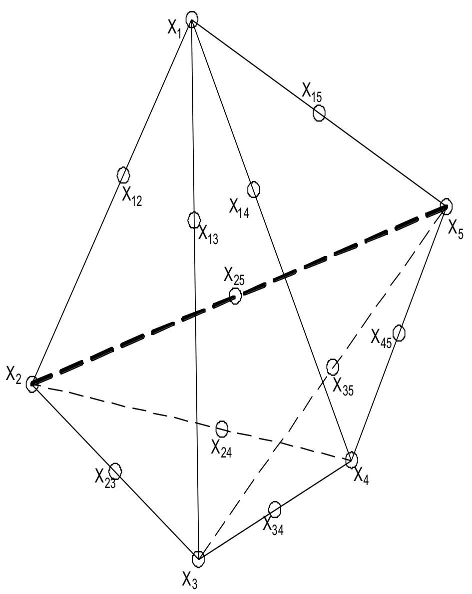

FIGURE 1. Simplex lattice for pseudo components

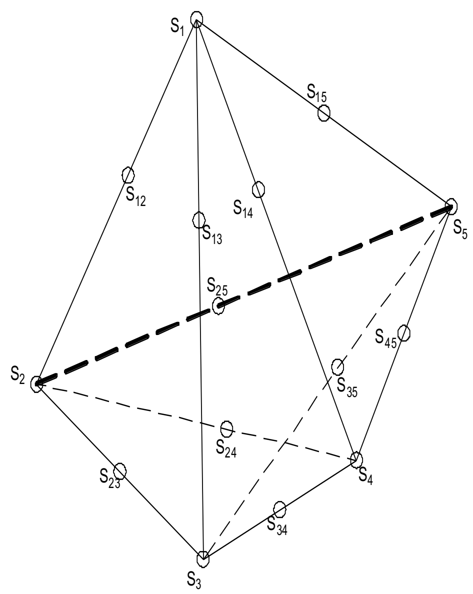

FIGURE 2. Simplex lattice for actual components

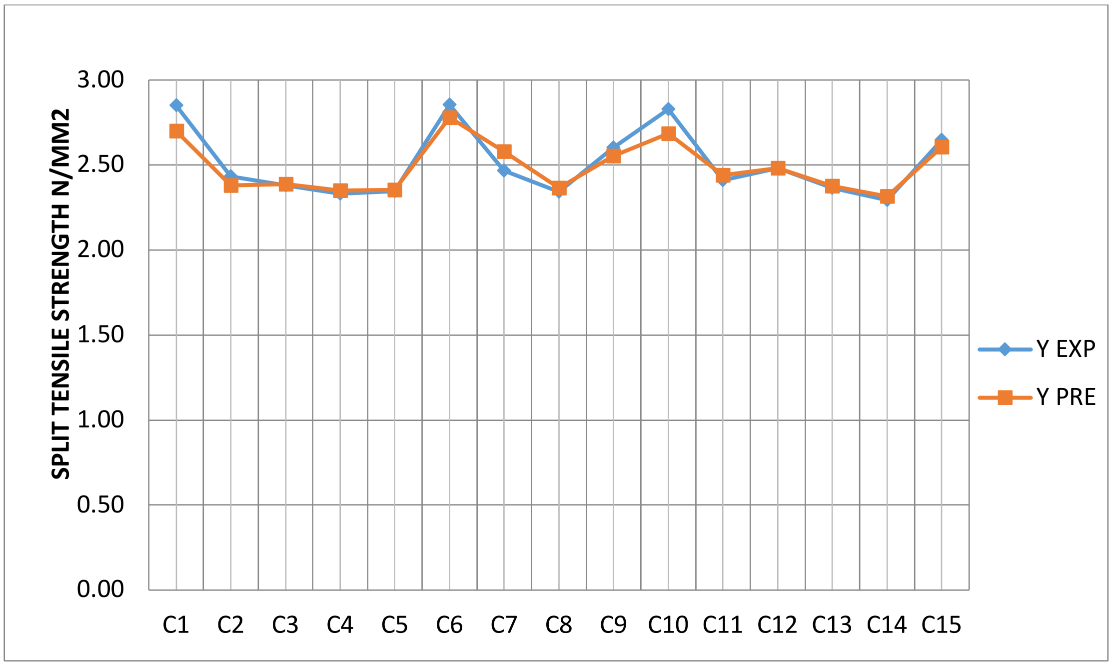

FIGURE 3. Comparison between Experimental and Predicted 28 days split tensile Strengths of concretes in 10% Crude oil/ water curing media

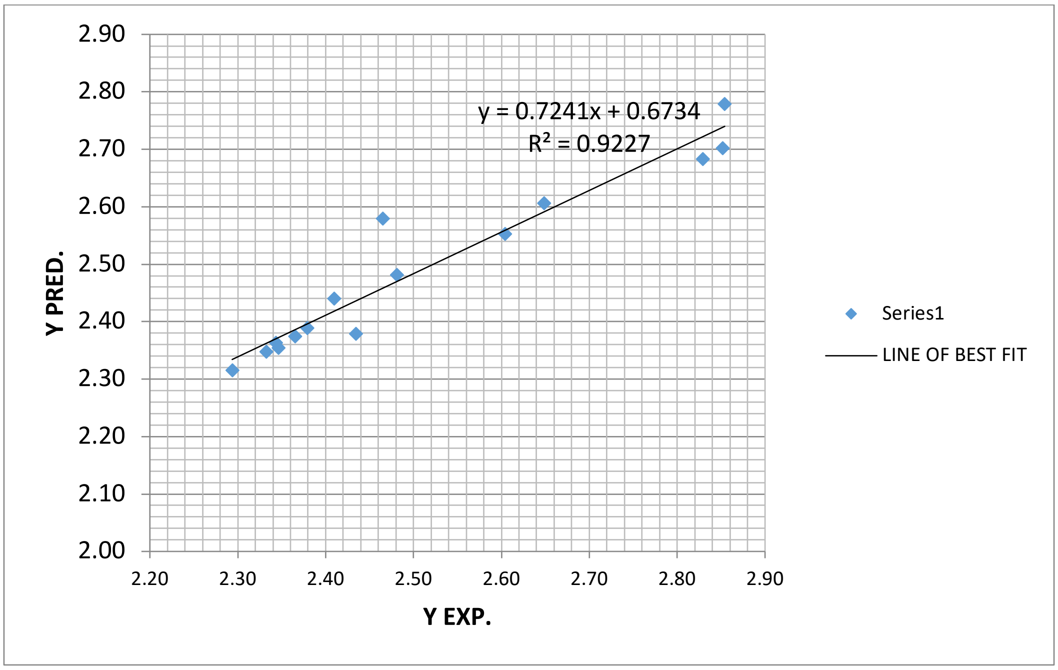

FIGURE 4. Scatterplot of Predicted vs. Experimental 28 days split tensile Strengths of concretes in 10% Crude oil/ water curing media

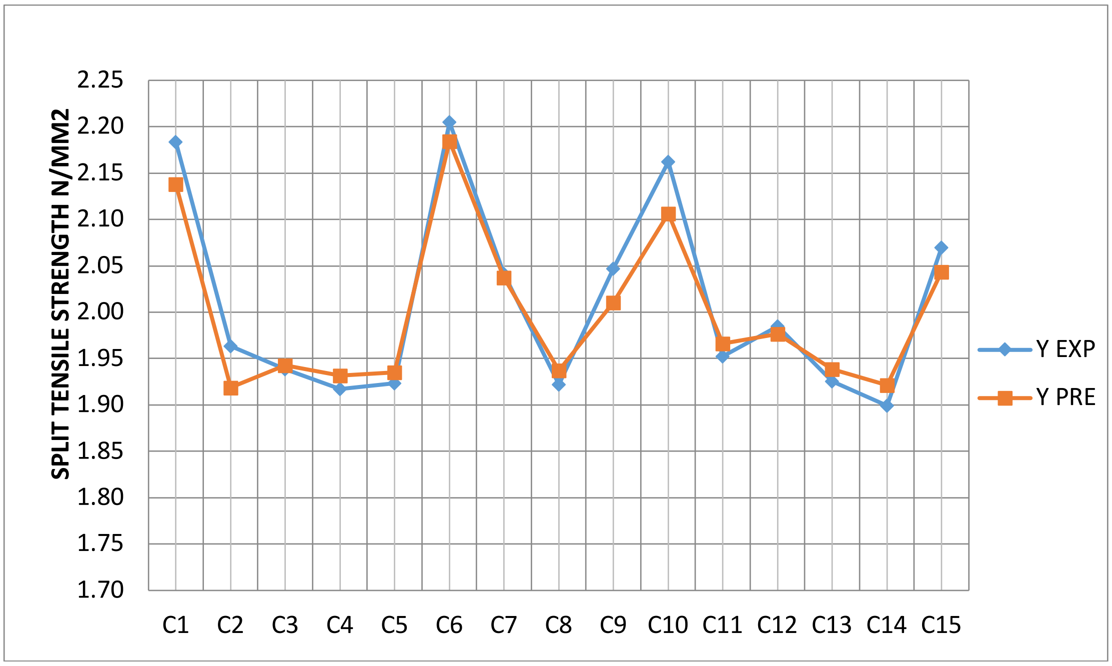

FIGURE 5. Comparison between Experimental and Predicted 7 days split tensile Strengths of concretes in 10% Crude oil/ water curing media

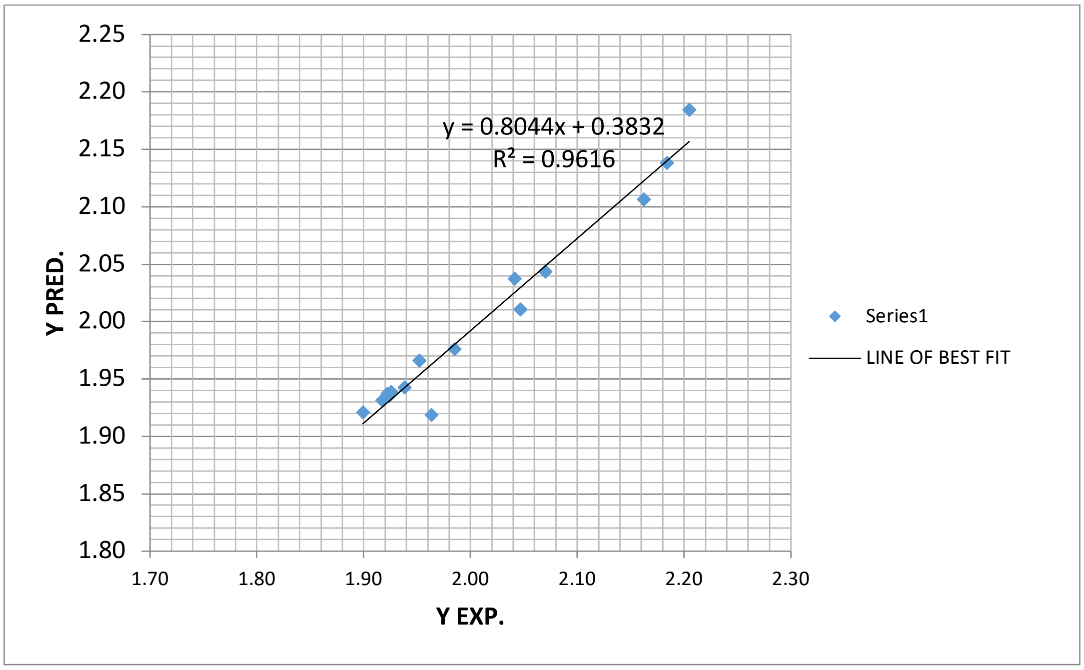

FIGURE 6. Scatterplot of Predicted vs. Experimental 7 days split tensile Strengths of concretes in 10% Crude oil/ water curing media

REFERENCES

Ajagbe, W. O. 2019. Modeling the effect of crude oil impacted sand on the properties of concrete using artificial neural network. https://www.hindawi.com/journals/isrn/2013/609379.

Amnesty International. 2018. https://www.amnesty.org/en/latest/news/2018/03/niger-delta-oil-spills-decoders/

Anya, C. U. 2016. *Models for Predicting the Structural Characteristics of Sand-quarry Dust Blocks.* (PhD Thesis) University of Nigeria, Nsukka, Nigeria.

Awoyera, P. 2020. Reinforced concrete deterioration caused by contaminated construction water. https://www.sciencedirect.com/science/article/abs/pii/S1350630720304349.

British Standard Institute. 1983. BS 1881: Part 117. Method for Determination of Tensile Splitting Strength. London: British Standard Institution. https://www.scribd.com/document/229939275/Bs-1881-117-Concrete-Dtermination-of-Tensile-Splitting-Str.

Cornell, J. A. 2011. *A Primer on Experiments with Mixtures.* A John Wiley & Sons Inc. Publications.

Ejeh, S. P. & Uche, O. A. 2009. Effect of crude oil spill on compressive strength of concrete materials. *Journal of Applied Science Research* 17: 55-61.

Ezihe, J. C. 2021. Modelling the effects of crude oil contaminated water on Structural properties of concrete. Unpublished Ph.D. Thesis. Department of Civil Engineering, University of Nigeria, Nsukka.

Ezihe, J. C. 2019. Mathematical model for predicting the water absorption of crude oil contaminated concretes. *The International Journal of Engineering and Science* 8(12): 36-40.

Gahlot, P. S. 2016. Fundamentals of Reinforced Cement Concrete Designs (CBS, 2016).

Nduka, J. K. 2011. Water quality issues in the Niger Delta of Nigeria: A look at heavy metal levels and some physicochemical properties. https://pubmed.ncbi.nlm.nih.gov/20607615/

Oba, K. M. 2019. A mathematical model to predict the tensile strength of asphalt concrete using quarry dust filler. *International Journal of Science and Engineering Research* 10(2): 1491-1498.

Osuji, S. O. & Nwankwo, E. 2015. Effect of crude oil contamination on the compressive strength of concrete. *Nigerian Journal of Technology* 34(2): 259-265.

Scheffe, H. 1958. Experiments with mixtures. *Journal of the Royal Statistical Society* 20: 344-360.

Ukoli, M. K. 2001. Environmental factors in the management of the oil and gas industry in Nigeria. https://www.econbiz.de/Record/environmental-factors-in-the-management-of-the-oil-and-gas-industry-in-nigeria-ukoli