



Regression Modelling of the Mechanical Properties of Sporosarcinal Pasteurii Concrete Using Datafit Software

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ABSTRACT

Sporosarcinal pasteurii concrete (S. Pasteurii concrete) is one of the many sustainable concretes which is yet to attain its full application in the construction industries. It is paramount to obtain optimum quantities of materials that can maximize the mechanical properties of a concrete without going through many trials and error experimentations which are time and resources consuming. The use of statical modelling tools in concrete technology helps in the optimization of the concrete materials for improved concrete performance. This research used Datafit software to model the compressive strength, tensile strength, flexural strength and creep of Sporosarcinal pasteurii Concrete (S. Pasteurii Concrete). The S. Pasteurii organisms were induced into the concrete at a concentration of 0, 1.5 x 10⁸CFU/ml, 6 x10⁸ CFU/ml, 1.2 x 10⁹ CFU/ml, 1.8 x 10⁹ CFU/ml and 2.4 x 10⁹ CFU/ml which correspond to the McFarland Scale of 0, 0.5OD, 2OD, 4OD and 6OD respectively. The bacterial solution and the nutrient content were 5% and 25% of the water required for the concrete mix. The compressive strength, tensile strength flexural strength was obtained at 56days, 28days, 28days and 365days respectively and the results were used for the model development and model validation taking the mechanical properties as the dependent variable (Y) and the curing age and bacterial concentration as independent variable, X1 and X2 respectively. The model performance was evaluated using the coefficient of determination (R²), the probability value (P) and the F ratio (F). The Coefficient of Determination of the compressive strength, tensile strength, flexural strength and compression creep are: 87%, 65%, 83% and 91% respectively, indicating that the goodness of fit of the models are high. The F ratio of the compressive strength, tensile strength, flexural strength and compression creep are: 16,3,6 and 240 respectively, indicating that there is a significant variation between the groups of data. The P Values of the mechanical properties considered in this study lies between 0 and 0.03 which are less than the significance level of 0.05. Therefore, this indicates that the regression models derived for the prediction of the mechanical properties of S. Pasteurii concrete accurately fits the experimental data.

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INTRODUCTION

The use of concrete in the construction industries cannot be over emphasised as it ranges from light structures to heavy structures. Concrete

is used worldwide and it uses is date back to the early civilization. Despite the popularity of concrete, it exhibits some issues like cracks and the emission of CO₂ which recourse to the

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production of sustainable concrete for environmental development (Jonker et al., 2010). Sustainable concrete are essentials for the development of infrastructures in developed countries in order to achieve the sustainable development goals. A lot of researches are aimed at producing cheaper and durable concrete through the inclusion of micro-organism into the concrete to improve the mechanical properties of the concrete and also to maximize the materials used for production. The action of the microbes in the concrete is known as the Microbial Induced Calcite Precipitation (Bhaduri and Montemagno, 2018; Hamed et al., 2018).

Microbial induced calcite Precipitation (MICP) has attracted attention in many disciplines of civil engineering due to the fact that it is a process where microorganism produces some amount of solid precipitation with the aid of chemical environment which can penetrate into a network of microscale pores thereby causing a long-range clogging and further results to an increase in the strength of the medium (Bhaduri and Montemagno, 2018, Fortin et al., 1997). The MICP Micro-organism used for this research is *Sporosarcina pasteurii* (*S. Pasteurii*). *Sporosarcina pasteurii* concrete is one of the many sustainable concretes which is yet to attain its full application in the construction industries. (Ahmed and Saba 2017; Gosh et al., 2019; Lapierre et al 2020; Ma, et al 2020; Cho et al., 2020). *S. Pasteurii* is readily available in the soil, has the ability to resist harsh environmental condition and precipitate calcium carbonate through microbial induced calcium precipitation (Yoosathaporn and Pathom 2016; Cappuccino and Sherman, 2014,).

S. pasteurii-concrete is a concrete in which *S. Pasteurii* is incorporated into the concrete to improve the properties of the concrete. Report from other researchers indicates that *S. Pasteurii* concrete has the advantage to self-heal cracks, since cracks in concrete are inevitable and can pose a risk to the concrete durability through the ingress of water and other chemical substance into the concrete thereby resulting to corrosion and deterioration of the reinforcement rod (Jonker et al., 2010). It has been reported that

the compressive strength of *S. Pasteurii*-concrete cubes is higher than the normal concrete cubes with the range of 5.2% to 30.2% depending on the growth medium used for the MICP (Yoosathaporn and Pathom, 2016).

Creep is long term deformation of a material. Materials that undergo creep are: steel, rocks, plastic and concrete. The emphasis of this study is based on the creep of *S. Pasteurii* concrete. Creep deformation occur in the direction of the applied load (Amlan and Devdas, 2017; Kamran, 2015; Shubham, 2017; Haseeb, 2017). Creep of a concrete is useful in the redistribution of internal stresses due to uniform load and restrained shrinkage. The effect of creep can be observed in most civil engineering structures ranging from small elements, such as beams, columns etc. to large mass concrete structures such as dams (Haseeb, 2017). Amlan and Devdas (2017) noted that the two main causes of creep are as a result of rearrangement of hydrated cement paste and expulsion of water from voids under load.

Regression modelling is a statistical method that is used to predict the properties of concrete. The advantages of regression modelling over other techniques have made it a trending statistical tool used in civil engineering for the prediction of future behaviour of concrete. These advantages include: the ability to predict concrete properties based on the experimental data input thereby reducing the need for extensive testing, it economizes resources and time compared to other experimental methods and it analyses the relationship between factors that control the properties of concrete (Palika, 2014, Kiambigi et al., 2019). The statistical tools used in the model's prediction include; coefficient of determination (R^2), adjusted coefficient of determination (Adj R^2), predicted coefficient of determination (pred R^2), prediction error sum of squares (PRESS), and p-values. Therefore, the goodness of fit of the model is based on the highest percentage of Adj R^2 and pred R^2 , the standard deviation of error and p-value for the lack-of-fit tests (Sunday 2022).

In this study the regression models are generated from experimental data using DataFit9.1 Software developed by Oakland

Technology Ltd, to predict the compressive strength, tensile strength, flexural strength and compression creep of the S. Pasteurii concrete produced with varying bacterial concentration of 0, 0.5, 2, 4 and 6OD. The curing age of the concrete and the bacterial concentrations is considered as the independent variable (X1 and X2 respectively) when generating the regression models.

It is relevant to develop regression models and optimize principal parameters related to the mechanical properties of the S. Pasteurii concrete in order to predict future outcomes that will enhance quick and accurate decisions about strength properties and compression creep of the concrete and hence evaluate the impact of individual parameter on the other. The development of regression models could identify the best solutions which could lead to improved strength, time and cost savings. However, the model graphs development could provide representation of complex concepts involved in the model equations. Datafit software assesses and calculates non-linear response surface of S. Pasteurii concrete on the basis of experimental design and can be used to predict the properties of the concrete.

Datafit software generates statistically validated predictive models that can be used for finding optimal process configurations of data that are related to one or more dependent variables (Olivares et al., 2022, Taku and Lawan 2024). The statistical analysis of data on the strength properties and compression creep of S. Pasteurii concrete, the model development and its validation, analysis of variance (ANOVA) and interaction plots as well as regression analysis could be performed with ease by using Datafit software.

The aim of this research is to develop regression models of the mechanical properties of sporosarcina pasteurii concrete. The objectives are as follows: development of the predictive regression models for the mechanical properties (compressive strength, flexural strength, split tensile strength and the compression creep) of S. pasteurii concrete and Validation of the predictive regression model for the mechanical properties of

S. Pasteurii concrete by comparing the model simulation to the experimental data set.

MATERIALS AND METHODS

Materials

The materials used for this research are: ordinary Portland cement, fine aggregates, coarse aggregates, portable water, micro-organism (*Sporosarcina pasteurii*), cementation reagents and generated dataset based on laboratory experiments. The data were evaluated for compressive strength of 1,3,7,14,21,28 and 56days of curing, splitting tensile strength of 3,7,14, and 28days of curing, flexural strength of 3,7,14, and 28 days of curing and compression creep for 365 days and Datafit 9.1 software.

Cement

Dangote Ordinary Portland Cement was used for this research. It was obtained from a cement shop at Samaru Zaria, Kaduna State. A mix ratio of 1:1.5:3 was adopted to meet the recommendation for minimum concrete strength.

Fine Aggregates

The fine (river sand) that was used was obtained from Ahmadu Bello University (ABU) dam samaru Zaria, Kaduna State. The fine aggregates were subjected to determine its properties: sieve analysis, test for clay and silt content, specific gravity test and fineness modulus all in accordance to BS EN196-3: 2016

Coarse Aggregates:

The coarse aggregates (crushed stones) used for this study was obtained from a quarry site opposite Nigeria College of Aviation technology along sokoto road Zaria, Kaduna. The following properties of the crushed stones was determined: particle size distribution, specific gravity, aggregate impact value, aggregate crushing value, bulk density, flakiness index, elongation index, water absorption, calcium carbonate content and silica- alkali reaction all in accordance to BS 812: 1995.



Water

The water used was obtained from the concrete laboratory of the department of Civil engineering ABU Zaria. It satisfied the requirements of BS EN 1008. (2002)

Microorganism

The microorganism used in this research work was *S. Pasteurii* which is classified according to the American Type Culture Collection as ATCC 11859. It was a rod-shaped Gram-positive bacterium with diameter 2 – 3µm and about 0.5 – 1.2µm wide and 1.3 - 4µm long. The *S. Pasteurii* microorganism was obtained from the department of micro biology laboratory Ahmadu Bello University Zaria.

Cementation Reagents

The cementation reagents required for the formation of MICP was obtained from the department of micro biology laboratory Ahmadu Bello University Zaria. The reagents used in this study were crystal violet (primary stain), Gram's iodine (Mordant), 95% ethyl alcohol (decolorizing agent) and safranin (counterstain).

DataFit software

DataFit Software is a statistical software developed by Oakland Technology Ltd. The version used for this study is DataFit 9.1 software.

Method

Determination of the Strength Properties of *S. Pasteurii* concrete

The compressive, flexural and split tensile strength properties of the hardened *S. pasteurii* concrete at various concentration of 0, 0.5, 2, 4 and 6OD was determined. For the compressive strength, three cubes of size 150 x 150 x 150mm was crushed for each curing day of 1, 3, 7, 14, 28 and 56 days. The average compressive strength was obtained as the compressive strength of the concrete at any of the curing age. For the split tensile strength, three cylindrical specimen of size 100mm x 200mm was used at each day to obtain the strength at 7, 14, 21 and 28 days. The average tensile strength was obtained. For the flexural strength, three beam

samples of 100 x 100 x 450mm was used at each curing day of 7, 14, 21 and 28days to obtain the average flexural strength.

Creep Test

The compressive creep test was conducted using the hydraulic compressive machine. The device allowed simultaneous loading of two aligned specimens. Longitudinal deformations were recorded by means of an inductive transducer located within a reservation created during casting by placing a removable metallic insert on the mould axis. Concrete cubes of size 150mm x 150mm x 150mm was loaded with a long-term load for 365days. The strain in the loaded concrete was recorded from the time of loading to the 365th day.

Statistical Modelling of Concrete

Regression models were generated from experimental data using DataFit Software 9.1 developed by Oakland Technology Ltd, to predict the compressive strength, tensile strength, flexural strength and compression creep of the *S. Pasteurii* concrete produced with varying bacterial concentration of 0, 0.5, 2, 4 and 6OD. The curing age of the concrete and the bacterial concentrations were considered as the independent variable (X1 and X2 respectively) when generating the regression models.

Model Validation

The models developed from Datafit9 software were validated using the properties of the *S. Pasteurii* concrete. The experimental data were inserted into the Datafit9 software and the model predicted values were obtained. The credibility of a predictive model is based on the ability of the model to be validated by confirming that it attains its aim for development by comparing the model simulation to the experimental data set. Other indicators used to validate the model were the Mean Absolute Error (MEA), Nash Sutcliffe Efficiency (NSE) and Root Mean Squaring Error (RMSE).

The Mean Absolute Error is defined as the average of the absolute difference between

the observed and the predicted values in the test sample.

$$MAE = \frac{\sum_{i=1}^n |M_i - P_i|}{n} \quad (1)$$

Where M_i , P_i and n denotes the absolute experimental values, predicted values and number of variables respectively.

The Nash-Sutcliffe Efficiency (NSE) account for the efficiency of a model by evaluating the degree to which the observed and simulated data fit the 1:1 line, and ranges from 0 to 1. Models with Nash-Sutcliffe Efficiency above 0.5 are said to be satisfactory, those between 0.6 and 0.75 are good while those greater than 0.75 indicate high quality. Lin, et al., (2017)

$$NSE = 1 - \frac{\sum_{i=1}^n [P_i - P_{iavg}]^2}{\sum_{i=1}^n [M_i - M_{iavg}]^2} \quad (2)$$

Where; M_i is the i th experimental value, M_{iavg} is the average experimental value, P_i is the i th predicted values, P_{iavg} is average predicted value and n is the number of samples.

The Root Mean Square Error (RMSE) is used for the evaluation of the quality of the prediction model and it is also used to estimate how well the model can predict the target value.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n [P_i - M_i]^2}{n}} \quad (3)$$

Where M_i is the absolute experimental values, P_i is the predicted values and n is the number of variables.

RESULTS AND DISCUSSIONS

The impact of the variables: curing age (X1) and bacteria concentration (X2) on the predicted results for compressive strength, split tensile strength, flexural strength and compression creep strength of *S. Pasteurii* concrete was compared with the experimental results.

Experimental Results

Table 1: Compressive Strength of *S. Pasteurii* Concrete

Curing Age	Compressive Strength of <i>S. Pasteurii</i> Concrete(N/mm2)				
(Days)	0OD	0.5OD	2OD	4OD	6OD
1	11.81	20.74	18.08	18.97	11.85
3	15.11	21.93	20.29	21.04	19.56
7	16.15	24	21.19	24	21.78
14	22.37	24.15	23.26	26.67	23.7
21	21.04	24.44	28.15	25.85	23.41
28	22.52	26.52	26.96	28.15	23.41
56	23.25	25.83	32.59	34.02	24.11

Table 2: Tensile Strength of *S. Pasteurii* Concrete

Curing Age	Tensile Strength of <i>S. Pasteurii</i> Concrete(N/mm2)				
(Days)	0OD	0.5OD	2OD	4OD	6OD
3	1.72	2.09	1.98	2.37	1.88
7	1.65	2.66	2.62	3.01	2.04
14	2.02	3.55	3.13	2.39	2.6
28	3.14	3.38	3.41	2.62	3.14

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Table 3: Flexural Strength of S. Pasteurii Concrete

Curing Age (Days)	Flexural strength of S. Pasteurii Concrete (N/mm ²)				
	0OD	0.5OD	2OD	4OD	6OD
3	1.35	3.6	2.1	2.7	2.7
7	2.18	3.53	2.1	3.15	2.85
14	2.7	3.98	3.68	3	2.7
28	2.7	3.9	2.94	3.98	2.93

Table 4: Creep Reading for S. Pasteurii Concrete

S/No	Load duration time (Days)	Creep deformation (x 10 ⁻⁴ mm)
1	0.042	4.86
2	0.08	4.83
3	0.1	4.81
4	0.2	4.83
5	1	4.85
6	2	4.85
7	3	4.72
8	4	4.84
9	5	4.87
10	6	4.89
11	7	4.87
12	14	4.86
13	21	4.85
14	28	5.20
15	59	5.11
16	87	5.29
17	118	5.30
18	148	5.17
19	179	4.33
20	209	3.89
21	240	4.06
22	271	4.09
23	301	4.07
24	332	4.07
25	365	4.18

Statistical Analysis of the Models

Table 5: Statistical Analysis of compressive strength of S-Pasteurii concrete Model

Variables	Coefficient	Standard Error	T-ratio	P- Value
A	29.56578586	3.65390172	8.091565709	0
B	-377.0026298	241.4243479	-1.561576672	0.13148
C	5553.426818	4783.847125	1.160870461	0.25711
D	-35112.08686	33504.65466	-1.047976385	0.30509
E	81667.27506	81089.15792	1.007129401	0.32392

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Variables	Coefficient	Standard Error	T-ratio	P- Value
F	-51748.64473	52133.87227	-0.992610801	0.3308
G	-6.2106E+12	592561.7497	-10480930.96	0
H	1.81142E+13	1728305.103	10480930.96	0
I	-1.29387E+13	1234503.645	-10480930.96	0
J	3.23469E+12	308625.9113	10480930.96	0
K	-2.58775E+11	24690.0729	-10480930.96	0

Legend/Key A, B, C, D, E, F, G, H, I, J and K are control variables with their respective values presented as the coefficient

Table 6 Statistical Analysis of Splitting Tensile strength of S. Pasteurii Concrete

Variables	Coefficient	Standard Error	T	P- Value
A	10275261533	107669.7744	95433.11098	0
B	-5.34314E+11	5598828.271	-95433.11095	0
C	8.55929E+12	89688922.11	95433.11095	0
D	-4.93418E+13	517030256.8	-95433.11095	0
E	8.4586E+13	886337583.2	95433.11095	0
F	-5.3433E+12	39786.2651	-134300096.3	0
G	1.55846E+13	116043.2732	134300096.2	0
H	-1.11319E+13	82888.0523	-134300096.2	0
I	2.78297E+12	20722.01307	134300096.2	0
J	-2.22637E+11	1657.761046	-134300096.2	0

Legend/Key A, B, C, D, E, F, G, H, I and J are control variables with their respective values presented as the coefficient

Table 7: Statistical Analysis of Flexural Strength of S. Pasteurii concrete Model

Variable	Coefficient	Standard Error	t-ratio	Prob(t)
A	2.526566957	0.702221806	3.597961409	0.00418
B	7.435479796	21.14922695	0.351572179	0.7318
C	-109.5938547	163.7097705	-0.669439914	0.51702
D	242.4901595	320.4622602	0.756688664	0.46513
E	1.13853E+13	83880.93084	135731797.6	0
F	-3.32072E+13	244652.715	-135731797.6	0
G	2.37194E+13	174751.9393	135731797.6	0
H	-5.92985E+12	43687.98482	-135731797.6	0
I	4.74388E+11	3495.038785	135731797.6	0

Legend/Key A, B, C, D, E, F, G, H and I are control variables with their respective values presented as the coefficient

Table 8: Statistical Analysis of Compression Creep of S. Pasteurii concrete Model

Variable	Coefficient	Standard Error	t-ratio	Prob(t)
A	3.692333	5.13E-02	71.91708	0
B	-2.47E-03	2.64E-04	-9.35149	0
C	0.208667	1.05E-02	19.82012	0

Legend/Key A, B and C are control variables with their respective values presented as the coefficient

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Regression Models for Strengths of Concrete

The regression equation generated from DataFit9.1 statistical software for the compressive strength model (f_c), splitting tensile

test model (f_{Ts}), flexural strength model (f_f) and compression creep model (f_{cr}) are presented in equations 4 to 11

$$f_c = A + \frac{B}{X_1} + \frac{C}{X_1^2} + \frac{D}{X_1^3} + \frac{E}{X_1^4} + \frac{F}{X_1^5} + GX_2 + HX_2^2 + IX_2^3 + JX_2^4 + KX_2^5 \quad (4)$$

$$f_c = 29.56578586 - \frac{377.0026298}{X_1} + \frac{5553.426818}{X_1^2} - \frac{35112.08686}{X_1^3} + \frac{81667.27506}{X_1^4} - \frac{51748.64473}{X_1^5} - 6.2106E + 12X_2 + 1.81142E + 13X_2^2 - 1.29387E + 13X_2^3 + 3.23469E + 12X_2^4 - 2.58775E + 11X_2^5 \quad (5)$$

$$f_{Ts} = A + \frac{B}{X_1} + \frac{C}{X_1^2} + \frac{D}{X_1^3} + \frac{E}{X_1^4} + FX_2 + GX_2^2 + HX_2^3 + IX_2^4 + JX_2^5 \quad (6)$$

$$f_{Ts} = 1028 E+8 - \frac{5.343E+11}{X_1} + \frac{8.559E+12}{X_1^2} + \frac{-4.934E+13}{X_1^3} + \frac{8.459E+13}{X_1^4} - 5.343E + 12X_2 + 1.558E + 13X_2^2 - 1.113E + 13X_2^3 + 2.782E + 12X_2^4 - 2.226E + 11X_2^5 \quad (7)$$

$$f_f = A + \frac{B}{X_1} + \frac{C}{X_1^2} + \frac{D}{X_1^3} + EX_2 + FX_2^2 + GX_2^3 + HX_2^4 + IX_2^5 \quad (8)$$

$$f_f = 2.526566957 + \frac{7.435479796}{X_1} + \frac{-109.5938547}{X_1^2} + \frac{242.4901595}{X_1^3} + 1.13853 \times 10^{13} X_2 - 3.32072 \times 10^{13} X_2^2 + 2.37194 \times 10^{13} X_2^3 - 5.92985 \times 10^{12} X_2^4 + 4.74388 \times 10^{11} X_2^5 \quad (9)$$

$$f_{cr} = A + BX_1 + CX_2 \quad (10)$$

$$f_{cr} = 3.692333 - 2.47 \times 10^{-3} X_1 + 0.208667 X_2 \quad (11)$$

Where: X_1 is curing age of the concrete for compressive, splitting tensile and flexural strength

X_2 is bacteria concentration

A, B, C, D, E, F, G, H, I, J and K are the control variables with constant values for each model.

Selection of Accurate Predictive Models

Table 9 presents the fit statistics results for the developed regression models and the coefficients of determination (R^2) for the respective models.

Table 9: Validity and accuracy of the developed models

S/N	Model	R^2	Adjusted R^2
1	Compressive strength	0.87228	0.81906
2	Split tensile strength	0.65976	0.50272
3	Flexural strength	0.82536	0.69835
4	Compression creep	0.94482	0.93240

Legend/key: R^2 represent the coefficient of determination

The integrity of the models was checked by R^2 , which is a global indicator for assessing the fitness of a model. All the mechanical properties tested for in Table 9 has an R^2 values that is approximately 1, which is indicating a high goodness of fit. The higher the R^2 value the better the regression models fit the laboratory data. From Table 9, the model of the compression creep of *S. Pasteurii* concrete has the best fit given that it R^2 Value is 94%. This is as a result of increase in the experimental data obtained, as stated by (Haque

et al., 2021). The R^2 values indicate that the variation of the models was significantly dependent on the variation of the curing age and the *S. Pasteurii* content. The R^2 values of the models were found to be suitably in agreement with adjusted R^2 because the differences were less than 0.2 in all models as reported by Haque et al., (2021).

Analysis of Variance of the Models

The DataFit9 software was able to generate the percentage error and the residual

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normal probability plot showing the deviation of the calculated Y values from the actual

experimental values for each S. Pasteurii concrete properties that was determined.

Table 10: Analysis of Variance of Compressive Strength of S. Pasteurii Concrete Model

Source	DF	SS	MS	F	P
Regression	10	687.9626411	68.79626411	16.39110848	0
Error	24	100.7320732	4.197169716		
Total	34	788.6947143			

Legend/key: DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares, F= the ratio of two variance estimate, P = Probability Value

Table 11: Analysis of Variance of Splitting Tensile Strength of S. Pasteurii Concrete Model

Source	DF	SS	MS	F	P
Regression	9	5.126035769	0.56955953	3.459498931	0.03313
Error	10	1.646364231	0.164636423		
Total	19	6.7724			

Legend/key: DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares, F= the ratio of two variance estimate, P = Probability Value

Table 12 Analysis of Variance of Flexural Strength of S. Pasteurii concrete Model

Source	DF	SS	MS	F	P
Regression	8	7.656741049	0.957092631	6.498320031	0.00291
Error	11	1.620113951	0.147283086		
Total	19	9.276855			

Legend/key: DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares, F= the ratio of two variance estimate, P = Probability Value

Table 13: Analysis of Variance of Compression Creep of S. Pasteurii concrete Model

Source	F	SS	MS	F	P
Regression	2	23.95562	11.97781	240.1439	0
Error	47	2.344249	4.99E-02		
Total	49	26.29987			

Legend/key: DF= Degree of Freedom, SS= Sum of Squares, MS= Mean Squares, F= the ratio of two variance estimate, P = Probability Value

The significance and goodness of fit test for S. Pasteurii concrete model was conducted using the T and P values to evaluate the slopes of the regression models. The evaluation is to check if the slope of the regression model is equal to zero as depicted in the null hypothesis.

The null hypothesis states that S. Pasteurii content and curing age of the samples

do not influence the strength of the concrete. Therefore, the null hypothesis is rejected because all the strength models increased with increase in curing age and S. Pasteurii content. Also, the low P-Value from Table 10 to Table 13 shows that the both variables are highly significant showing that the variation in the compressive, split tensile, flexural strength and compression creep of the

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concrete is as a result of curing age and *S. Pasteurii* content.

Models Validation

Fig. 1 to Fig.4 shows the diagnostics plots of residuals. The plots shown in Fig.1 to Fig.4 indicates that the concentration of data points towards the linear regression line; which indicate the adequacy of the models. Few outliers were found in all cases which indicates the fitness of the data with the predictive models for the responses. This is in line with the Taku and Lawan (2024). The

few outliers observed may be due to uncontrollable factors such as environmental fluctuation, instrumental limitation, human error, unaccounted variable etc. that were likely to occur during the experiments. The random scatter of data points between upper and lower limits is also an indication of the adequacy of the models for the responses. The random scatter of data points along the 450 linear regression lines in Fig. 1 to Fig.4 indicated better predictive models were selected for all the responses.

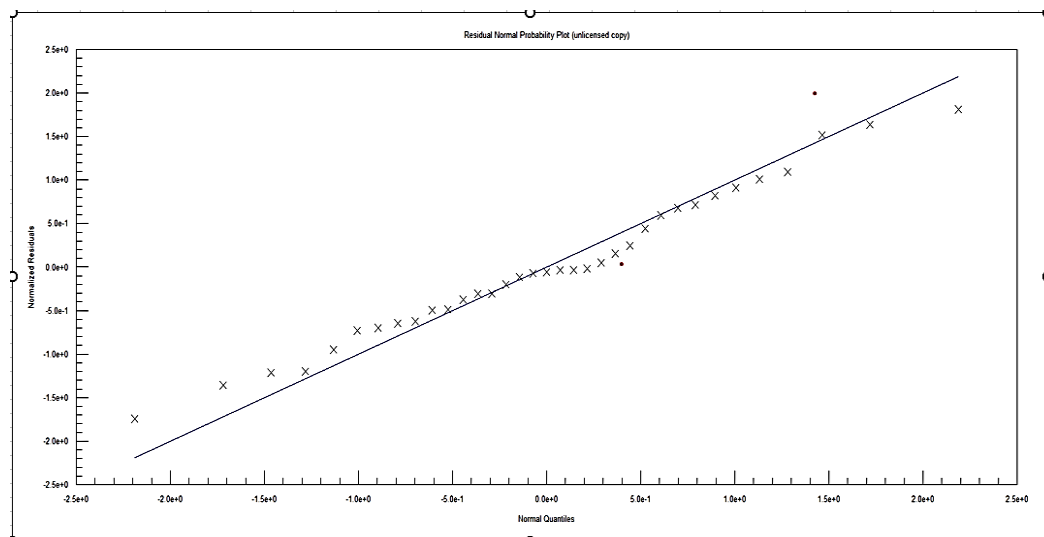


Figure 1 Normalized Residual against Normal Quantiles for Compressive strength of *S. Pasteurii* Concrete

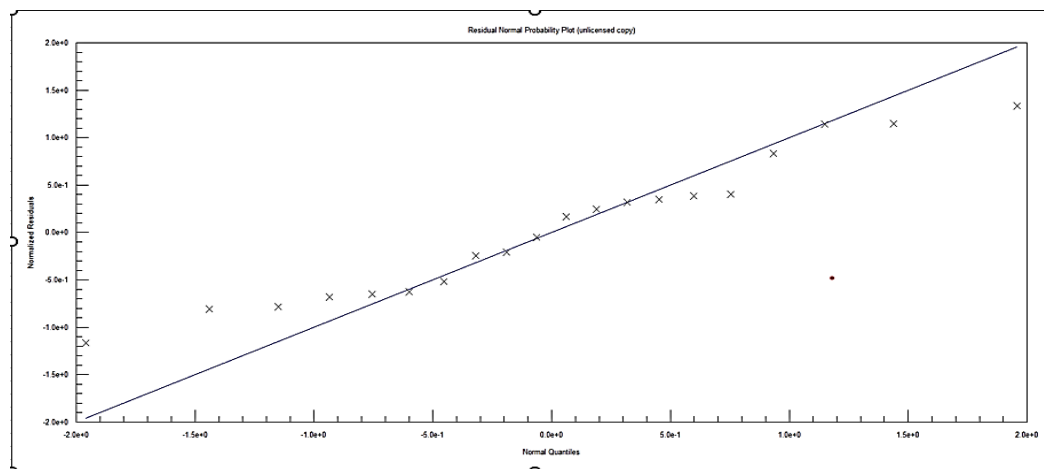


Figure 2. Normalized Residuals against Normal Quantiles for Tensile Strength of *S. Pasteurii* Concrete

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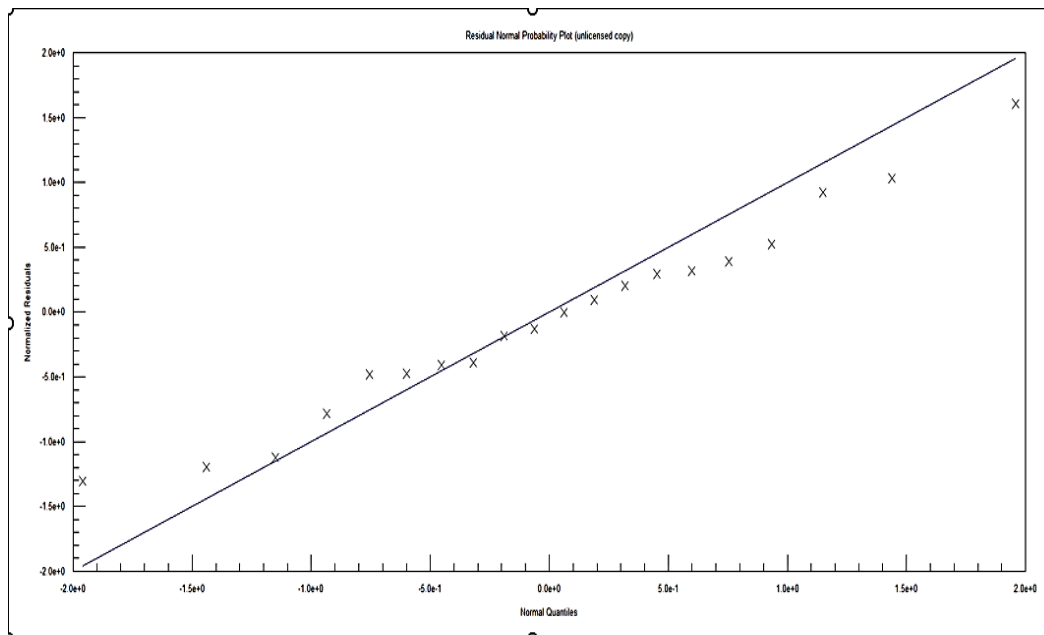


Figure 3. Normalized Residuals against Normal Quantiles for Flexural Strength of S. Pasteurii Concrete

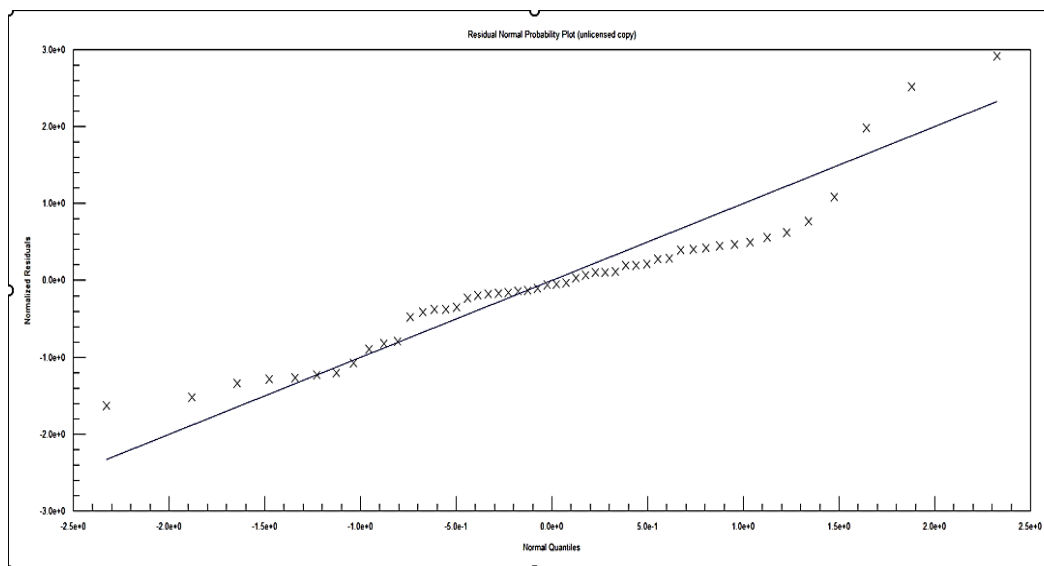


Figure 4. Normalized Residuals against Normal Quantiles for compression Creep of S. Pasteurii Concrete

CONCLUSION

Based on the results presented, the following conclusion were obtained:

1. The Coefficient of Determination of the compressive, tensile strength, flexural

strength and compression creep are: 87%, 65%, 83% and 91% respectively. Therefore, the regression models derived for the prediction of the strength and compression creep of S. Pasteurii concrete are adequate

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for predicting the compressive, tensile, flexural strength and compression creep of the concrete.

2. The random scatter of data points along the 450 linear regression lines indicated better predictive models were selected for all the responses.

RECOMMENDATIONS

Based on the results obtained from this study, the following recommendations are made:

1. The developed regression models could be used for prediction of future strength and compression creep of *S. Pasteurii* concrete
2. The developed mathematical models could help for formulation and hypothesis testing.

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