Modelling The Mechanical, Thermo-Physical, And Filtration Properties Of Dried Clay-Sand Mixtures For Water Storage Vessel Using Regression Method

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ABSTRACT: The study estimated on some mathematical models to predict accurately the relationship between the compressive force, crushing strength, thermal conductivity, filtration rate and permeability of dried clay-sand mixtures within experimental limit. The dependent parameter is the investigated properties of the dried clay-sand mixtures while the sample of dried clay-sand mixtures is the independent parameters. The experimental data were modelled using simple linear regression method. The data were analysed with the aid of statistical software called Statistical Package for Social Science (SPSS), version 17. The findings show that the coefficient of determination (R^2) of the formulated models is significantly high with respect to the adjusted R^2 at 95% confidence interval. The F-value and t-statistic shows that the regression models and the investigated parameters are significant to the model. The estimated result from the models and the investigated experimental result were highly significant and explained a very high percentage effect of what was taking place in the samples of dried clay-sand mixtures. This result showed that the investigated properties parameters can be predicted accurately using the established relationship with the samples of dried clay-sand mixtures. It is also observed that the estimated result from the models having clay-sand mixture specimen with 0% weight of sand has the highest compressive force, crushing strength, least thermal conductivity, least filtration rate and least permeability, which will be the ideal specimen for making water storage vessels.

KEY WORDS: Mathematical models, Dried clay-sand mixtures, Mechanical properties, Thermo-physical properties, Filtration properties, Water storage vessel, Regression method

1. INTRODUCTION

Fitting a model for the investigated locally raw material for water vessel has become very necessary because there is need for optimization when it comes to the correct mix proportion ratio of the experimental sample that has the adequate handling strength for filtration and storage after fabrication. The fitted models require an adequate agreement of the investigated properties so as to minimize the defect that may likely arise during fabrication process. A lot of research study had been carried out in fitting a mathematical model to a clay related samples with respect to their investigated properties. Nwakonobi et al., [1] developed a mathematical model to optimize the mix proportion that will produce the maximium strength of clay-ricehusk-cement mixture using scheffe's simplex lattice approach. The model they formulated was used to compare favourably with their experimental data. Their findings shows that the optimum value of strength predicted by this model is 18.204Nmm-2 corresponding to a mix proportion of 77.80, 14.16 and 8.04 percent of clay, ricehusk and cement respectively at optimum water content of 23.22%. Benamar et al., [2] developed a mathematical model used for simulating the soil suffusion curves obtained with a short soil sample.

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The comparison of their model and experimental results indicate a quite good agreement. Ayadi et al., [3] studied clay's mineralogy effect on rheological behaviour of ceramic suspensions using an experimental design. Their statistical study shows that the fitted model was adequate to describe the rheological behaviour of clay suspensions. Mama et al., [4] developed a mathematical model for predicting compressive strength of sandcrete blocks using statistical analysis for the sandcrete block data obtained from the experimental work done in their research. The results of predictions were comparatively analysed using t-test. Their findings show that the developed models are acceptable for the prediction of compressive strength of sandcrete blocks. The objective of the research study is specifically to develop a statistically adequate model for clay-sand mixture that is a predictor of the compressive force, crushing strength, thermal conductivity, filtration rate and permeability of the mixture given any mix proportion of the samples of the mixture.

2. METHODOLOGY

The research study is based on the experimental data of the work done by Raimi [5]. The experimental data comprises of the mechanical, thermo-physical and filtration properties of the dried clay mixture of different sand concentrations for water vessel. The experimental data comprises of eleven (11) samples which varies in percentage of sand by weight of clay. The experimental data is analyzed using simple linear regression method with the aid of statistical software called Statistical Package for Social Science (SPSS), version 17.

3. DATA PRESENTATION

The data to be analysed in this research study is presented below in Table 1-3 based on the experimental investigated properties of the dried clay-sand mixtures.

Table 1: Mechanical properties

Sample	Percentage of sand by 50g of clay (P_{s1})	Compressive force (F_c)	Crushing strength (C_s)
1	0	3575	7.28
2	10	2208	4.50
3	20	2058	4.19
4	30	2200	4.48
5	40	2166	4.41
6	50	2120	4.32
7	60	1890	3.85
8	70	1400	2.85
9	80	1379	2.80
10	90	960	1.96
11	100	750	1.53

Table 2: Thermo-Physical properties

Sample	Percentage of sand by 200g of clay (P_{s2})	Thermal conductivity (T_c)
1	0	0.0133
2	10	0.0146
3	20	0.0150
4	30	0.0233
5	40	0.0253
6	50	0.0386
7	60	0.0444
8	70	0.0545
9	80	0.1057
10	90	0.1091
11	100	0.1191

Table 3: Filtration properties

Sample	Percentage of sand by 250g of clay (P_{s3})	Filtration rate (f_r)	Permeability (P_b)
1	0	0.0042	0.0017
2	10	0.0069	0.0028
3	20	0.0071	0.0029
4	30	0.0076	0.0031
5	40	0.0083	0.0034
6	50	0.0088	0.0036
7	60	0.0095	0.0039
8	70	0.0108	0.0044
9	80	0.0115	0.0047
10	90	0.0133	0.0054
11	100	0.0145	0.0059

N.B: The mass of clay for the respective investigated properties of the samples is constant as seen in Table 1-3.

4. MODEL FORMULATION

The following are the models formulated in this research study:

$$\widehat{F_c} = a_0 + a_1 P_{s1} + \varepsilon_1 \quad (1)$$
$$\widehat{C_s} = b_0 + b_1 P_{s1} + \varepsilon_2 \quad (2)$$
$$\widehat{T_c} = c_0 + c_1 P_{s2} + \varepsilon_3 \quad (3)$$
$$\widehat{f_r} = d_0 + d_1 P_{s3} + \varepsilon_4 \quad (4)$$
$$\widehat{P_b} = e_0 + e_1 P_{s3} + \varepsilon_5 \quad (5)$$

Where:

$\widehat{F_c}$ = Estimated Compressive force (N)
$\widehat{C_s}$ = Estimated Crushing strength (MNm^{-2})
$\widehat{T_c}$ = Estimated Thermal conductivity ($Wm^{-1}k^{-1}$)
$\widehat{f_r}$ = Estimated Filtration Rate (cm^3s^{-1})
$\widehat{P_b}$ = Estimated Permeability (Darcy)
$\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4 \& \varepsilon_5 = The\ Regression\ Residual$

The defined models will be used to predict the properties of the percentage of sand by weight of clay (P_s) within the experimental limit of the investigated samples. $a_0\ to\ a_1, b_0\ to\ b_1, c_0\ to\ c_1, d_0\ to\ d_1, and\ e_0\ to\ e_1$ are coefficients of regression models for compressive force, crushing strength, thermal conductivity and permeability respectively which were to be determined from the SPSS analysis. Coefficients of determination (R^2), F-statistic and t-test were also obtained for the models using the same statistical software package. The agreement of the estimated results (from the models) with the observed data was indicated by the values of R^2.

5. DATA ANALYSIS

The experimental investigated data in Table 1, Table 2 and Table 3 respectively, is analysed with the aid of SPSS. The extracted output of the result is shown in Table 4. The estimated regression models of the investigated properties are also included in the Table 4. Analysis of the tested regression models of the investigated properties is estimated and then compared with the experimental data as seen in Table 5.

Table 4: Extracted SPSS Output Result of the Experimental Investigated data

Properties		Equation Models	$R^2(\%)$	R^2_{adj} (%)	F-statistic	t-statistic	P-value.
Mechanical Properties	Compressive force (F_c)	$\widehat{F_c} = 2929.182 - 20.936 * P_{s1}$ (6)	82.3	80.3	41.839	15.297	0.00
						-6.468	0.00
	Crushing strength (C_s)	$\widehat{C_s} = 5.965 - 0.043 * P_{s1}$ (7)	82.3	80.4	41.931	15.314	0.00
						-6.475	0.00
Thermo-Physical Properties	Thermal conductivity (T_c)	$\widehat{T_c} = -0.006 + 0.001 * P_{s2}$ (8)	86.6	85.1	58.093	-0.689	0.508
						7.622	0.00
Filtration Properties	Filtration rate (f_r)	$\widehat{f_r} = 0.005 + (8.877E - 5) * P_{s3}$ (9)	95.7	95.2	200.129	13.149	0.00
						14.147	0.00
	Permeability (P_b)	$\widehat{P_b} = 0.002 + (3.627E - 5) * P_{s3}$ (10)	96.1	95.7	221.831	13.787	0.00
						14.894	0.00

Table 5: Investigated Experimental data compared with the Estimated (Theoretical) data of the regression models

Sample	Experimental F_c	Estimated F_c	Experimental C_s	Estimated C_s	Experimental T_c	Estimated T_c	Experimental f_r	Estimated f_r	Experimental P_b	Estimated P_b
1	3575	2929.18	7.28	5.97	0.0133	-0.006	0.0042	0.005	0.0017	0.002
2	2208	2719.82	4.5	5.54	0.0146	0.004	0.0069	0.0059	0.0028	0.0024
3	2058	2510.46	4.19	5.11	0.015	0.014	0.0071	0.0068	0.0029	0.0027
4	2200	2301.1	4.48	4.68	0.0233	0.024	0.0076	0.0077	0.0031	0.0031
5	2166	2091.74	4.41	4.25	0.0253	0.034	0.0083	0.0086	0.0034	0.0035
6	2120	1882.38	4.32	3.82	0.0386	0.044	0.0088	0.0094	0.0036	0.0038
7	1890	1673.02	3.85	3.39	0.0444	0.054	0.0095	0.0103	0.0039	0.0042
8	1400	1463.66	2.85	2.96	0.0545	0.064	0.0108	0.0112	0.0044	0.0045
9	1379	1254.3	2.8	2.53	0.1057	0.074	0.0115	0.0121	0.0047	0.0049
10	960	1044.94	1.96	2.1	0.1091	0.084	0.0133	0.013	0.0054	0.0053
11	750	835.58	1.53	1.67	0.1191	0.094	0.0145	0.0139	0.0059	0.0056

6. DISCUSSION OF RESULTS

I. MODEL 6: COMPRESSIVE FORCE

The sample data were tested at 95% confidence interval using a two tail test. The coefficient of multiple determination (R^2) is 82.3%. This means that the explanatory variable (percentage of sand by weight of clay) accounted for 82.3% of the total change in the dependent variable (F_c). The remaining 17.7% is explained by other exogenous factor in the model. This shows a good fit to the model. The adjusted R^2 (80.3%) shows that the R^2 indicates a strong behaviour of the dried clay mixtures of different sand concentration. Since the F-value is 41.839 and P-value is < 0.05, then we can infer that the regression model is significant. The P-value for the t-statistic of the variable (sample clay-sand mixtures) is ≤ *0.05,* so we conclude that the variable is significant to the model. The result of the estimated data (theoretical data) from the model and the experimented data were plotted as shown in figure 1. The value of $R^2(82.3\%)$ showed that there was strong agreement between the estimated and the experimental data. Therefore, the model is good predictor of compressive force of dried clay mixture with different sand concentration.

II. MODEL 7: CRUSHING STRENGTH

The sample data were tested at 95% confidence interval using a two tail test. The coefficient of multiple determination (R^2) is 82.3%. This means that the explanatory variable (percentage of sand by weight of clay) accounted for 82.3% of the total change in the dependent variable (C_s). The remaining 17.7% is explained by other exogenous factor in the model. This shows a good fit to the model. The adjusted R^2 (80.4%) shows that the R^2 indicates a strong behaviour of the dried clay mixtures of different sand concentration. Since the F-value is 41.931 and P-value is < 0.05, then we can infer that the regression model is significant. The P-value for the t-statistic of the variable (sample clay-sand mixtures) is ≤ *0.05,* so we conclude that the variable is significant to the model. The result of the estimated data (theoretical data) from the model and the experimental data were plotted as shown in figure 2. The value of $R^2(82.3\%)$ showed that there was strong agreement between the estimated and the experimental data. Therefore, the model is good predictor of crushing strength of dried clay mixture with different sand concentration.

III. MODEL 8: THERMAL CONDUCTIVITY

The sample data were tested at 95% confidence interval using a two tail test. The coefficient of multiple determination (R^2) is 86.6%. This means that the explanatory variable (percentage of sand by weight of clay) accounted for 86.6% of the total change in the dependent variable (T_c). The remaining 13.4% is explained by other exogenous factor in the model. This shows a good fit to the model. The adjusted R^2 (85.1%) shows that the R^2 indicates a strong behaviour of the dried clay mixtures of different sand concentration. Since the F-value is 58.093 and P-value is < 0.05, then we can infer that the regression model is significant. The P-value for the t-statistic of the variable (sample clay-sand mixtures) is ≤ *0.05,* so we conclude that the variable is significant to the model. The result of the estimated data (theoretical data) from the model and the experimental data were plotted as shown in figure 3. The value of $R^2(86.6\%)$ showed that there was strong agreement between the estimated and the experimental data. Therefore, the model is good predictor of thermal conductivity of dried clay mixture with different sand concentration.

IV. MODEL 9: FILTRATION RATE

The sample data were tested at 95% confidence interval using a two tail test. The coefficient of multiple determination (R^2) is 95.7%. This means that the explanatory variable (percentage of sand by weight of clay) accounted for 95.7% of the total change in the dependent variable (f_r). The remaining 4.3% is explained by other exogenous factor in the model. This shows a good fit to the model. The adjusted R^2 (95.2%) shows that the R^2 indicates a strong behaviour of the dried clay mixtures of different sand concentration. Since the F-value is 200.129 and P-value is < 0.05, then we can infer that the regression model is significant. The P-value for the t-statistic of the variable (sample clay-sand mixtures) is ≤ *0.05,* so we conclude that the variable is significant to the model. The result of the estimated data (theoretical data) from the model and the experimental data were plotted as shown in figure 4. The value of $R^2(95.7\%)$ showed that there was strong agreement between the estimated and the experimental data. Therefore, the model is good predictor of filtration rate of dried clay mixture with different sand concentration.

V. MODEL 10: PERMEABILITY

The sample data were tested at 95% confidence interval using a two tail test. The coefficient of multiple determination (R^2) is 96.1%. This means that the explanatory variable (percentage of sand by weight of clay) accounted for 96.1% of the total change in the dependent variable (P_b). The remaining 3.9% is explained by other exogenous factor in the model. This shows a good fit to the model. The adjusted R^2 (95.7%) shows that the R^2 indicates a strong behaviour of the dried clay mixtures of different sand concentration. Since the F-value is 221.831 and P-value is < 0.05, then we can infer that the regression model is significant. The P-value for the t-statistic of the variable (sample clay-sand mixtures) is ≤ *0.05,* so we conclude that the variable is significant to the model. The result of the estimated data (theoretical data) from the model and the experimented data were plotted as shown in figure 5. The value of $R^2(96.1\%)$ showed that there was strong agreement between the estimated and the experimental data. Therefore, the model is good predictor of permeability of dried clay mixture with different sand concentration.

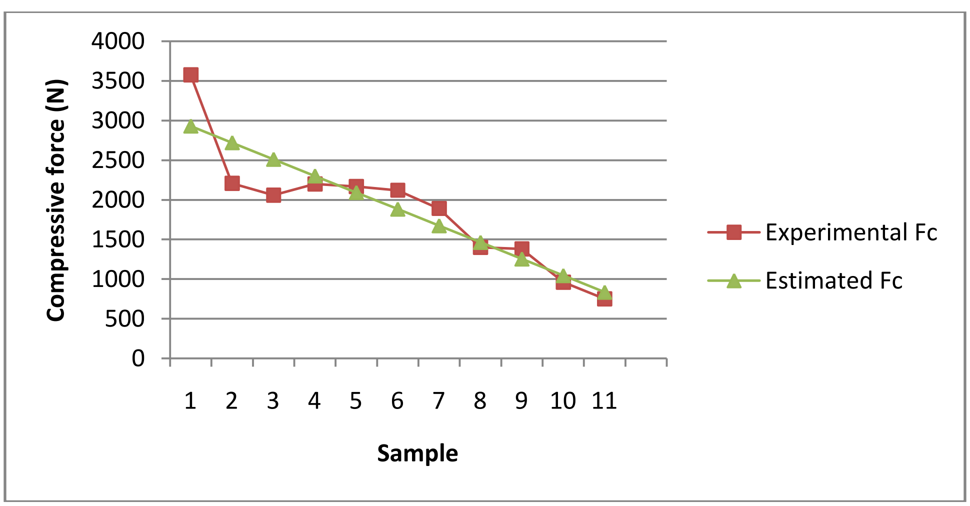

Fig.1: Relationship between Experimental and Estimated value of Dried Clay-Sand Mixtures of Compressive Force (F_c)

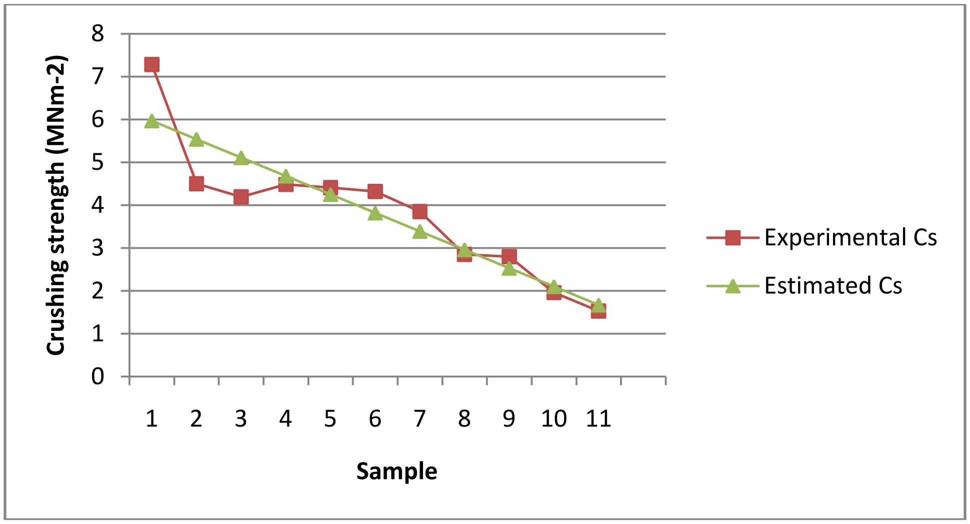

Fig.2: Relationship between Experimental and Estimated value of Dried Clay-Sand Mixtures of Crushing Strength (C_s)

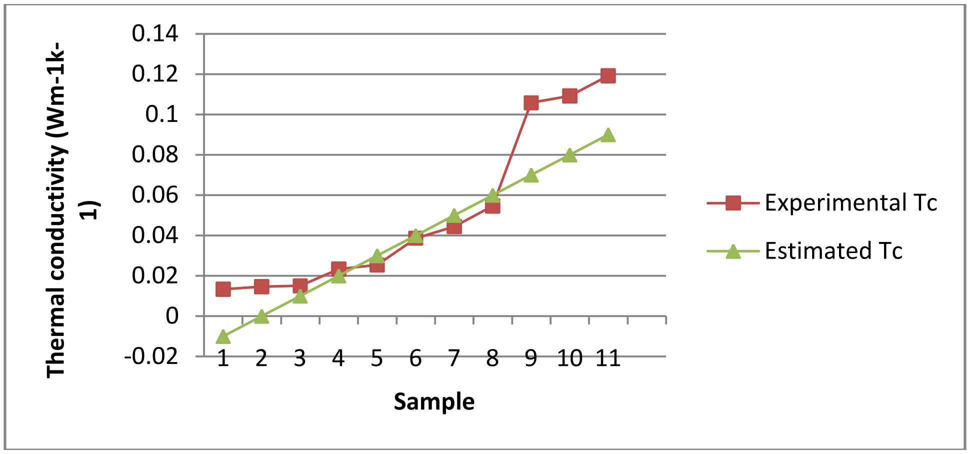

Fig.3: Relationship between Experimental and Estimated value of Dried Clay-Sand Mixtures of Thermal-Conductivity (T_c)

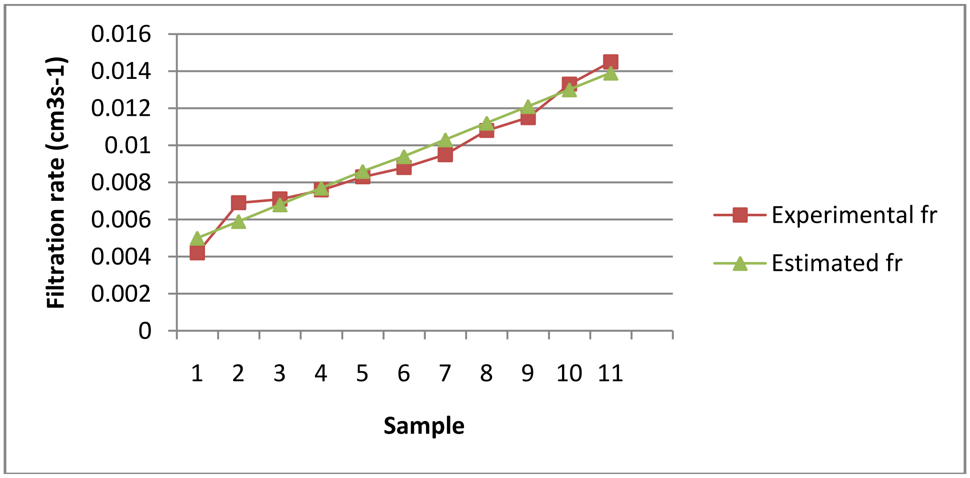

Fig.4: Relationship between Experimental and Estimated value of Dried Clay-Sand Mixtures of Filtration Rate (f_r)

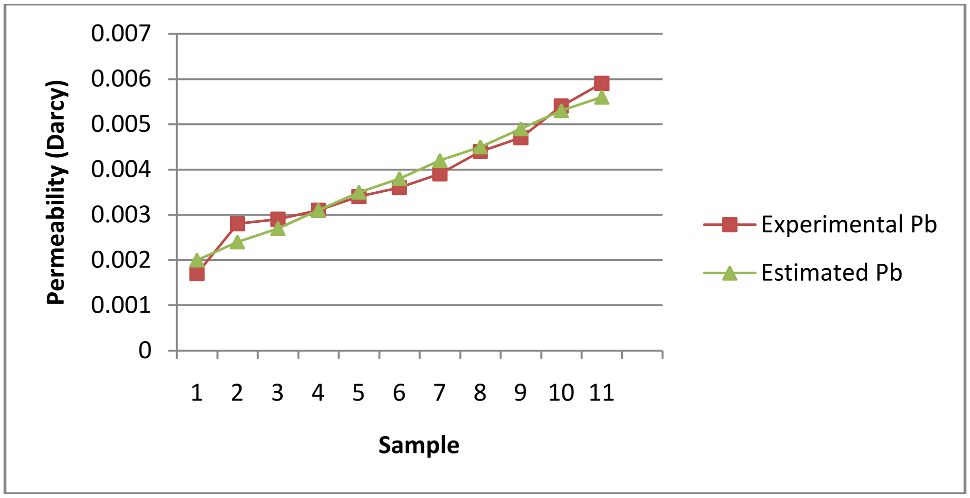

Fig.5: Relationship between Experimental and Estimated value of Dried Clay-Sand Mixtures of Permeability (P_b)

7. CONCLUSION

The respective models as for compressive force, crushing strength, thermal conductivity, filtration rate and permeability described in this paper study can predict accurately the established relationships of the properties among the samples of dried clay mixtures of different sand concentration within the limit of the experimental data. The models displayed a very high coefficient of determination (R^2) that tells us how significant the models are in term of prediction of the properties of the investigated samples. The models would help researchers to look into some design considerations when fabricating water storage vessel with the locally raw material against the defect of inadequate proportion mixing ratio of the clay-sand mixtures so as to enhance the handling strength. It can generally be concluded that these models show good agreement with the experimental results.

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