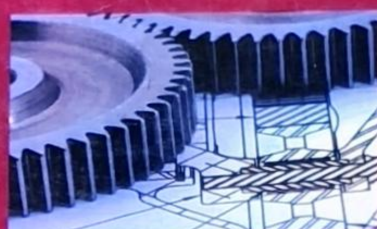
Volume 3 No. 1 - 2016

FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA
Technology for Empowerment

ISSN: 2465 - 7425

NIGERIA JOURNAL OF ENGINEERING AND APPLIED SCIENCES (NJEAS)

Statistical Models for Compressive Strength of Concrete with Fly Ash as Sand Replacement Material

M. Abdullahi[1], A. U. Raji[1], O. James[1] and T. Y. Tsado[1]
[1]Civil Engineering Department, Federal University of Technology, Minna
Email: m.abdullahi@futminna.edu.ng, abdulapai@yahoo.com

Abstract
Statistical models for the prediction of compressive strength of concrete with fly ash as sand replacement material have been developed in this paper. Secondary data were used for the model development in MINITAB environment. The polynomial models show the relationship between the properties of concrete and its mix compositions. The models were fit with polynomial terms that produced curvilinear effects on the surface plot. These models were developed at 0.05 levels of significance for the terms. The result shows that the models are adequate to predict the underlying relationship with P-values less than 0.05 for each of the variable retained in the model. The adjusted coefficient of determination for the models of compressive strength at 7 and 28 days chosen were 0.9737 and 0.9797 respectively. This shows that the models have the capabilities of explaining 97.37 and 97.97% of variability in the data under consideration. This shows that the models are adequate in predicting the compressive strength of concrete at 7 and 28 days.
Keywords: Models, Compressive strength, Concrete, Fly ash, Replacement materials.

Introduction

Municipal solid wastes and the processes involved in manufacturing and servicing industries produce numerous waste materials. Environmental awareness has contributed immensely to the concerns related with waste disposal. Managing solid waste is among the major problems facing the environment in the world. With the insufficiency of space for land filling and owing to its rising cost, utilization of waste has become a promising alternative to disposal. Several researches have been carried out on the utilisation of waste products as a replacement of natural sand in concrete (Bahoria *et al.*, 2013, Mohammed *et al.*, 2014a, Mohammed *et al.*, 2014b, Mohammed *et al.*, 2013, Mohammed *et al.*, 2011a, Mohammed *et al.*, 2011b, Abdullahi *et al.*, 2009). Ash from coal based power plants is one of such wastes.

Concrete is a mixture of cement, aggregates and water. Other materials added at the mixer are referred to as admixtures (Taylor, 2000). Concrete is a composite construction material that has widely gained acceptance as a viable material in the construction industry and is used extensively in most Civil Engineering projects. Thus, considering environmental sustainability and the conservation of energy and resources, concrete is presumed to be the most preferred construction material. Enormous natural resources is consumed on a daily basis in the production of concrete and it is believed that one day these natural resources will become extinct thus the need to search for a compatible material to replace sand in concrete has become very vital in light of the world facing serious problems due to the decreased availability of river sand (Govndarajan, 2014).

Presently, fine aggregate which is a natural resource is gradually being exploited as a result of the need to meet the high demand of concrete in the construction industry. Here concrete is made by using fly ash to partially replace fine aggregate (sand). This way the natural resources (fine aggregate) can be saved, by using alternative product. The demand for building materials like fine aggregate, cement and coarse aggregate is increasing in Nigeria due to increase in growth of population, economy and living standards of the people. Based on the Nigeria cement report of 2013; projected cement consumption in the country is estimated to be 23.2 metric tons per annum. The projection show 8.5% Compound Annual Growth Rate (CAGR) in cement consumption in Nigeria from 2012-2015 (Nigeria Cement Sector Report: Emerging Prominence from a Deficit Past, 2013). Cement concrete is the most preferred and most used material of construction because of its wide variety of skills, ease in production and use. Three characteristics are considered in using concrete, namely, its resilience, its cheapness of construction as a result of improvement in design and reduced material cost, and the environmental protection and preservation of energy. These aspects may be satisfied by using fly ash in concrete (Aruna and Kavitha, 2014).

Fly ash (FA) is among the by products resulting from burning of coal which composes of tiny particles that ascends with flue or vent gases. Fly ash plays the role of a pozzolana when applied as a binder. Pozzolanas are siliceous or siliceous/aluminous materials which forms a cementitious compound when combined with lime and water. The pozzolanas are those materials lacking independent cement properties, but exihibit cementitious properties in its pulverized separated shape when mixed with calcium hydroxide and moisture. Cementitious compounds are formed as a result of chemical reactions between the pozzolana and calcium hydroxide at room temperature. Certain similarities and dissimilarities exist between Ordinary Portland Cement (OPC) and pozzolanas. Pozzolanas also hydrate in water as OPC, though they do not yield the strength required as Ordinary Portland Cement but develops strength over a longer period. Fly ash respond to calcium hydroxide released due to cement hydration and develops numerous calcium aluminum and calcium silicate hydrates. Fly ash is the most popular, suitable and frequently used pozzolanas worldwide (Madhavi *et al.*, 2010).

As by-products of burning of coal in thermal power plants, fly ash is removed as fine molecular residues from the dust collecting system, before releasing it to the atmosphere. Particles of fly ash are normally spherical, with diameters ranging from less than 1mm to 150mm. The dust collection equipment determines to a large extent the range of sizes of the particles of any given fly ash. The type and quantity of inflammable substance present in the coal used, gives an idea of the composition of the fly ash. A large percentage of fly ash comprises of glasses and chemical compound produced from the following elements namely calcium, magnesium and silicon. Incombustible coal remnants gather carbon particles with fly ash. The amount of these carbon particles depend on certain factors which include the air and/or fuel, the rate of combustion of coal, and the level of combustion of the coal. Generally, ash produced as a result of the combustion of sub-bituminous coal has little quantities. Bituminous coals produce unburned carbon in large quantity (Ramezanianpour, 2014).

Studies made on the use of fly ash (FA) show that fly ash improves the structure of Portland cement which eventually enhances its longevity. Numerous building codes approve using fly ash as an admixture in concrete. Several structures have been constructed such as the Petros Tower in Malaysia, Great Belt Bridge and Euro Tunnel in different locations. Both Class C and Class F fly ashes can be conveniently used as partial cement replacements. Class "F" fly ash has unpredictable effects on the concrete's air content, resulting in reduction of resistance to the damage caused by freeze/thaw. Most often fly ash can be used to replace cement at levels up to 30% by mass, and most recently it is believed to replace higher dosages in certain applications. To that effect, various methods are established for partially replacing cement with volumes of fly ash as high as 50%. Researchers are optimistic that cement replacement with fly ash will, to a large extent, reduce the greenhouse gas of concrete, as manufacturing a ton of cement produces close to an equal amount of Carbon dioxide (CO_2) while no CO_2 is generated with fly ash. Although, manufacture of Portland cement has reached nearly four billion metric tons in 2013, replacing huge quota of this quantity with fly ash will reduce to a large extent the carbon emissions associated with construction, in as much as production of fly ash is taken as a waste.

However, very few researches have been carried out on the use of fly ash as a replacement for fine aggregate in concrete. Thus some industrial wastes are effectively utilized in the production of concrete. However, the present rising depletion of fine aggregate in concrete has led to an overwhelming search for possible means for its replacement. Fly ash can generally be used as an admixture in the manufacture of cement, as a replacement for cement and in concrete. Adequate research has been done on the partial replacement of sand in structural concrete. An increase in fly ash content results in higher strength for a given density, as fly ash is of pozzolonic nature. Guidelines for predicting compressive strength of concrete having fly ash as a material partially replacing sand or fine aggregate is not readily available (Rajamane, *et al.*, 2006). It is advantageous to have models for the prediction of compressive strength for fly ash concrete. Previous researchers have developed models for properties of concrete and mixture proportioning (Abdullahi *et al.*, 2009a; Abdullahi *et al.*, 2009b). It would be advantageous to have models for the prediction of compressive strength of fly ash concrete. The research presented here aimed at developing models for predicting the compressive strength of concrete using fly ash as sand replacement material. This was achieved by establishing the graphical relationship between the properties of concrete and its mix composition and obtaining the models relating the properties of concrete and its mix composition using MINITAB.

Materials and Method

The experimental data from secondary source was used for the model development. A scientific approach for carrying out the research was adopted and there were no tests carried out of any sort as secondary data used for the study was extracted from the research work carried out by Rajamane, *et al.,* (2006). The prediction of compressive strength of concrete with fly ash as sand replacement material was studied. Statistical software Minitab 15 was used to develop the model that will predict the strength of the FAC.

Experimental data

The tabular data used was taken from Table 3 in (Rajamane, *et al.,* 2006). For developing models of compressive strength of concrete, certain parameters were considered and extracted from the table. These include the water/binder ratio (w_b), the water/cement ratio (w_c), the fly ash addition factor (m), the sand replacement level (p_s), the fly ash fraction in binder (p) and the 7 and 28 days compressive strength determined from the tests carried out under controlled standard laboratory conditions. The aim of the experiment that was carried out is to develop an equation that will predict compressive strength of FACs (fly ash concretes) with FA (fly ash) as Sand Replacement Material (SRM) by considering a cement concrete mix having proportions of cement, sand, coarse aggregate and water at 1:1:2:0.35; and by preparing fly ash concrete with fly ash at Sand Replacement Levels (SRL) of 20%, 40% and 60% with each sand replacement level having three water cement ratios. A number of 28 mixes were prepared and their compressive strengths determined. An extensive data for analyzing compressive strength in that regard was generated and the same data was used for this research. This data is shown in Table 1.

Table 1: Comparison between compressive strengths from tests and prediction formulae

Mix ID	W_b	W_c	M	P_s	P	f_{test}, N/mm^2 7days	f_{test}, N/mm^2 28days
S_0	0.35	0.35	0.0	0.0	0.00	35.20	46.10
S_1	0.25	0.30	1.0	0.2	0.17	44.20	65.20
S_2	0.42	0.50	1.0	0.2	0.17	25.60	35.90
S_3	0.38	0.45	1.00	0.20	0.17	29.20	41.50
S_4	0.21	0.30	1.00	0.40	0.29	49.20	70.20
S_5	0.43	0.60	1.00	0.40	0.29	23.10	30.20
S_6	0.32	0.45	1.00	0.40	0.29	32.50	46.20
S_7	0.25	0.40	1.00	0.60	0.38	38.90	59.10
S_8	0.38	0.60	1.00	0.60	0.38	25.10	34.90
S_9	0.34	0.55	1.00	0.60	0.38	28.10	42.20
S_{10}	0.24	0.30	1.20	0.20	0.19	44.60	69.40
S_{11}	0.40	0.50	1.20	0.20	0.19	24.60	36.40
S_{12}	0.36	0.45	1.20	0.20	0.19	28.60	43.10
S_{13}	0.20	0.30	1.20	0.40	0.32	55.10	71.00
S_{14}	0.41	0.60	1.20	0.40	0.32	24.80	35.10
S_{15}	0.30	0.45	1.20	0.40	0.32	34.20	45.60
S_{16}	0.23	0.40	1.20	0.60	0.42	46.10	59.10
S_{17}	0.35	0.60	1.20	0.60	0.42	28.20	39.50
S_{18}	0.32	0.55	1.20	0.60	0.42	29.40	44.60
S_{19}	0.23	0.30	1.60	0.20	0.24	48.30	62.90
S_{20}	0.38	0.50	1.60	0.20	0.24	24.90	36.20
S_{21}	0.34	0.45	1.60	0.20	0.24	32.60	45.90
S_{22}	0.24	0.40	1.60	0.40	0.39	37.90	62.70
S_{23}	0.37	0.60	1.60	0.40	0.39	23.10	37.50
S_{24}	0.34	0.55	1.60	0.40	0.39	30.00	42.10
S_{25}	0.20	0.40	1.60	0.60	0.49	44.90	65.90
S_{26}	0.36	0.70	1.60	0.60	0.49	24.90	34.10
S_{27}	0.28	0.55	1.60	0.60	0.49	30.70	49.20

Source: Rajamane *et al.*, (2006).

Model development

Models were developed with the data in Table 1 using Minitab15. The model development started by substituting in the data in Table 1 by substituting w_b, w_c, m, p_s, and p with X_1, X_2, X_3, X_4, and X_5 respectively. This is shown generically below

Water / Binder ratio, $w_b = X_1$
Water / Cement ratio, $w_c = X_2$
Fly ash addition factor, $m = X_3$
Sand replacement level, $p_s = X_4$
Fly ash fraction in binder, $p = X_5$
7 Days compressive strength, $f_{7days} = Y_1$
28 Days compressive strength, $f_{28days} = Y_2$

This was followed by defining the custom response surface design for each column factor and stating the low and high levels for each column. The result of this action is shown in Table 2.

Table 2: Defined custom response surface design

X_1	X_2	X_3	X_4	X_5	Y_1	Y_2	StdOrder	RunOrder	Blocks	PtType
0.35	0.35	0.0	0.0	0.00	35.2	46.1	1	1	1	1
0.25	0.30	1.0	0.2	0.17	44.2	65.2	2	2	1	1
0.42	0.50	1.0	0.2	0.17	25.6	35.9	3	3	1	1
0.38	0.45	1.0	0.2	0.17	29.2	41.5	4	4	1	1
0.21	0.30	1.0	0.4	0.29	49.2	70.2	5	5	1	1
0.43	0.60	1.0	0.4	0.29	23.1	30.2	6	6	1	1
0.32	0.45	1.0	0.4	0.29	32.5	46.2	7	7	1	1
0.25	0.40	1.0	0.6	0.38	38.9	59.1	8	8	1	1
0.38	0.60	1.0	0.6	0.38	25.1	34.9	9	9	1	1
0.34	0.55	1.0	0.6	0.38	28.1	42.2	10	10	1	1
0.24	0.30	1.2	0.2	0.19	44.6	69.4	11	11	1	1
0.40	0.50	1.2	0.2	0.19	24.6	36.4	12	12	1	1
0.36	0.45	1.2	0.2	0.19	28.6	43.1	13	13	1	1
0.20	0.30	1.2	0.4	0.32	55.1	71.0	14	14	1	1
0.41	0.60	1.2	0.4	0.32	24.8	35.1	15	15	1	1
0.30	0.45	1.2	0.4	0.32	34.2	45.6	16	16	1	1
0.23	0.40	1.2	0.6	0.42	46.1	59.1	17	17	1	1
0.35	0.60	1.2	0.6	0.42	28.2	39.5	18	18	1	1
0.32	0.55	1.2	0.6	0.42	29.4	44.6	19	19	1	1
0.23	0.30	1.6	0.2	0.24	48.3	62.9	20	20	1	1
0.38	0.50	1.6	0.2	0.24	24.9	36.2	21	21	1	1
0.34	0.45	1.6	0.2	0.24	32.6	45.9	22	22	1	1
0.24	0.40	1.6	0.4	0.39	37.9	62.7	23	23	1	1
0.37	0.60	1.6	0.4	0.39	23.1	37.5	24	24	1	1
0.34	0.55	1.6	0.4	0.39	30.0	42.1	25	25	1	1
0.20	0.40	1.6	0.6	0.49	44.9	65.9	26	26	1	1
0.36	0.70	1.6	0.6	0.49	24.9	34.1	27	27	1	1
0.28	0.55	1.6	0.6	0.49	30.7	49.2	28	28	1	1

Subsequently, an analysis on the response surface generated by the action above has revealed the possibility of developing four different polynomial models. This include the linear model, the interaction model, the pure quadratic and the full quadratic model. These models and their expressions are shown as follows:

i. Linear model

$$Y = a_0 + a_1 x_1 + a_2 x_2 + a_3 x_3 + a_4 x_4 + a_5 x_5 \quad (1)$$

ii. Interaction model

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_1x_2 + a_7x_1x_3 + a_8x_1x_4 + a_9x_1x_5 + a_{10}x_2x_3 + a_{11}x_2x_4 + a_{12}x_2x_5 + a_{13}x_3x_4 + a_{14}x_3x_5 + a_{15}x_4x_5 \quad (2)$$

iii. Pure quadratic model

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_1^2 + a_7x_2^2 + a_8x_3^2 + a_9x_4^2 + a_{10}x_5 \quad (3)$$

v. Full quadratic model

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_1x_2 + a_7x_1x_3 + a_8x_1x_4 + a_9x_1x_5 + a_{10}x_2x_3 + a_{11}x_2x_4 + a_{12}x_2x_5 + a_{13}x_3x_4 + a_{14}x_3x_5 + a_{15}x_4x_5 + a_{16}x_1^2 + a_{17}x_2^2 + a_{18}x_3^2 + a_{19}x_4^2 + a_{20}x_5^2 \quad (4)$$

Where;

Y = Response or dependent variable,

x = Predictor, and x_1, x_2, x_3, x_4, x_5 are input variables.

The term x_i signifies the result of individual factors, while the product x_ix_j signifies that of interaction, whereas the term x_i^2 implies the effect of the square model. The terms a_0, a_1, a_2, a_3, a_4, a_5 ….. a_{20} are coefficients.

The number of coefficients in each of the equations above signifies the minimum number of experimental data capable of fitting the polynomial model. A further analysis of the response surface for this experiment revealed that a linear model with a subset of the squares and interaction model will be appropriate for both the 7 and 28 days compressive strengths of the FAC. This was achieved by using backward and forward searching technique. The 7 days compressive strength (denoted as Y_1) was selected and a suitable term resulting in an acceptable level of significance (P-value) of less than 5% on successive removal of terms that do not fit in the model from selected terms to available terms of the response surface interface; and including the terms that fit the model from available terms to the selected estimable terms of the response surface design interface of the software. The stated design was carried out using uncoded units and the same process described above was repeated for the 28 days compressive strength (denoted as Y_2).

On completing the task above and further analyzing the response surface, graphs were plotted so as to constitute the desired response values and operating conditions. In order to produce a clear picture of the response surface a surface plot was chosen and the option of the software to generate plots for all pairs of factors was selected. This action yielded graphs plotted in three dimensional views.

Results and Discussion

The polynomial models developed in this work are presented. The results from the regression analysis and response surface plots are discussed and the graphical models are interpreted.

Response surface regression for compressive strength at 7 days

From Table 3, the polynomial model for the compressive strength of concrete at 7 days with fly ash partially replacing sand is as follows:

$$Y_1 = 94.69 + 97.87X_1 - 336.13X_2 - 15.95X_3 - 216.5X_4 + 409.34X_5 + 195.36X_2^2 - 191.96X_4^2 - 923.82X_5^2 + 952.31X_4{*}X_5 \quad (5)$$

Equation 5 is the model developed for the compressive strength of concrete at 7 days. Table 3 and 4 show the outcome of the response surface regression of the compressive strength at 7 days. The P-values of each of the coefficients are less than 0.05, indicating that the inclusion of those variables in the model will increase its predictive capability and should be retained. The adjusted coefficient of determination, R-Sq (adjusted) is 0.9737. This implies that the model can explain the variability in the data by 97.37%, indicating that the model is adequate. Table 4 shows the analysis of variance for the compressive strength at 7 days. The p-values of linear, square and interaction are all less than 0.05, indicating that all the terms are significant and should be retained in the model.

Table 3: Estimated regression coefficients for Y_1

Term	Coefficient	SE Coefficient	T	P
Constant	94.69	4.993	18.963	0.000
X_1	97.87	44.776	2.186	0.042
X_2	-336.13	58.610	-5.735	0.000
X_3	-15.95	5.285	-3.018	0.007
X_4	-216.5	65.862	-3.287	0.004
X_5	409.34	109.812	3.728	0.002
X_2*X_2	195.36	34.464	5.668	0.000
X_4*X_4	-191.96	72.519	-2.647	0.016
X_5*X_5	-923.82	267.094	-3.459	0.003
X_4*X_5	952.31	278.773	3.416	0.003

Standard Error of Regression, S = 1.49596

Prediction Sum of Squares, PRESS = 92.539

Coefficient of Multiple Determination, R-Sq = 98.25%

R-Sq (predicted) = 95.98% R-Sq (adjusted) = 97.37%

Table 4: Analysis of variance for Y1

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2259.41	2259.412	251.0458	112.18	0.000
Linear	5	2158.95	276.653	55.3305	24.72	0.000
Square	3	74.35	95.458	31.8194	14.22	0.000
Interaction	1	26.12	26.115	26.1153	11.67	0.003
Residual Error	18	40.28	40.282	2.2379		
Total	27	2299.69				

DF= Degree of freedom, Seq SS= sequential sum of squares, Adj SS= Adjusted sum of squares, F = ratio of mean squares, and P = Level of significance

Surface plot for compressive strength at 7 days

The developed model is used to obtain the surface plot. This gives a pictorial view of the model in three dimensions. The pictorial views of the model are shown in Figs. 1 and 2.

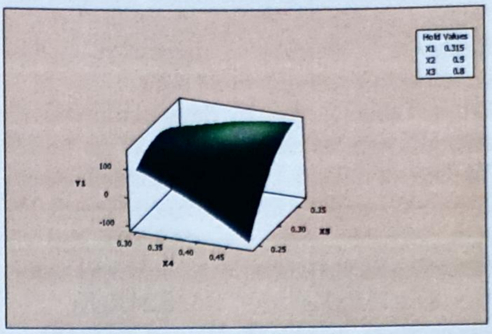


Fig. 1: Surface plot of Y_1 vs X_5, X_4

Fig. 1, revealed that at seven (7) days the compressive strength decreases as the level of sand replacement increases. A further analysis of the plot revealed an appreciable increase in the compressive strength following an increase in the fraction of fly ash in the binder portion of the concrete. This implies that increasing the fraction of fly ash in the binder portion enhances the seven (7) days compressive strength (f_{7days}) of the concrete.

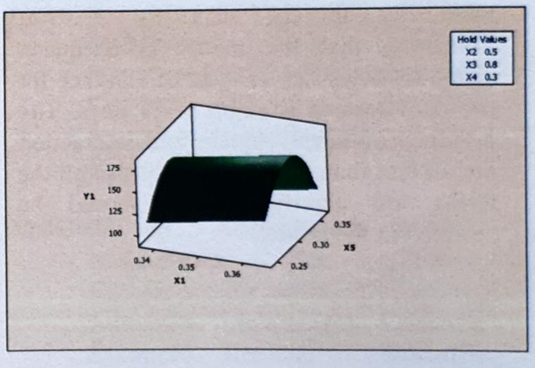


Fig. 2: Surface plot of Y_1 and X_1, X_5

The result of Fig. 2 indicates that the compressive strength at 7 days increases slightly with a gradual increase in the water – binder ratio. A further analysis on the plot shows appreciable increment in compressive strength at the early stage of increasing the fly ash fraction in the binder portion of the concrete; but subsequent increase of the fraction of fly ash in the binder has shown a drastic decrease in the compressive strength.

Response surface regression for compressive strength at 28 days

From Table 5, the 28 days compressive strength can be expressed as

$$Y_2 = -65.95 + 215.77X_1 - 296.71X_2 + 276.65X_3 + 330.87X_4 - 326.63X_5 + 5.03X_2^2 + 841.56X_5^2 - 559.55X_1X_3 - 695.97X_1X_4 + 1055.41X_1X_5 + 713.63X_2X_3 + 872.71X_2X_4 - 1328.24X_2X_5 - 442.90X_3X_4 - 551.28X_4X_5 \quad (6)$$

Equation 6 is the reduced full quadratic model developed for the compressive strength of concrete at 28 days. Table 5 and 6 shows the outcome of the response surface regression of the compressive strength at 28 days. The P-values of each of the coefficients are less than 0.05, indicating that the inclusion of those variables in the model will increase its predictive capability and should be retained. The adjusted coefficient of determination, R-Sq (adjusted), is 0.9797. This implies that the model can explain the variability in the data by 97.97%, indicating that the model is adequate. Table 6 shows the analysis of variance for the compressive strength at 28 days. The p-values of linear, square and interaction are all less than 0.05, indicating that all the terms are significant and should be retained in the model.

Table 5: Estimated regression coefficients for Y_2

Term	Coefficient	SE Coefficient	T	P
Constant	-65.95	42.918	-1.537	0.015
X_1	215.77	88.169	2.447	0.031
X_2	-296.71	111.890	-2.652	0.021
X_3	276.65	106.141	2.606	0.023
X_4	330.87	125.796	2.630	0.022
X_5	-326.63	130.492	-2.503	0.028
X_2X_2	5.03	1.991	2.528	0.027
X_5X_5	841.56	289.640	2.906	0.013
X_1X_3	-559.55	215.350	-2.598	0.023
X_1X_4	-695.97	262.204	-2.654	0.021
X_1X_5	1055.41	391.253	2.698	0.019
X_2X_3	713.63	273.773	2.607	0.023
X_2X_4	872.71	324.899	2.686	0.020
X_2X_5	-1328.24	489.278	-2.715	0.019
X_3X_5	-442.90	163.123	-2.715	0.019
X_4X_5	-551.28	194.955	-2,828	0.015

S = 1.81764 PRESS = 3303.87

R-Sq = 99.10% R-Sq (predicted) = 24.81%

R-Sq (adjusted) = 97.97%

Table 6: Analysis of variance for Y_2

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	15	2354.26	4354.262	290.2841	87.86	0.000
Linear	5	4268.92	131.202	26.2408	7.94	0.002
Square	2	27.80	46.108	23.0541	6.98	0.010
Interaction	8	57.54	57.543	7.1929	2.18	0.108
Residual Error	12	39.65	39.646	3.3038		
Total	27	4392.91				

Surface plot for compressive strength at 28 days

The developed model for compressive strength at 28 days is used to obtain the surface plot. The three dimensional pictorial views of the model are shown in Figs 3 and 4. Based on the graphical representation of the surface plot above, it can be seen that there is a gradual decrease in the 28 days compressive strength of concrete on successive increase in the water-cement ratio of the concrete. Moreover, increasing the sand replacement level of the mixture reveals an appreciable increase in the compressive strength of the concrete. A thorough analysis of the surface plot of Fig. 4 above shows a gradual increase in the 28 days compressive strength of concrete following an increase in the addition factor of fly ash in the concrete mix. A further look at the plot reveals a significant increase in compressive strength as the level of partial replacement of sand with fly ash increases.

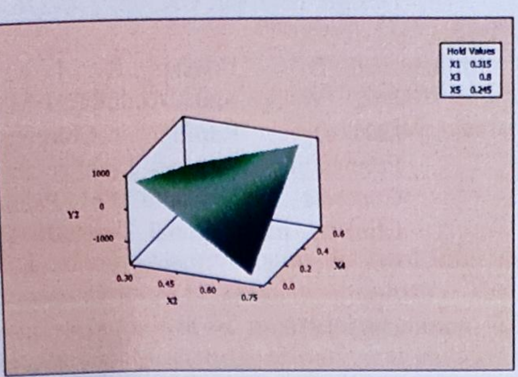


Fig. 3: Surface plot of Y_2 vs X_2, X_4

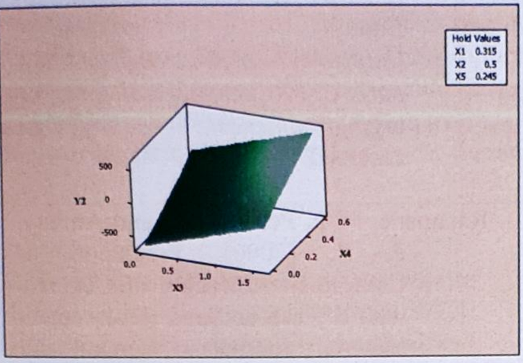


Fig. 4: Surface plot of Y_2 versus X_3, X_4

Conclusions and Recommendations

Conclusions

Based on the results obtained from the experimental design developed and analysis carried out using Minitab statistical, the following are hereby concluded:

1. The reduced full quadratic models have been developed for the prediction of compressive strength of concrete at 7 and 28 days with predictive capabilities of 97.37 and 97.97% respectively.
2. The response surface plots give graphical description of the relationship between compressive strengths at 7 and 28 days, and two variables from the water/binder ration, water/cement ratio, fly ash addition factor, sand replacement level and fly ash fraction in binder keeping other variables constant.

Recommendations

Based on the analysis carried out and the results obtained from the statistical models for compressive strength of concrete with fly ash as sand replacement material, the following recommendations are deduced:

1. The models developed herein can be used to predict the seven (7) and twenty eight (28) days compressive strength of concrete.
2. The response surface plots is recommended for use to obtain a pictorial relationship between compressive strength and various input parameters considered in this work.

References

Abdullahi, M., Al-Mattarneh, H.M.A, Mohammed, B.S. (2009a). Statistical Modeling of Lightweight Concrete Mixtures. European Journal of Scientific Research. Vol. 31, No 1,124-131.

Abdullahi, M., Al-Mattarneh, H.M.A, Mohammed, B.S. (2009b). Equations for Mix Design of Structural Lightweight Concrete. European Journal of Scientific Research. Vol. 31, No. 1, 132-141.

Aruna, K. E, and Kavitha, M. (2014). Studies on Partial Replacement of Sand with Fly Ash in Concrete. European Journal of Advances in Engineering and Technology, Vol. 1, No 2, 89-92.

Bahoria, B.V., Parbat, D.K, Naganaik, P.B, Waghe, U.P. (2013). Comprehensive Literature Review on Use of Waste Product in Concrete. International Journal of Application or Innovation in Engineering and Management. Vol. 2, No. 4, 387-3942.

Govindarajan, D., Keerthana, M., Kumara, R. G., Prasanna, K. R. (2014), Experimental Investigation on Replacement of Fine Aggregate with Bottom Ash in Concrete. International Journal of Chem-Tech Research. Vol. 6, No. 14, 5570-5574.

Madhan, T.C, Raju, S. L, Mathur, D. (2014). Durability and Strength Properties of High Volume Fly Ash Concrete. Journal of Civil Engineering Research. Vol. 4, No. 2A, 7-11.

Mohammed, B. S., Abdullahi, M., Hoong, C .K. (2014a) Statistical Models for Concrete Containing Wood Chipping as Partial Replacement to Fine Aggregate. Construction and Building Materials, Elsevier UK. 55, 13-19.

Mohammed, B. S., Al-Ganad, M. A., and Abdullahi, M. (2011b) Analytical And Experimental Studies on Composite Slab Utilising Palm Oil Clinker Concrete. Construction and Building Materials, Elsevier UK. Vol. 25, No. 8, 3550-3560.

Mohammed, B S., Foo, W.L., Hossain, K.M.A., Abdullahi M. (2014b). Flexural Strength of Palm Oil Clinker Concrete Beam. Material and Design. Elsevier, UK. 53, 325-331.

Mohammed, B. S., Foo, W.L., Hossain, K.M.A, Abdullahi, M. (2013). Shear Strength of Palm Oil Clinker Concrete Beam. Material and Design. Elsevier, UK, 46, 270-276.

Mohammed, B. S., Hossain, K. M. A., Foo, W.L., and Abdullahi M. (2011a) Rapid Chloride Permeability Test on Lightweight Concrete Made with Oil Palm Clinker. International Journal of Engineering Research and Applications. India, Vol. 1, No. 4, 1863-1870.

Nigeria Cement Sector Report: Emerging Prominence From a Deficit Past (2013). CardinalStone Partners Equity Resaerch. (*https://www.proshareng.com/.../reports/CSPRCementSectoReportEmergingrominencer..*). Date accessed: 13/01/2017.

Rajamane, N. P, Peter, J. A., and Ambily, P. S. (2006). Prediction of Compressive Strength of Concrete with Fly ash as Sand Replacement Material. Journal of Cement and Concrete Composites. 29(3), pp 218-223.

Ramezanianpour, A. A. (2014). Cement Replacement Materials: Properties, Durability, Sustainability. Springer Berlin Heidelberg.

Taylor, G. D (2000) Materials in Construction: An Introduction. Pearson Education Limited, Singapore.