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Modeling of the Effect of Moulding Variable Parameters on some Properties of Clay- Bonded Sand

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Abstract

Modeling of the effect of moulding variable parameters on some properties of clay-bonded sand has been carried out. The data used for the work was generated at the National Metallurgical Development Centre, Jos sand testing laboratory. The data was used for modeling the effect of moulding variables on the green shear strength and bulk density of clay-bonded sand. Individual regression equations were developed, multiple regression equations were developed alongside with their coefficient of correlation and coefficient of determination and multiple determinations. These were sufficient for the explanation of the effect of moulding variable parameters on the two properties of the clay-bonded sand. The green shear strength had a multiple coefficient of determination of 0.5 and bulk density had a multiple coefficient of determination of 0.47.

Keywords: Modeling; Clay-bonded sand; Variable; Moulding; Parameter; Properties

1. Introduction

Moulding variable parameters are numerous and their control is very important in attaining acceptable moulding properties of clay-bonded sands. The mulling station is the central point where most of these variables are controlled. These variables include mulling time, clay content, moisture content, ramming and other additives. These variable parameters have varying effect and influence on the properties of clay-bonded sands. Ihom et al [1] and several other authors have clearly shown in their individual work, how clay and moisture content variation affect properties like green permeability, green compression strength, dry compression strength, dry shear strength, bulk density and shatter index [2-4]. Ihom [5] in his work 'foundry raw materials for sand casting and testing procedures' clearly explains the interactions between clay, sand and moisture and the effect these interactions have on properties of clay-bonded sands. According to Ihom [5] 'clay acquires its bonding action in the presence of moisture. When water is added to clay it penetrates the mixture and forms a surface film which coats the surface of each flake as more water is added the thickness of the film increases up to a certain limit after which the excess water remain in the fluid state. The thickness of this water film varies with the clay mineral and the quantity of clay. The bonding of clay depends on the mixing and the thickness of water film it can contain. This has effect on properties like the strengths, permeability, mouldability, shatter index, compactability and flowability.'

When sand is rammed in the mould the sand grains are forced together the clay coating on each coating acts in such a way that it not only locks the grains in position, but also makes them retain that position, if the water is added in the exact quantity required, to form the films, bonding action is best. if water is in excess the strength is reduced and the mould gets weakened. Rundman in Ihom [5] have explained how water is involved with the sand and clay in a moulding mixture using a low moisture model involving polarized water molecules on both clay and sand and a high moisture model involving ionic bonds between the Na ions and the water molecules. The polar bonding at low moisture is referred to as rigid water bonding and the ion water bonding at high moisture is referred to as bridge bonding. Surface defects on castings are, therefore more prevalent when the warm wet strength of the sand is low. This condition occurs when the clay binder has insufficient quantity of the adsorbed species which account for ionic bridge bonding, that portion of the bonding mechanism which is so important at high moistures and temperatures.

Modeling of the effect of moulding variable parameters on some properties of clay-bonded sand particularly the variation in clay and moisture content is important. The interrelations involved have been explained above. The mathematical models will further bring out the relationships and also make the relationship available for utilization for practical purposes. Using the developed models, a known variation in clay and moisture content can be used to predict the properties of the clay-bonded sand [6-10].

The objective of this work is to undertake the modeling of the effect of moulding variable parameters on some properties of clay-bonded sand.

2. Materials and Method

2.1 Materials.

The materials that were used for this work included; foundry sand, clay binder from Baroid of Nig. Ltd., Port-Harcourt-Nigeria. Water was from the sand testing laboratory water system. The equipment used for the work included; sand rammer equipped with bulk density tester, universal strength testing machine, digital weighing balance, mixer, electric permmeters and sieve shaker among others.

2.2 Method

The tests to determine the effect of moulding variable parameters on some properties of clay-bonded sand was carried out at National Metallurgical Development Centre, Jos, sand testing laboratory. During the mulling of the moulding mixture, the two variables were clay and moisture content. The mulling time, ramming, sand type, and other variables were kept constant. All the tests carried out conformed to AFS standard for testing moulding mixtures in the foundry. The results generated are presented in Table 1.

Table 1 Moulding Mixture Properties

Green Shear Strength KN/m^2 (Y_1)	0	8.96	10.34	7.59	8.96	9.65	11.03
Bulk Density g/cm^3 (Y_2)	1.48	1.48	1.51	1.58	1.58	1.60	1.62
Clay Content % (X_1)	1.5	2	3	4	5	6	7
Moisture Content % (X_2)	2	3	4	5	6	7	8

2.21 Multiple Regression Model Development

The basic two variable models (one dependent and one independent variable) is

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$$Y = a + bx \qquad (1)$$

Which can be solved using the normal equations thus:

$$\sum Y = an + b\sum x \qquad (2)$$

$$\sum XY = a\sum X + b\sum X^2 \qquad (3)$$

From this can be developed models with more than two variables and this is illustrated below using a 3 variable model (one dependent and two independent variables, Y, X_1, and X_2)

$$Y = a + b_{1X_1} + b_{2\,X_2} \qquad (4)$$

This can be solved by the normal equations for a three variable model, as follows:

$$\sum Y = an + b_1\sum X_1 + b_2\sum X_2 \qquad (5)$$

$$\sum X_1\, Y = a\sum X_1 + b_1\sum X_1^2 + b_2\sum X_1 X_2 \qquad (6)$$

$$\sum X_2\, Y = a\sum X_2 + b_1\sum X_1 X_2 + b_2\sum X_2^2 \qquad (7)$$

The line of best fit gives way to a plane of best fit, b_1 is the slope of the plane along the X_1 axis, b_2 is the slope along the X_2 axis and the plane cuts the Y axis at `a'. The aim of adding to the simple two variable models is to improve the fit of the data.

$$b_x = \frac{n\sum X_Y - \sum X \sum Y}{n\sum X^2 - (\sum X)^2} \qquad (8)$$

$$a_x = \frac{\sum Y}{n} - \frac{bX_{\sum X}}{n} \qquad (9)$$

The coefficient of correlation between the variables is given by

$$r_X = \frac{n\sum X\, Y_1 - \sum X \sum Y_1}{\sqrt{n\sum X^2 - (\sum X)^2} \times \sqrt{n\sum Y_1^2 - (\sum Y)^2}} \qquad (10)$$

r_X^2 *is* Coefficient of determination for Y: X

The closeness of fit is measured by the coefficient of multiple determination R^2 for which the general formula and a useful computational formula is given below

$$R^2 = \frac{a\sum Y + b_1\sum X_{1Y} + b_2 \sum X_{2Y} - \frac{(\sum Y)^2}{n}}{\sum Y^2 - \frac{(\sum Y)^2}{n}} \qquad (11)$$

Table 2 gives the calculation of separate regressions with green shear strength as $Y_{1,}$ clay content as X_1 and moisture content as $X_{2.}$

Table 2 Calculation of Separate Regressions with Green Shear Strength as Y_1

N	Y_1	Y^2_1	X_1	X^2_1	X_2	X^2_2	X_1Y_1	X_2Y_1	X_1X_2
1	0	0	1.5	2.25	2	4	0	0	3.0
2	8.96	80.28	2	4	3	9	17.92	26.88	6.0
3	10.34	106.92	3	9	4	16	31.02	41.36	12.0
4	7.59	57.61	4	16	5	25	30.36	37.95	20.0
5	8.96	80.28	5	25	6	36	44.80	56.76	30.0
6	9.65	93.12	6	36	7	49	57.9	67.55	42.0
7	11.03	121.66	7	49	8	64	77.21	88.24	56.0
∑	56.53	539.87	28.5	141.25	35	203	259.21	318.74	169.0

For Regression of Green Shear Strength Y_1 on X_1 (% Clay content variation)

The regression equation for the relationship of % clay content and green shear strength of the mould is

$$Y_{1X_1} = 3.39 + 1.15X_1 \qquad (12)$$

The coefficient of correlation for this relationship in equation 12 (from equation 10) is

$$r_{X_1} = 0.63$$

The coefficient of determination r^2 for regression Y_{1X1}: X_1 is

$$r^2_{X1} = 0.40$$

For Regression of Green Shear Strength Y_1 on % Moisture Content Variation X_2 (Y_1: X_2)

The regression equation for the relationship of green shear strength of the moulding mixture with % moisture content variation (from equation 1) is

$$Y_{1X_2} = 1.63 + 1.29X_2 \qquad (13)$$

The coefficient of correlation for this relationship in equation 13 (from equation 10) is

$r_{X2} = 0.75$

The coefficient of determination r^2 for regression Y_{1X2} : X_2 is

$$r^2_{X_2} = 0.56$$

The Multiple Regression (Y_1: X_1 and X_2)

The multiple regression calculations are carried out using the three variable normal equations (equations 4-7) and this gave rise to a multiple regression equation with best fit with X_1 and X_2 considered in the relationship. The developed mathematical model based on the two variables of clay and moisture content is

$$Y_1 = -22.68 - 36.79X_1 + 36.11X_2 \qquad (14)$$

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This mathematical model is derived with the combined influence of clay content and moisture content all taken into account and therefore can be used to predict the green shear strength of the sand mould. Table 3 shows empirical values of Green shear strength alongside with calculated values using mathematical model of equation 14

Table 3 Empirical Values of Green Shear Strength Alongside Calculated values using Equation 14

n	X_1	X_2	Empirical values of Green Shear Strength kN/m^2 (Y_1)	Calculated values of Green Shear Strength kN/m^2 (Y_1)
1	1.5	2	0	-5.65
2	2	3	8.96	12.07
3	3	4	10.34	11.39
4	4	5	7.59	10.71
5	5	6	8.96	10.03
6	6	7	9.65	9.35
7	7	8	11.03	8.67

Coefficient of Multiple Determination, R^2

The coefficient of multiple determination R^2 for the developed model equation for the relationship between green shear strength Y_1 and the two variables of clay and moisture content is

$R^2 = 0.5$

Table 4 Calculation of Separate Regressions with Bulk Density as Y_2

n	Y_2	Y_2	X_1	X_1^2	X_2	X_2^2	X_1Y_2	X_2Y_2	X_1X_2
1	1.48	2.19	1.5	2.25	2	4	2.22	2.96	3
2	1.48	2.19	2.0	4.00	3	9	2.96	4.44	6
3	1.51	2.28	3.0	9.00	4	16	4.53	6.04	12
4	1.58	2.50	4.0	16.00	5	25	6.32	7.90	20
5	1.58	2.50	5.0	25.00	6	36	7.90	9.48	30
6	1.60	2.56	6.0	36.00	7	49	7.60	11.20	42
7	1.62	2.62	7.0	49.00	8	64	11.34	12.96	56
$\sum$	10.85	16.89	28.5	141.25	35	203	44.87	54.98	169

For Regression of Bulk Density (Y_2) on % clay content variation (X_1) (Y_2 : X_1)

The regression equation for the relationship of bulk density of the moulding mixture with % clay content variation from equation 1 is

$$Y_{2X_1} = 1.44 + 0.028X_1 \qquad (15)$$

The coefficient of correlation for this relationship in equation 15 (from equation 10) is

$r_{X_1} = 0.51$

The coefficient of determination r^2 for regression Y_{2X1} : X_1 is

$r_{X1}^2 = 0.26$

For Regression of Bulk Density Y_2 on % Moisture Content variation X_2 (Y_2: X_2)

The regression equation for the relationship of bulk density of the moulding mixture with % moisture content variation from equation 1 is

$$Y_{2X_2} = 1.42 + 0.026X_2 \qquad (16)$$

The coefficient of correlation r for this relationship in equation 16 (from equation 10) is

$r_{X2} = 0.51$

The coefficient of determination r^2 for regression Y_{2X2}: X_2 is

$r_{X_2}^2 = 0.26$

The Multiple Regression (Y_2 : X_1 and X_2)

The multiple regression calculations are carried out using the three variable normal equations (equations 4-7) and this gave rise to a multiple regression equation with best fit with X_1 and X_2 considered in the relationship. The developed mathematical model for the relationship between bulk density and the two variables of clay and moisture content is

$$Y_2 = 1.48 + 0.09X_1 - 0.059X_2 \qquad (17)$$

Table 5 shows empirical values of bulk density alongside with calculated values using mathematical model of equation 17

Table 5 Empirical values of Bulk Density Alongside with Calculated Values using Equation 17

n	X_1	X_2	Empirical values of Bulk Density g/cm^3 (Y_2)	Calculated values of Bulk Density g/cm^3 (Y_2)
1	1.5	2	1.48	1.497
2	2	3	1.48	1.483
3	3	4	1.51	1.514
4	4	5	1.58	1.545
5	5	6	1.58	1.576
6	6	7	1.60	1.607
7	7	8	1.62	1.638

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Coefficient of Multiple Determination, R^2 for Bulk Density Y_2.

From equation 11 the coefficient of Multiple Determination R^2 for the regression equation of equation 17 is

$R^2 = 0.47$

3. Results and Discussion

3.1 Results

The result of the regression analysis is here presented

Regression of green shear strength Y_1 on % clay content variation X_1

$$Y_{1X_1} = 3.39 + 1.15X_1 \qquad (12)$$

The coefficient of correlation r and determination r^2 for $Y_{1X1} : X_1$ are

$r_{X_1} = 0.63$ and $r^2_{X1} = 0.40$

Regression of green shear strength Y_1 on % moisture content variation X_2 ($Y_{1X1} : X_2$)

$$Y_{1X_2} = 1.63 + 1.29X_2 \qquad (13)$$

The coefficients of correlation r and determination r^2 for Y_{1X2}: X_2 are $r_{X_2} = 0.75$ and $r^2_{X2} = 0.56$

The multiple regression of green shear strength on X_1 and X_2 (Y_1: X_1 and X_2) is found to be

$$Y_1 = -22.68 - 36.79X_1 + 36.11X_2 \qquad (14)$$

The coefficient of multiple determination, R^2 for green shear strength Y_1 is $R^2 = 0.50$

Table 3 gives the empirical values of green shear strength alongside calculated values using equation 14.

The results for regression study of bulk density are as follows:

Regression $Y_2 : X_1$ is

$$Y_{2X_1} = 1.44 + 0.028X_1 \qquad (15)$$

The coefficients of correlation r and determination r^2 for equation 15 are

$r_{X_1} = 0.51$ and $r^2_{X1} = 0.26$

Regression $Y_2 : X_2$ is

$$Y_{2X_2} = 1.42 + 0.026X_2 \quad (16)$$

The coefficients of correlation r and determination, r^2 for equation 16 are

$r_{X2} = 0.51$ and $r_{X2}^2 = 0.26$

The multiple regression (Y_2: X_1 and X_2) for bulk density on X_1 and X_2 is found to be

$$Y_2 = 1.48 + 0.09X_1 - 0.059X_2 \quad (17)$$

Table 5shows empirical values of bulk density alongside calculated values using equation 17

The coefficient of multiple determination, R^2 for bulk density Y_2 is found to be

$R^2 = 0.47$

3.2 Discussion

The result of the study has shown the various stages adopted in the modeling of the effects of the two variables of clay and moisture content on the two properties of the clay-bonded sand. Equation 12 is a modeled equation showing the relationship between green shear strength and clay content only. The relationship has a coefficient of correlation r, of 0.63 and a coefficient of determination r^2_{x1} of 0.4. The correlation is positive and above average, with the coefficient of determination of 0.4 it means 40% of the increase in green shear strength is caused by increase in clay content. The developed model equation in equation 13 shows the relationship between green shear strength and moisture content. The relationship has a coefficient of correlation of 0.75 and a coefficient of determination r^2_{x2} of 0.56. The coefficient of correlation is strongly positive which means any change in moisture content will bring about a positive change in green shear strength. The 0.56 value of coefficient of determination means that 56% change or increase in green shear strength is brought about by changes in the value of moisture content of the moulding moisture. The above relationships are based on the individual relationship or influence of clay and moisture content on green shear strength. In real world of moulding mixture the two variables of clay and moisture content have a resultant effect and the resultant effect is shown in equation 14. This equation can be used in predicting the green shear strength of the moulding mixture. This is because it takes into account the combined effect of the two variables on the properties of the moulding mixture. Table 3 shows the empirical values of green shear strength alongside the calculated values using the developed mathematical model of equation 14. Looking at Table 3, at 1.5% clay and 2% moisture content the empirical value is 0. The moulding mixture was not mouldable, the calculated or predicted value is -5.65 KN/m^2, this value confirms why the moulding mixture could not be moulded. The value of the green shear strength is too small for the moulding mixture to be moulded. Comparing the empirical values and the calculated values using the model equation the values are close but not exact, but can be used for estimation purposes, more so that the equation is the best fit for the empirical result. The coefficient of multiple determination of green shear strength on clay and moisture content is 0.5. It is the combined effect of the clay and moisture content on the green shear strength, and it is moderately strong relationship. 50% of the changes in green shear strength are due to the combined effect of clay and moisture content. The modeled effects of the two independent variables on the dependent variable, (green shear strength) agrees with observations made by several authors [9-15]

The effect of the two variables (of clay and moisture content) on bulk density has equally been examined. Equation 15 shows the relationship between bulk density and clay content. The model equation has a correlation coefficient of 0.51 and a coefficient of determination of 0.26. The correlation is moderately strong but the coefficient of determination shows that only 26% of the changes in bulk density are due to changes in clay content. Equation 16 is the developed model for the relationship between bulk density and moisture content. The relationship has a correlation coefficient of 0.51 and a coefficient of determination of 0.26. The relationship has a moderately strong positive correlation but the coefficient of determination indicates that only 26% of the changes in bulk density are due to changes in moisture content of the moulding mixture. The multiple regression takes into account the combined effect of the two independent variables of clay and moisture content on the properties of the moulding mixture. The developed model equation in equation 17 shows the relationship between bulk density and clay and moisture content. Their combined effect is given by the coefficient of multiple determination which is 0.47 which means that 47% of the changes or increase in bulk density is due to the combined effect of clay and moisture content. Table 3 presents the empirical values of the bulk density alongside the calculated or predicted values using the developed model equation of equation 17. Comparing the values on both sides it can be seen that they are quite close such that the developed model equation in equation 17 can be used to predict bulk density values on the shop floor. Appraising the developed models and the defined effects of the two moulding mixture variables on the properties of moulding mixtures with respect to green shear strength and bulk density; the models and their explanation are in agreement with observations and existing theories made by other authors in their individual work [13-16]. Apart from clay and moisture content other variables too contribute to green shear strength and bulk density of moulding mixtures. The contributions made by the two variables have been shown in this work.

4. Conclusion

The study 'modeling of the effect of moulding variable parameters on some properties of clay-bonded sand' has been carried out. The study has carefully drawn up the following conclusions:

1. Two models have been developed, one for the relationship between green shear strength and the two variables of clay and moisture content and the other one between bulk density and the two variables of clay and moisture content.
2. The two models can be used to predict green shear strength and bulk density
3. The work has established the effect of the independent variables on shear strength and bulk density through the models developed in the study.
4. The developed models were used in explaining the relationship between the dependent variable and the independent variables. These explanations were in agreement with existing theories as presented by other authors.
5. The developed models have clearly presented the effect of moulding variable parameters on the two properties of clay-bonded sand (green shear strength and bulk density)

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