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Modeling Dry Compressive Strength of Sodium Silicate Bonded Kaolin Refractory Bricks

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Abstract

Modeling the dry compressive strength of sodium silicate bonded kaolin refractory bricks was studied. The materials used for this research work included refractory clay obtained from Ijero-Ekiti (7º 49΄N and 5º 5΄E) kaolin deposit, and sodium silicate obtained from the open market in Lagos (6° 27′ 11″N 3° 23′ 45″E) all in the Southwestern Nigeria. The mineralogical composition of the kaolin clay was determined using the Energy Dispersive X-Ray Fluorescence Spectrometer (ED-XRF). The clay samples were crushed and sieved using the laboratory pulveriser, ball mill and sieve shaker respectively to obtain 100 μm diameter particles. Manual pipe extruder of dimension 30 mm diameter by 43.30 mm height was used to prepare the samples with varying percentage volume of sodium silicate 5 %, 7.5 % 10 %, 12.5 %, 15 %, 17.5 %, 20% and 22.5 % while kaolin and water were kept at 50 % and 5 % respectively for the comprehensive test. The samples were left to dry in the open laboratory atmosphere for 24 hours to remove moisture. The samples were then were fired in an electrically powered muffle furnace. Firing was done at the following temperatures; 700ºC, 750ºC, 800ºC, 850ºC, 900ºC, 950ºC, 1000ºC and 1100ºC. Compressive strength test was carried out on the dried samples using a Testometric Universal Testing Machine (TUTM) equipped with a computer and printer, optimum compression of 4.41 kN/mm^2 was obtained at 12.5 % sodium silicate; the experimental results were modeled with MATLAB and Origin packages using polynomial regression equations that predicted the estimated values for dry compressive strength and later validated with Pearson's rank correlation coefficient, thereby obtaining a very high positive correlation value of 0.97.

Keywords: Modeling, Dry Compressive Strength, Sodium Silicate, Kaolin, Refractory Bricks

1. Introduction

Refractories are materials that can withstand high temperatures and chemical attack of slags without failing, they can be classified as acid, basic or neutral; some are also referred to as special refractories.

They are thermal insulators which are used essentially in the metallurgical industries for furnace linings, kilns, nozzles for pouring molten metal, heat exchangers and driers [Hassan, 2001 and Guo, 2004].

Refractory materials are extensively used in the metal industries, along with glass melting and other heat treatment operations (Ndaliman, 2001). The atmosphere in which a refractory is to operate can dictate the materials that can be used in particular applications; for example, graphite refractories can operate at temperatures of up to several thousand degrees Celsius under reducing conditions, or oxygen free conditions, such as vacuum. However, they may begin to sublime at approximately 1000^{0}C under oxidizing conditions. The type of materials that a refractory comes into contact with can also dictate which material will be suitable for a particular refractory purpose. For instance, in steel making, basic refractories are used because the refractories are often exposed to basic slags containing magnesium and calcium oxides. If the refractory lining were made from acidic refractories, it would be eroded quickly by the chemical interaction of the basic slag and the acidic lining (e.g. silica), thereby forming low melting point compounds.

Compressive strength is a measure of the stress at which a material fails under load. Brittle ceramics display much higher strengths in compression than in tension (on the order of a factor of 10), and they are generally utilized when load conditions are compressive (Callister, 2000). Attempt is being made in this research work to explore the use of kaolinite clay from Ijero using sodium silicate as a binder and then model the dry compressive strength property, Ijero is located in coordinates 7º 49´N and 5º 5´E in Ijero-Ekiti local government of Ekiti state, South West of Nigeria as shown in Figure 1.

Figure 1: Map of Ijero - Ekiti
(Source: weather – forecast.com, 2012)

2. Methodology

The kaolin clay was sourced from Ijero deposit in natural form; samples were taken for mineralogical analysis at the Nigerian Metallurgical Development Company, Jos using the Electron Dispersive

X - Ray Fluorescence Spectrometer (ED-XRF), the result is presented in Table 1 while sodium silicate was sourced from the open market in Lagos.

Table 1: Mineralogical Composition of Kaolinite Clay

Channel	Compound	Percentage Weight (%)
Al	Al_2O_3	39.60
Si	SiO_2	58.00
K	K_2O	0.895
Ti	TiO_2	0.020
Cr	Cr_2O_3	0.016
Mn	MnO	0.051
Fe	Fe_2O_3	0.638
Ni	NiO	0.0063
Cu	CuO	0.053
Zn	ZnO	0.043
Ga	Ga_2O_3	0.013
Rb	Rb_2O	0.038
Y	Y_2O_3	0.015
Zr	ZrO_2	0.0090
Nb	Nb_2O_5	0.038
Ru	RuO_2	0.347
Sb	Sb_2O_3	0.05
Ba	BaO	0.03
Eu	Eu_2O_3	0.007
Re	Re_2O_7	0.02
Pb	PbO	0.11

The kaolin was beneficiated by crushing, washing, drying at 100^0C for 2 hours, grinding and pulverizing (through 100 mesh) (Ibitoye and Amuda, 2002). Samples were then wet - milled to obtain homogeneous mixture of sodium silicate and water thereby obtain green strength. Manual pipe extruder measuring 43.30 mm diameter by 30 mm height was used to prepare the sample, the samples were prepared with varying percentage weight of sodium silicate namely : 5 %, 7.5 %, 10 %, 12.5 %, 15 %, 17.5, 20 % and 22.5 % while kaolin and water were kept at 50 % and 5 % respectively for the compressive test. The samples were left to dry in the open laboratory atmosphere for 24 hours to remove moisture. Each sample of varying weight percentage of sodium silicate was loaded in a muffle furnace and was held for 2 hours at the following temperatures 700^0C, 750^0C, 800^0C, 850^0C, 900^0C, 950^0C, 1000^0C and 1100^0C before the dry compressive strength tests were carried out with Testometric compressive strength tester (Ibitoye and Amuda, 2002). The pictorial view of the developed kaolin refractory bricks is presented in Figure 2.

Figure 2: Sodium Silicate Bonded Kaolin Refractory Bricks (Source: Bodede, 2012)

The compressive strength is calculated using equation (1):

Compressive strength = $\frac{F}{A}$ (N/mm^2)……………………… (1) (Wikipedia, 2012)

where F: total load on specimen at failure (N) and A: cross sectional area of specimen (mm^2).
Presented in Table 2 are the results of the dry compressive strength analysis when compared with the other variables.

Table 2: Compressive Strength Test Experimental Results

Sodium Silicate (%)	**Compressive Strength (N/mm^2)**
5.00	3109.9
7.50	3889.3
10.00	4148.2
12.50	4414.1
15.00	4040.4
17.50	2417.3
20.00	5298.6
22.50	1695.0

3. Development of Model

The model was developed using MATLAB and origin software packages while Figure 3 presents the variation of sodium silicate with the dry compressive strength.

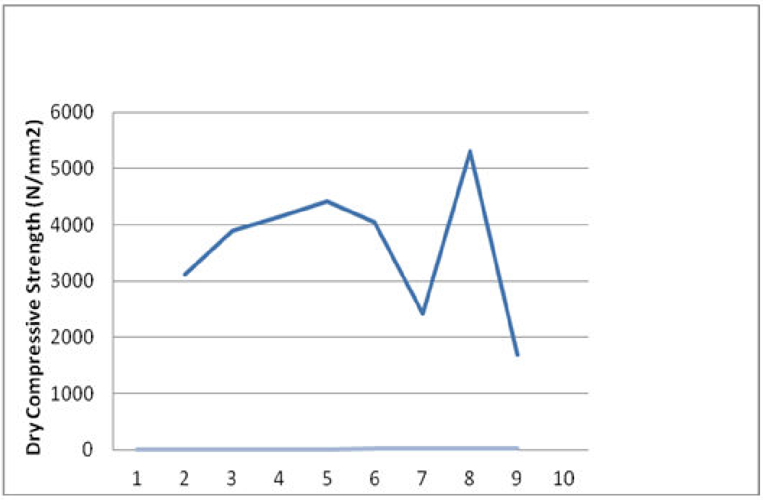

Figure 3: Variation of Percentage Sodium Silicate with Dry Compressive Strength

4. Validation of Model

The developed model was validated through statistical tools using correlation coefficient (Pearson's rank correlation coefficient) and standard error. Pearson's rank correlation coefficient is

$$R = 1- \frac{6\sum d^2}{n(n^2-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

= 1-0.022143

= 0.97

This is the deviation of the predicted value from the observed value. It is given by:

$$E_{YX} = \sqrt{\frac{\sum (Y-Yr)^2}{n}} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

where:

Y = the actual value (Observed) and Yr = the predicted value (Dass, 2005).

5. Standard Error of Prediction

The Karl Pearson's equation for calculating the standard error of the predicted numerical data (Y) was used and is given as:

$$SE_{y\text{-}x} = \sqrt{\left[\frac{1}{n(n-2)}\right] n\sum y^2 (\sum Y)^2 - \frac{[nExy-(Ex)(Ey)]^2}{nEx^2-(Ex)^2}} \quad \ldots \quad ..(4)$$

where Y = Numerical data; X = Experimental data; and N = No of pair test samples.

5. Discussion

The dry compressive strength of the samples were increased steadily with percentage volume of sodium silicate from 5 % up to 12.5 %; giving optimum dry compressive strength of 4414.1 N/mm^2 at 12.5 % sodium silicate content. Ibitoye and Amuda (2002) reportedly obtained optimum dry compression of 92 KN/mm^2 when percentage sodium silicate content was varied between 2 % - 10 %, the variation of the optimum dry compression observed from this work and that of Ibitoye and Amuda (2002) may be attributed to the fact that charcoal was used as an additive to kaolin clay as used in their work (Bodede, 2012).

Table 3 give the results of modeled estimated values of dry compressive strength of refractory bricks from MATLAB and origin software packages while Figure 3 presents the variation of sodium silicate with the dry compressive strength.
The modeled results are presented in Table 4.

Table 3: Result of Polynomial Regression for Variation of Sodium Silicate with Compressive Strength

Parameter	Value	Error
A	-170906.25833	91667.56803
B_1	101963.26047	51592.37197
B_2	-23508.28841	11342.8144
B_3	2745.06849	1256.34728
B_4	-171.51258	74.44146
B_5	5.45267	2.25046
B_6	-0.06917	0.02726

Table 4: Modelled Results of Compressive Strength

Experimental Value of Dry Compressive Strength (N/mm^2)	Estimated Value of Dry Compressive Strength (N/mm^2)
3109.9	3188.035588
3889.3	3529.455017
4148.2	4684.583971
4414.1	4376.947882
4040.4	3305.484265
2417.3	3219.786177
5298.6	4995.345676
1695.0	1713.161424

6. Validation of Results

When the numerical and experimental data in Figure 2 were validated with Pearson's correlation coefficient, a very high positive correlation (0.97) was observed (Bodede, 2012).

7. Conclusion

Modeled Dry Compressive Strength of Sodium Silicate bonded Kaolin Refractory Bricks has been presented in this paper. The following conclusions were drawn from the research work:

(a) The polynomial regression analysis is a power tool to estimate theoretically the dry compressive strength of the kaolin refractory.

(b) The numerical and experimental values were in agreement with each other.

(c) Increased percentage volume of sodium silicate on dry compressive strength was remarkable as it gave steady increased strength until optimum value of dry compression of 4414.1N/mm^2 was obtained at 12.5 % sodium silicate content.

(d) Based on the results obtained, it may be concluded that sodium silicate could be used as a binder for kaolin clay refractory.

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