Abstract

The importation of refractory materials is one of the biggest challenges industries faced in third world countries, of which Nigeria is one of them. The addition of palm bunch ash to clay in the production of clay bricks is one of the ways refractory materials are produced. The clay used here was Nsu clay. This work looked at the compressive strength of refractory bricks which is one of the properties of refractory materials. The work eliminates the traditional methods of trial and error and the rigorous mathematical analysis associated with the formation of some regression models in the prediction of some properties of refractory bricks. This was achieved by the use of Surface Response method. A regression model to predict the strength of a refractory brick was formulated, the model was found to be adequate based of the analysis of variance in which the Rsq, Rsq (adjusted) and Rsq (prediction) were found to be adequate, hence the model can be used to predict the compressive strength of refractory bricks. The optimal compressive strength was found to be 30.1513KN/m² at a ratio of 1:0.2570 at a water/clay ratio of 4.2590. Also, from the results it can be seen that the compressive strength of bricks decrease with increase in the percentages of palm bunch ash.

Keywords: Clay; Refractory; Brick; Compressive Strength; Palm Bunch Ash.

1. Introduction

Nigeria is a third world country in dire need of cutting edge technology. The use of refractory materials such as bricks is very essential in the metallurgical industries as iron and steel industries. Almost all the metallurgical processes are heat generating system, which require refractory materials that can withstand both physical and chemical action of molten materials (Hassan et al 2014). The chief material in the production of refractory material is clay. Clay is made into refractory material by cutting molded clay into various shapes and fired in the kiln. The firing processes transform the clay into the intending use with very high compressive strength and
excellent weathering qualities. Without refractory materials it will be very difficult to develop heavy industries and the necessary power production required for industrialization (Marwa et al 2009). Often times, admixtures such as palm bunch ash are added to raw mixes of burnt bricks in order to modify the properties or reduce the cost of the final product (Onwuka et al 2014). The addition of ash to bricks produces clay refractory. The term refractory means hard to fuse (Malu et al 2007). Refractory materials are generally employed for the construction of furnace flues, crucible etc. used in high temperature operations because of their resistance to the corrosive action of glasses and slag present therein. The use of software to develop a model for the prediction of the compressive strength of refractory bricks is aimed at producing refractory bricks which is of optimal value, without passing through the rigorous tradition methods which is cumbersome, material wasting and time wasting.

2. Materials and method

2.1. Material

The unprocessed dry clay called Nsu clay was obtained from Isu Ihime Mbano L.G.A. of Imo State Nigeria. The palm bunch ash was obtained by burning palm bunch, a waste product from palm oil mill at Ada Palm in Ugwuta in Imo State Nigeria in the open air.

2.2. Material Preparation

The unprocessed clay was made into a slip by adding water to it, it later crushed, mashed, washed and stirred. It was later made to pass through a BS sieve with 300\(\mu m\) and filtered to remove oversized quartz, such as vegetables and other unwanted materials. The filtration process was repeated several times until all the clay powder was washed off completely. The filtered slip was allowed to settle after a little alum was added to fasten settlement process. After sedimentation the top was carefully filtered off leaving a slimy pest behind. Lastly the clay was dried in the sun and grounded with mortar and pestle to increase its compacting properties as well as aid proper blending with the ash.

The palm bunch ash was dried in the sun and was burnt completely in the open in an open drum. The ash from the process was then made to pass through BS sieve of 212\(\mu m\). The water used was a clean pipe borne water obtained from municipal water supply.

2.3. Methods

The mix proportioning refers as the mix ratios of the various components in the mixture, and was done using Surface Response Method. The total number of components are three (water, clay and palm bunch ash), so a total of twenty (20) mixes was generated by the software. The mix ratios are as seen in table 1.0. \(X_1\), \(X_2\) and \(X_3\) represent the mix ratio of water/clay ratio, clay/clay ratio and palm ash/clay ratio respectively.
Table 1: Mix ratios from response surface

| S/N | X₁      | X₂      | X₃      |
|-----|---------|---------|---------|
| 1   | 4.0556  | 1.0000  | 0.11111 |
| 2   | 4.13793 | 0.9999  | 0.149425|
| 3   | 4.18648 | 1.0000  | 0.165501|
| 4   | 4.20588 | 0.9999  | 0.176471|
| 5   | 4.22646 | 1.0000  | 0.180575|
| 6   | 4.26829 | 0.9999  | 0.219512|
| 7   | 4.27711 | 1.0000  | 0.204819|
| 8   | 4.28395 | 1.0000  | 0.234568|
| 9   | 4.28571 | 1.0000  | 0.242236|
| 10  | 4.30303 | 0.9999  | 0.212121|
| 11  | 4.31707 | 1.0000  | 0.219512|
| 12  | 4.32653 | 1.0000  | 0.224490|
| 13  | 4.35897 | 0.9999  | 0.282051|
| 14  | 4.37500 | 1.0000  | 0.250000|
| 15  | 4.43421 | 1.0000  | 0.315789|
| 16  | 4.44325 | 0.9999  | 0.310693|
| 17  | 4.45408 | 1.0000  | 0.275510|
| 18  | 4.47815 | 1.0000  | 0.285347|
| 19  | 4.48387 | 0.9999  | 0.290323|
| 20  | 4.60000 | 1.0000  | 0.333333|

2.4. Production of Palm Bunch Ash – Clay Bricks

For each mix ratios the masses were carefully measured out using weighing balance. The clay and the ash were thoroughly in the dry state and water was added, gradually the mixed raw material was thoroughly mixed together to increase the plasticity and binding properties of the clay. When the required plasticity is obtained, the raw material mixture is cast using small moulds.

2.5. Drying Process

The cast bricks were air dried for 72 hours after which the samples were placed in a kiln for drying. The drying was carried out in order to avoid the formation of steam within the body.

2.6. Firing Process

Firing was done in an electric furnace in the laboratory, the sample were fired from 0°C to 1200°C and soaked at that temperature for 1 hour. The firing schedule is as follows;

Table 2: Firing schedule

| Temperature          | Total time taken |
|----------------------|------------------|
| 0°C to 900°C         | 2 hours          |
| 900°C to 1000°C      | 2 minutes        |
| 1000°C to 1100°C     | 10 minutes       |
| 1100°C to 1200°C     | 7 minutes then soaked. |
2.7. Cold Crushing Strength

The cold crushing strength was determined by applying uniaxial load on the specimen in cold condition. The metallurgical mounting press was used to produce this load through the hydraulic ram. The load at which the samples fracture are noted from the dial gauge. The crushing strength can be calculated from the equation;

\[
cold\ \text{crushing}\ \text{strength}\ \sigma = \frac{force\ (F)}{cross\ \text{sectional}\ \text{area}\ \text{of}\ \text{punch}\ (A)}
\]

\[
cold\ \text{crushing}\ \text{strength}\ \sigma = \frac{load \times 9.81}{cross\ \text{sectional}\ \text{area}\ \text{of}\ \text{punch}\ (A)}
\]

3. Chemical Analysis of Nsu Clay

The chemical analysis was carried at the PRODA laboratory Enugu and is as presented in table 3

3.1. Results and Analysis

Table 3: Chemical analysis of Nsu clay

| Compound | Chemical composition in percentage (%) |
|----------|----------------------------------------|
| CaO      | 4.87                                   |
| MgO      | 5.21                                   |
| Fe₂O₃    | 1.76                                   |
| Na₂O     | 0.92                                   |
| K₂O      | 1.68                                   |
| Al₂O₃    | 24.74                                  |
| P₂O₅     | 0.51                                   |
| TiO₂     | 0.69                                   |
| SO₃      | 1.1                                    |
| SiO₂     | 46.44                                  |
| Loss in ignition | 9.6                                 |

Table 4: Compressive strength

| S/N | X₁    | X₂    | X₃    | Compressive strength (KN/m²) |
|-----|-------|-------|-------|------------------------------|
| 1   | 4.05556 | 1.0000 | 0.111111 | 29.0652                     |
| 2   | 4.13793 | 0.9999 | 0.149425 | 26.4391                     |
| 3   | 4.18648 | 1.0000 | 0.165501 | 25.8480                     |
| 4   | 4.20588 | 0.9999 | 0.176471 | 25.6961                     |
| 5   | 4.22646 | 1.0000 | 0.180575 | 23.7042                     |
| 6   | 4.26829 | 0.9999 | 0.219512 | 23.5122                     |
| 7   | 4.27711 | 1.0000 | 0.204819 | 23.4500                     |
| 8   | 4.28395 | 1.0000 | 0.234568 | 21.6642                     |
| 9   | 4.28571 | 1.0000 | 0.242236 | 21.5578                     |
| 10  | 4.30303 | 0.9999 | 0.212121 | 21.0700                     |
| 11  | 4.31707 | 1.0000 | 0.219512 | 20.8198                     |
| 12  | 4.32653 | 1.0000 | 0.224490 | 20.7169                     |
3.2. Analysis of Results

The following terms cannot be estimated and were removed:
X2*X2

Analysis of Variance

| Source                  | DF | Adj SS   | Adj MS  | F-Value | P-Value |
|-------------------------|----|----------|---------|---------|---------|
| Model                   | 8  | 220.122  | 27.5153 | 67.93   | 0.000   |
| Linear                  | 3  | 163.748  | 54.5827 | 134.76  | 0.000   |
| X1                      | 1  | 2.883    | 2.8826  | 7.12    | 0.022   |
| X2                      | 1  | 0.491    | 0.4905  | 1.21    | 0.295   |
| X3                      | 1  | 0.698    | 0.6981  | 1.72    | 0.216   |
| Square                  | 2  | 3.885    | 1.9423  | 4.80    | 0.032   |
| X1*X1                   | 1  | 1.324    | 1.3245  | 3.27    | 0.098   |
| X3*X3                   | 1  | 0.657    | 0.6571  | 1.62    | 0.229   |
| 2-Way Interaction       | 3  | 2.765    | 0.9218  | 2.28    | 0.137   |
| X1*X2                   | 1  | 0.952    | 0.9523  | 2.35    | 0.153   |
| X1*X3                   | 1  | 1.037    | 1.0365  | 2.56    | 0.138   |
| X2*X3                   | 1  | 0.352    | 0.3517  | 0.87    | 0.371   |
| Error                   | 11 | 4.455    | 0.4050  | -       | -       |
| Total                   | 19 | 224.578  | -       | -       | -       |

Model Summary

| S                | R-sq | R-sq(adj) | R-sq(pred) |
|------------------|------|-----------|------------|
| 0.636425         | 98.02% | 96.57%    | 91.51%     |

Coded Coefficients

| Term    | Effect | Coef SE | Coef | T-Value | P-Value | VIF |
|---------|--------|---------|------|---------|---------|-----|
| Constant| -      | 20.944  | 0.311| 67.25   | 0.000   | -   |
| X1      | -30.73 | -15.36  | 5.76 | -2.67   | 0.022   | 365.25 |
| X2      | 0.474  | 0.237   | 0.215| 1.10    | 0.295   | 2.09 |
| X3      | 14.85  | 7.43    | 5.66 | 1.31    | 0.216   | 432.16 |
| X1*X1   | -64.6  | -32.3   | 17.9 | -1.81   | 0.098 c | -   |
| X3*X3   | -37.1  | -18.6   | 14.6 | -1.27   | 0.229   | 1031.74 |
| X1*X2   | 3.63   | 1.82    | 1.18 | 1.53    | 0.153   | 15.41 |
| X1*X3   | 103.5  | 51.8    | 32.4 | 1.60    | 0.138   | 4466.63 |
| X2*X3   | -1.90  | -0.95   | 1.02 | -0.93   | 0.371   | 14.52 |
Regression Equation in Uncoded Units

\[ Y = 528371 - 130074X_1 - 534737X_2 + 163925X_3 - 436X_1^2 - 1504X_2^2 + 133415X_3^2 + 1711X_1X_3 - 170605X_2X_3 \]

Equation 3 in the model equation for the prediction of the compressive strength of refractory bricks.

![Surface Plots of Y](image_url)

Figure 1: The interactions between the various mixes and the compressive strength.

![Optimal Design](image_url)

Figure 2: The maximum compressive strength (30.4255KN/m²) at mix ration of 1.000:0.1111 and water/clay ratio of 4.0556
3.3. Discussion of Results

Twenty mixes were used based on the number generated by the software. From the results it can be seen that the addition of palm bunch ash to clay bricks reduces the compressive strength of the brick, this is because as more ash is added more pores are created which in turn reduces the compressive strength. The ash is added to the brick to enhance their properties. The interaction between the mixes and the compressive strength is as shown in fig 1.0. The figure shows all the interactions against the compressive strength. The figure shows the interaction that can give the maximum and the minimum compressive strength. The maximum compressive strength of strength 30.4255 KN/m$^2$ at mix ration of 1.000:0.1111 and water/clay ratio of 4.0556 was achievable. The graph on figure 3 shows that as the percentage of palm bunch increases the lower the compressive strength of the refractory bricks produced. From the analysis of the results the R$^2$ value is 98.02% which means that the model can be use to predict responses from the various mixes, hence the model can be used to predict the compressive strength of refractory bricks. The R$^2$(adj)) value is 96.57% which shows how well the model predicts new observations. The R$^2$(pred) value is 91.51% which is okay.

3.4. Conclusion

The addition of palm bunch ash to bricks reduces the compressive strength of refractory brick. This is because as more ash is added to the brick more pores are created which in turn reduce the compressive strength of the refractory material. This pores are created when the ash are burnt off during the sintering process. The use of Surface Response Method reduces the rigorous mathematical analysis encountered in the formation of regression models. A regression model that can be used to predict the compressive strength of refractory bricks was developed based on the mixes produce. From this, refractory clay bricks with desired compressive strength can be produced locally and this will go a long way in discouraging the importation of refractory materials for our industries; hence reduce the stress on our local currency. This will also encourage the growth of our local industries.
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