Variation of Some Physical Properties of Rice Husk Ash Refractory with Temperature

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Abstract: ***The influence of sintering temperature on the thermal conductivity of rice husk ash refractory is examined in this research. Cylindrical disk made from RHA whose chemical composition measured by XRF were sintered in the temperature range of 1000℃ − 1400℃. the crystalline phase transformation studied by XRD. The thermal conductivity of these Rice Husk Ash refractory was determined using the hot flux method and values calculated using Fourier's equation for steady state heat conduction. Porosity and density test were also carried out Result showed that there was an increase in apparent density and conductivity with increasing sintering temperature though the values are still low and satisfactory for most insulation applications. Porosity of rice husk ash refractory decreases with increasing sintering temperature therefore the gains of higher strength from higher sintering temperature are not negated.***

Keywords: Rice Husk Ash, temperature, refractory.

1. Introduction

Rice is one of the major crops produced by many countries of the world. Rice husk is produced from its grain during the beneficiation process in milling industries. The most challenging problem faced by countries producing rice today is how to dispose the husk [2]. In Nigeria for instance, a large quantity of rice husk is dumped at rice milling stations as waste. This causes environmental problems and damage on the land [5]. Rice husk produces another residue called Rice Husk Ash when burnt in open environment. The ashes produced have low nutritious value, have chemical, mineralogical and morphological characteristics depending on the equipment and parameters of the process during burning of the husk [3]. In Benue state of Nigeria, some farmers burn the ash on land used for the cultivation of maize, millet and guinea corn in order to enhance high productivity. This help in a way to minimize the husk. Amorphous silica is produced when rice husk ash is burnt at a controlled temperature of less or equal 700℃ . When rice husk ash is burnt at a temperature above 700℃, crystalline silica is produced. The major compound in rice husk ash is silica about 80% to 95% [1]. It is reported that the melting point of rice husk ash is 1440℃ [4].

Rice husk ash has many applications due to its properties. It is an excellent insulator because of its low thermal conductivity and has applications in steel foundries and refractory bricks. It is an active pozzolan and has applications in concrete industries. In its purified form it can be used in silicon chip manufacture. This research focuses on variation of some physical properties of RHA refractory in the temperature range of 1000 to 1400^{o}C, a region of phase transformation from tridymite to cristobalite

2. Materials and Methods

2.1. Rice Husk Ash (RHA) Production

Rice husk were collected from five different rice milling stations in the middle belt region of Nigeria Rice husk with few amounts of clay particles and other impurities was selected for use in this research work. The husk was first sieved manually to remove broken rice particles and other impurities Rice husk was first burn in an open environment. Air was blown to aid ignition since rice husk is very difficult to ignite. This action produces the black ash. The produced black ash was allowed to cool in an open environment for 24 hours. Carbolite furnace model GPC 12/81+103 with temperature range from 0℃ − 1200℃ was then used to fired the black ash at a controlled temperature of 650℃.This process produces white amorphous rice husk ash. The chemical composition of the ash was first determined by XRF using energy dispersive X-ray spectrometry model minipal 4 © 2005,PW 4025/45B Panalytical B.v.

2.2. Formulation or Mixing

The fabrication of the refractory was done from several different formulations containing Rice Husk Ash, Starch and Bentonite as binders and plasticizers; wood saw dust, flux and water. Mixing of components was done manually for 15 minutes. The amount of each ceramic paste was determined in terms of mass (weight).The water ratio was also calculated based on the weight of the solid mass. The maximum amount of wood saw dust added was 15g to avoid laminating effect during forming and sintering. The rigid rice husk ash refractories were formed by the pressing method. The specimens were molded in cylindrical form.

2.3. Drying and Sintering

The formed Rice Husk Ash refractories were allowed to dry in an open air shield without sunlight for a period of 21 days. The pressed Rice Husk Ash refractory were sintered in a carbolite furnace model no RHF 16/16 for a maximum period of six hours at the rate of 250°C/hour.The soaking period was 2 hours for each particular temperature. Sample Rice Husk Ash refractories were sintered at different temperatures in the range $1000℃ - 1400℃$.

2.4. X-ray Diffraction Analysis

X-ray diffraction analysis was done on samples sintered in the temperature range of $1000\,℃ - 1400℃$. X-ray mini diffractometer model MD-10 with $Cuk\alpha$ radiation of wavelength 1.5406nm was used for the analysis. The samples were exposed to X-ray generator running at 25kv. The 2θ angle for the machine ranges from 16-72^{o} .The unknown samples were search matched with the known samples from the database available at International Center for Diffraction data (ICDD).

2.5. Thermal Conductivity Test

The thermal conductivity test was carried out using the hot flux method based on unidirectional heat transfer at steady state for a system of sandwich-like. The test was done in accordance with ASTM 1225/87.A heat source was used to feed the system. Thermal conductivity was calculated using Fourier's equation for steady state heat conduction

$$K=\frac{Q\Delta x}{A\Delta T} \quad (1)$$

2.6. Apparent Density Test

The test to determine apparent density of RHA refractory was carried out in accordance with ASTM C693.The steps were as follows:

1. The refractory were weighed in air using a balance (m_o) g
2. The refractory were suspended in water and the weight recorded as (m_1) g
3. The refractory were again suspended in water and allowed to saturate with water then they were removed and weight recorded as (m_2) g.
4.

$$\text{Volume of water displaced} = \frac{\text{Density of water}}{\text{Mass of water displaced}} = \frac{\rho_w}{(m_2 - m_1)} \quad (2)$$

$$\text{Apparent density} = \frac{\text{Density of water}}{\text{Total volume including volume of voids(pores)}} \quad (3)$$

$$\text{Apparent Density} = \frac{m_o \rho_w}{m_2 - m_1} \quad (3)$$

The density of water (ρ_w) is 1gcm^{-3}.

2.7 Porosity Test

The refractory were first weighed and recorded as W_0. The refractory were then immersed in water at room temperature and removed; the weight recorded as w_1. They were then allowed to absorb water to saturation; the weight recorded as w_2.

Volume of pore spaces available=W_2-W_o
Volume of test pieces=W_2-W_1

$$porosity = \left[\frac{w_2 - w_o}{(w_2 - w_1)\rho_w}\right] \times 100 \quad (4)$$

Where ρ_w is the density of water (1gcm^{-3}). The test was done in accordance with ASTM C20-00

3. Results

The chemical composition of rice husk ash burnt at 650^{o}C by X-ray fluorescence (XRF) is shown in table 1. The X-ray diffractograms for RHA refractory showing the peak positions for crystobalite and tridymite in temperature range 1000 ^{o}C to 1400^{o} C is in figure 1.

Table 1: Chemical Composition of Rice Husk Ash by XRF

Compound	*Concen-Tration (%)*	*Com-pound*	*Concen-Tration (%)*	*Com-pound*	*Concen Tration (%)*
$Si0_2$	82.800	$RU0_2$	0.275	$Zr0_2$	0.020
P_20_5	5.400	$S0_3$	0.200	Re_20_7	0.020
K_20	2.570	$Ti0_2$	0.110	Y_20_3	0.012
Ca0	1.660	Zn0	0.090	EU_20_3	0.010
Fe_20_3	0.836	Cu0	0.066	Cr_20_3	0.014
Mg0	0.800	Rb_20	0.038	Ni0	0.008
Mn0	0.321	Ba0	0.030		

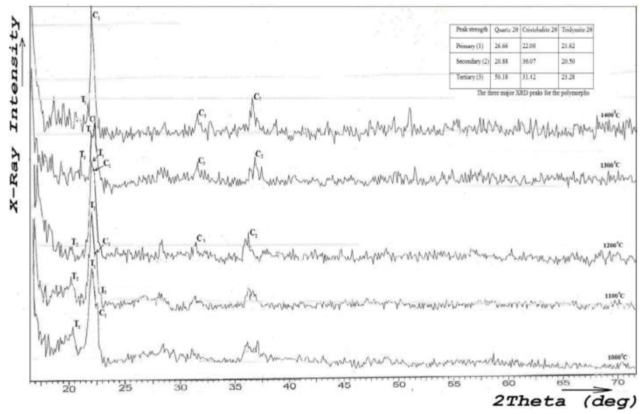

Figure 1: X-ray Diffractograms for Rice Husk Ash Thermal Insulators in Temperature range 1000^{o}C to 1400 ^{o}C (The symbols C and T are peak positions for cristobalite and tridymite respectively)

The thermal conductivity of the Pressed Rice Husk Ash refractory was determined based on the method described above. The result is shown in table 2 below at different sintering temperature and the corresponding curve in figure 2.

Table 2: Result of Thermal Conductivity

Sintering Temperature (℃)	*Thermal Conductivity* ($Wm^{-1}k^{-1}$)
1000	0.44
1100	0.49
1200	0.51
1250	0.57
1300	0.66
1400	0.70

Table 3 below shows the result of apparent density and apparent porosity of the refractory sintered in the range of 1000°C-1400°C. The graph which shows the variation of sintering temperature with the refractory apparent density is given in figure 3. The graph of variation of sintering temperature and porosity of the refractory is shown below in fig 4.

Table3: Result of Apparent density

Sintering temperature(℃)	*Apparent density (kg/m³)*	*Porosity (%)*
1000	350	65
1100	420	55
1200	530	44
1250	860	28
1300	950	8
1400	960	5

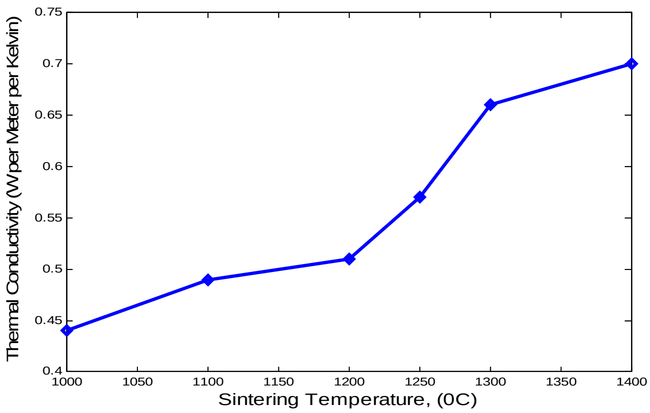

Figure 2: Graph of Thermal Conductivity against Sintering Temperature

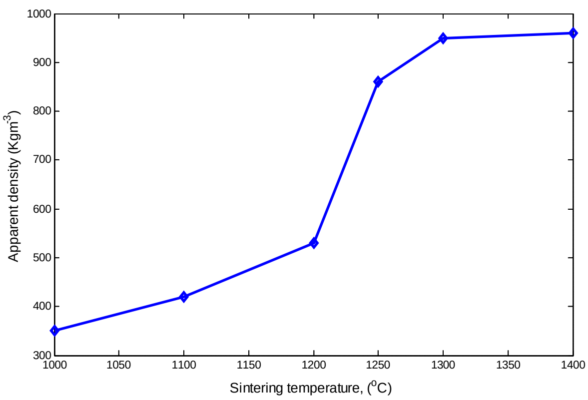

Figure 3: Graph of Apparent Density against Sintering Temperature

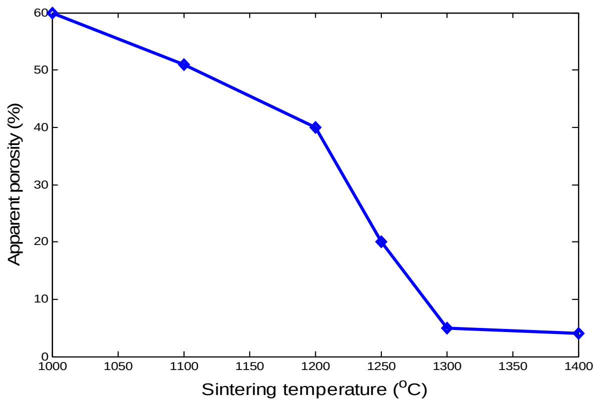

Figure 4: Graph of apparent porosity against sintering temperature

4. Discussions

Rice husk ash produced was milky white in color with high percentage content of $Si0_2$ (82.80%) and major impurities such as $P_2 0_5, K_2 0, Ca0$ *etc* were present. The ashes have characteristics such as coarse grains, crystalline and specific gravity of 2.17. All the above mentioned properties are close to natural silica or quartz traditionally used for thermal insulator fabrication in Kilns and, steel furnace. From the result of thermal conductivity of the refractory sintered at different temperatures in table 2 and result of apparent density and porosity in table3, it is observed that even though the thermal conductivity values are low, thermal conductivity and apparent density increases with increased sintering temperature. This increase in the refractory properties with increase sintering temperature may be attributed to the decrease in porosity .The low thermal conductivity values of the refractory (thermal insulators) may be due to their porous nature, grain boundaries and other microscopic imperfections which affect photon conductivity (conduction by radiation) at such higher sintering temperature. The increase in k-value with increased higher sintering temperature is based on the fact that at such higher sintering temperature photon conductivity (radiation) is the predominant mechanism of energy transfer and so despite the porous nature, grain boundaries and other microscopic imperfections that may be present thermal conductivity increases with increased sintering temperature. The phases of silica present at these temperatures are tridymite and cristobalite. Figure 4 shows that apparent density of the RHA refractory increases with increase in sintering temperature. However these values show low apparent density as a consequence of high porosity which is greater or equal to 40% at temperature between 1000°C - 1200°C. At temperatures between 1250°C -1400°C the density rises above 600kgm^{-3}. This is due to decrease in porosity of the refractory.

5. Conclusions

X-ray Fluorescence (XRF) shows the presence of silicon (IV) oxide as the major compound in rice husk ash with the highest percentage of 82.8%.Major impurities in rice husk ash include; $P_2 0_5$ (5.400%), K_2 0 (2.570%) and Ca0 (1.66%).The properties of the rice husk ash used in this research shows that it is a good raw material for thermal insulator (refractory) fabrication. The Pressed Rice Husk Ash refractory formed has been found to have thermal conductivity values (K-value) less than 1.The thermal conductivity values of the refractory are low but increases with increased higher sintering temperature from 1000℃ − 1400℃ . Apparent density of the refractory increase as porosity decreases. Tridymite and cristobalite phases of silica were predominant after sintering the thermal insulators at the said temperatures.

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