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Fabrication and Characterization of Thermal Insulators Using Rice Husk Ash and Evaluation of Effect of High Temperature on Thermal Conductivity of the Insulators

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Abstract: This paper present a novel, simple and cost effective method of fabricating thermal insulators using a common waste material known as Rice Husk (RH). The ash used in this research work was calcined at a temperature of 600℃. Chemical composition of the rice husk ash was determined by XRF. The as- produced thermal insulators were formed by pressing method and sintered at high temperatures. Thermal conductivity of the Rice Husk Ash (RHA) thermal insulators was determined using the hot flux method (ASTM E 1225/87) and values calculated using Fourier's equation for steady state heat conduction. XRF result shows SiO_2 as the major compound with some oxide impurities such as P_2O_5, K_2O, and CaO. Result of thermal conductivity shows that even though k-values are low at higher sintering temperatures the values increase with increased sintering temperature. This result suggests photon conductivity (radiation) mechanism of heat transport at high temperatures. The result also suggests high insulation from the thermal insulators.

Keywords: Rice husk ash, Thermal conductivity, Thermal insulators

I. INTRODUCTION

One of the major crops produced by many countries in the world today is rice. The global annual production of rice equals 579,500,000 tones as reported by FAO in 2002. Rice husk is a natural sheath that form and cover the grain of rice [1]. The husk is produce from the grain by milling process. Disposal of the husk is the major challenge face by many countries [2]. Nigeria for instance is face by this challenge. A large quantity of rice husk is dump at rice milling stations as waste. These possess environmental threat and damage on the land [3]. Rice husk produces another residue known as rice husk ash (RHA) when burnt at low temperature in open environment. The ashes produced have low nutritious value, and have chemical, mineralogical and morphological characteristics depending on the equipment and the process parameters during burning of the husk [4]. In Benue state of Nigeria, some farmer burn rice husk on land and use it as manual to enhance high productivity of crops. This help in a way to minimize the husk. Amorphous silica is produced from rice husk at low temperature below 700˚C. Beyond this temperature, crystalline silica is produced. Rice husk ash contain mainly silica about 80% to 95% [5]. Rice husk silica melt at temperature of 1440˚C [6].

Rice husk ash has many applications due to its properties. It is an excellent insulator based on its low thermal conductivity and is used in steel foundries and refractory bricks. This forms the basis of this research work. In this paper therefore, we investigate the effect of high sintering temperature (1000˚C-1400˚C) on thermal conductivity of RHA thermal insulators.

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Thermal Insulators

A thermal insulator is a material that does not let heat pass through easily. It has properties such as low thermal conductivity (k-value), high heat resistance and high permeability to allow air to pass through its pores [7]. Therefore a material is accepted as a thermal insulator if its thermal conductivity is below 1 and in the case of ceramics, thermal conductivity value usually lie in the range of 0.5 to 1.5 $Wm^{-1}k^{-1}$ [8].

Thermal Conductivity

Thermal conductivity (k-value) is the materials ability to conduct heat. Heat Conduction in solid requires the transfer of energy between vibrating atoms. At low temperatures, the transfer of energy is through phonons. Phonon conductivity is affected by phonon-phonon interactions, pores, imperfections (such as cracks) and grain boundaries. In crystalline ceramics, Phonon conductivity decreases with increasing temperature as the amount of scattering increases i.e. below 800˚C**.** Amorphous ceramics do not have ordered lattice and they are mostly affected by the scattering making them good insulators [9]. The scattering also takes into account crystallite size, grain size and discontinuities [10]. The major mechanism of energy transfer at high temperatures is photon conductivity (radiation) and it is a mode of conduction that is essential in glass, transparent crystalline ceramics and porous ceramics. It is found that thermal conductivity increases with increased temperature in these materials [9].

II. MATERIALS AND METHODS

Raw Materials

The raw materials used for the fabrication of thermal insulators in this research work include; rice husk ash (major raw material), plasticizer, additives, binders, and wood sawdust, which act as load or porosity –maker agent.

Rice Husk Ash (RHA) Collection and Production

Rice husk was collected from Zaki-Biam rice milling station and it 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˚C-1200˚C was then used to fire the black ash at a controlled temperature of 600˚C. This process produces coarse white amorphous rice husk ash.

Chemical Composition of Rice Husk Ash

Chemical composition of the ashes was determined by XRF using energy dispersive X-ray spectrometry model minipal 4© 2005, PW 4025/45B P analytical B.v.

Formulation of Thermal Insulator Paste or Mixing

The fabrication of the thermal insulators was done from several different formulations containing Rice Husk Ash, Starch, Sodium silicate and bentonite as binders and plasticizers; wood saw dust, flux and water. Mixing of components was done manually for 15 minutes. The quantity of each ceramic paste added was determined in terms of mass (weight). The water ratio was also determined depending on the weight of the solid mass. The maximum amount of wood saw dust added was 3g to avoid laminating effect during forming and sintering. Rice Husk Ash Thermal Insulators pastes after formulation were formed by the pressing method. The specimens were molded in cylindrical form.

Drying and Sintering

The formed Rice Husk Ash Thermal insulators were allowed to dry in an open air shield without sunlight for a period of 21 days. The Pressed Rice Husk Ash Thermal Insulators 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. The formed Rice Husk Ash Thermal Insulators were sintered at different temperatures in the range 1000˚C-1400˚C.

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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 E 1225/87. Thermal conductivity was determined using Fourier's equation for steady state heat conduction.

$$K = \frac{Q \Delta x}{A \Delta T}$$

III. RESULTS

The chemical composition of rice husk ash by XRF shows the presence of twenty-one compounds with silica having the highest percentage of 82.8%. The result is shown in Table 1 below.

Table 1. Chemical composition of rice husk ash by XRF.

Compound	Percentage (%)
SiO_2	84.4
P_2O_5	3.8
K_2O	1.47
CaO	2.76
Fe_2O_3	0.736
MgO	0.9
MnO	0.321
RuO_2	0.275
SO_3	0.2
TiO_2	0.11
ZnO	0.09
CuO	0.066
Rb_2O	0.038
BaO	0.03
ZrO_2	0.02
Re_2O_7	0.02
Y_2O_3	0.012
Eu_2O_3	0.01
Cr_2O_3	0.014
NiO	0.008
V_2O_5	0.006

The thermal conductivity of the pressed rice husk ash thermal insulators was determined based on the method described above. The result is shown in Table 2 below.

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Table 2. Result of thermal conductivity.

Sintering Temperature (°C)	Thermal Conductivity ($Wm^{-1}k^{-1}$)
1000	0.3
1100	0.4
1200	0.52
1250	0.56
1300	0.68
1400	0.74

The graph of thermal conductivity against sintering temperature is shown in Fig. 1.

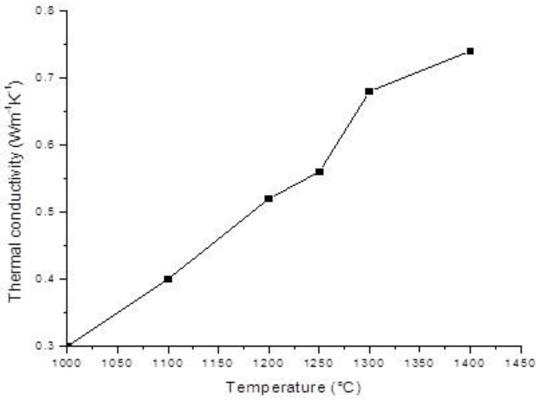

Fig. 1. Graph of thermal conductivity against sintering temperature.

IV. DISCUSSIONS

Rice husk ash produced was milky white in color with high percentage content of SiO_2 and some major impurities. The ashes have characteristics such as coarse grains, loss of ignition of 12.0%, amorphous phase and specific gravity of 2.17. All the above mentioned properties confirmed that the ash was excellently suitable for thermal insulator fabrication. The results of specific gravity obtained in this research work shows that rice husk ash have density of 2170 Kgm^{-3}. Coarse grains enhance the formation of porous structures and oxides such as K_20 and Ca0 enhance the formation of vitreous phase during sintering of the thermal insulator. From the result of thermal conductivity of the insulators sintered at different higher temperatures in Table 2, it is observed that even though the thermal conductivity values are low, thermal conductivity increases with increased sintering temperature .The low thermal conductivity values of the insulators may be due to the porous nature of the insulators, grain boundaries and 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) becomes the predominant mechanism of energy transfer and so despite the porous nature, grain boundaries and microscopic imperfections that may be present thermal conductivity increases with increased sintering temperature.

V. CONCLUSION

X-ray Fluorescence (XRF) shows the presence of silica as the major compound in rice husk ash. Major impurities in rice husk ash include; P_2O_5, K_2O and CaO. The properties of the rice husk ash used in this research shows that the ash is an excellent raw material for thermal insulator fabrication. The Pressed Rice Husk Ash Thermal insulator formed has been found to have thermal conductivity values (K-value) less than 1 from 0.30-0.72 $Wm^{-1}K^{-1}$. The thermal conductivity values of thermal insulators at higher temperatures from 1000˚C-1400˚C are low but increase with increased sintering temperatures. The result is slightly different from that obtained by other researchers' i.e. 0.30 W m^{-1} K^{-1} (at 1000˚C) below 0.5 $Wm^{-1}K^{-1}$ for ceramics as cited in literature. This may be due to voids left by bigger pores, large grain boundaries, and imperfections produced during production or sintering.

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