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Full Length Article

Preparation of forsterite refractory using highly abundant amorphous rice husk silica for thermal insulation

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ABSTRACT

The aim of the study was to investigate the effect of amorphous silica on the phase formation and study the physical characteristics of forsterite refractory prepared from quartz and MgO powder. Various samples were subjected to sintering temperature around 1100 °C and development of forsterite phase was characterized using Fourier Transform Infrared (FTIR) spectroscopy, X-ray diffraction (XRD), and scanning electron microscopy (SEM). The result indicate that the addition of rice husk ash (RHA) significantly affect the formation of forsterite phase. As the amount of RHA increased, it led to a better reaction between amorphous silica and periclase, later that will transform into forsterite phase at a temperature around 1100 °C. Formation of forsterite resulted in decrease of density, porosity, and thermal conductivity, while the opposite was observed for Cold Crushing Strength. Formation of forsterite phase was identified by XRD analysis of the sample. Based on the characteristics, the samples were considered as an insulator and of the potential use as refractory devices.

1. Introduction

Crystalline magnesium silicate with chemical formula Mg_2SiO_4 is known as forsterite. This is the mineral phase involved in refractory, named after the German scientist Johann Forster. Forsterite is mainly composed of the anion SiO_4^{4-} and the cation Mg^{2+} in a molar ratio 1:2 [1]. It is a magnesia–silica system which belongs to the group of olivines. It also shows good refractoriness due to high melting point (1890 °C), low dielectric permittivity (67 to 72×10^{-12} F/m at 1 MHz), low thermal expansion (2.8×10^{-5} to 4.5×10^{-5} °C^{-1} from 27 to 1870 °C), good chemical stability and excellent insulation properties even at high temperatures. It shows extremely low electrical conductivity that makes it an ideal substrate material for electronics and tunable laser. It is a heat-preservation refractory due to the low heat conductivity (about 1/3–1/4 of the pure MgO) [2–8]. Due to above characteristics forsterite refractory can be used in steel-making as drainage sand, and in casting models as metallurgy accessories, torpedo's, ladles, continuous casting tundish, non-ferrous metal smelting, glassmaking, rotary cement kiln and so on [9,10]. Forsterite refractories are also useful for metallurgical units and for making casting nozzles [11,12].

In the last few decades forsterite refractories were prepared by different minerals such as serpentine, olivine etc. [13,14]. Forsterite refractories were also prepared through waste like iron ore tailing [15]. Another raw material for preparation of ceramics is 'rice husk' (RH) because this is a renewable source of silica that contains high amount of silica and it is abundantly available. Also extraction of silica from RH is not so difficult. Silica found from RH was used for preparation of borosilicate, cordierite, carbosil, alumino-silicate and mullite [16–21]. The potential of rice husk as an excellent source of high-grade amorphous silica has also been investigated in many other studies [22–24]. This amorphous silica can be utilized for preparation of solar grade silicon, silicon carbide, magnesium–alumina–silica, and lithium–aluminum–silica [25–28].

Forsterite has been synthesized by different methods such as solid-state reaction, self-propagation high temperature synthesis, and sol–gel route [29–32]. Sol–gel route is an efficient route for the preparation of forsterite because it provides a molecular-level of mixing and high degree of homogeneity but in multi-component silicate systems, the hydrolysis and condensation rates are different within silica and the other alkoxides which may cause non-uniform precipitation and chemical inhomogeneity of the gels, and also results in higher crystallization temperature and undesired phases.

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Table 1
XRF of RHA.

Compound	Concentration (%)	Compound	Concentration (%)
SiO_2	92.81	ZnO	0.091
Na_2O	2.658	CuO	0.058
P_2O_5	1.071	Rb_2O	0.036
K_2O	1.021	BaO	0.031
CaO	0.417	ZrO_2	0.025
Fe_2O_3	0.312	Re_2O_7	0.021
MgO	0.212	Y_2O_3	0.012
RuO_2	0.151	Eu_2O_3	0.010
SO_3	0.132	Cr_2O_3	0.005
TiO_2	0.112	NiO	0.002

Abundant availability and high content of silica made RH an appropriate material for utilization in forsterite refractory manufacturing. The objective of this work is to evaluate the potential of rice husk silica as an alternative to commonly used silica for production of high strength forsterite refractory material for thermal insulation purpose using solid-state reaction. This ingredient and the process used for preparation of forsterite refractory aims to manufacture forsterite refractory at a low cost.

2. Materials & experimental

RHA, a burnt by-product of RH is produced in rice mills by burning at around 500 °C. We collected RHA from rice mills, where RH was used as fuel. RHA has different chemical, mineralogical and morphological characteristics depending on the process acquired during the burning of the husk as well as on the rice variety, soil chemistry, climatic conditions, and also on the geographic localization of the culture [33,34]. The RHA which was combusted earlier at 500 °C contained trace amount of unburnt carbon. To remove the unburnt carbon from RHA it was further heated at 600 °C for 2 h. The chemical composition was analyzed by using the X-ray fluorescence spectrometer (XRF) shown in Table 1. It was found that RHA contains 92% of SiO_2. The XRD analysis shown in Fig. 1 was carried out for RHA and the results were recorded from 10°–90° range of 2Θ with the help of "Rigaku Desktop Miniflex II X-Ray Diffractometer", equipped with Ni filter and the CuKα radiation (Serial no: HD20972, Japan). Absence of any sharp peak in XRD pattern indicates that RHA consist amorphous silica only. The amorphous silica presents in RHA is also called "active silica", which is consider to be more reactive than the crystalline form of silica because it lacks the "long-range order characteristics" of a crystal. Raw materials such as magnesium oxide (99% pure) and quartz (98% pure) were purchased from Lobachemie Pvt. Ltd., India.

In the present work different types of samples were prepared containing rice husk ash, MgO, and quartz in different proportions, Q2 shown in Table 2. Initially, all ingredients were crushed and sieved

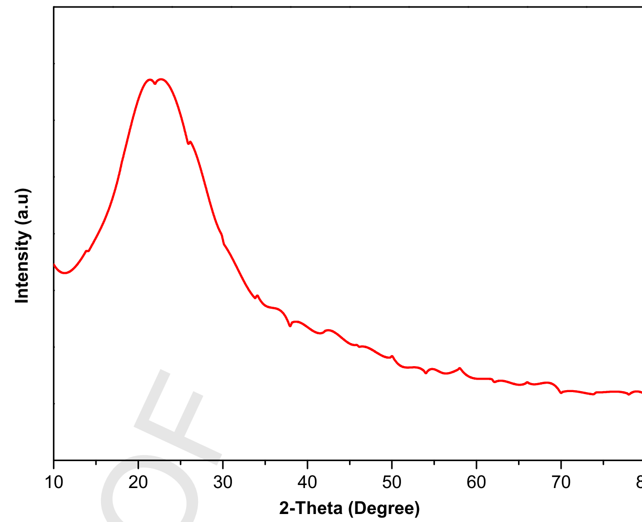

Fig. 1. XRD Analysis of RHA.

Table 2
Composition of samples.

Sample	MgO (wt %)	Quartz (wt %)	RHA (wt %)
Sample 1	57	33	10
Sample 2	57	23	20
Sample 3	57	13	30
Sample 4	57	00	43

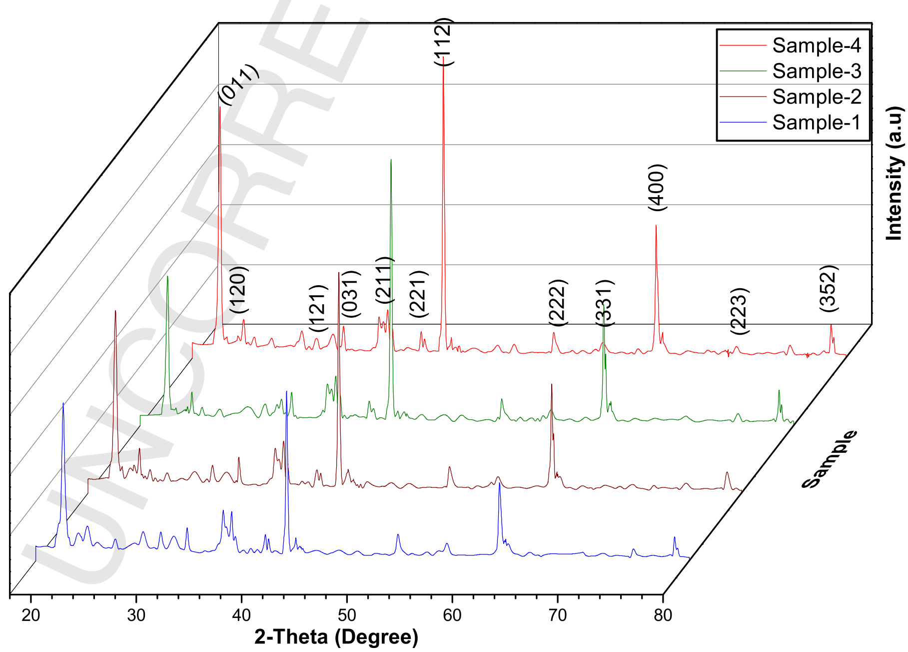

Fig. 2. XRD analysis (a) sample-1, (b) sample-2, (c) sample-3, (d) sample-4.