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Fabrication and properties of cordierite / anorthite composites

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ABSTRACT

The designed cordierite/anorthite batch compositions were studied to gain the favorable properties of both materials where, cordierite has low thermal expansion coffecient and high strength than anorthite.Low cost starting materials such as sugar beat filter cake and talc carbonate were used in the present study. Examination of the effect of cordierite addition (in the range of 10-25mass-%) on the physical, mechanical, electrical and thermal expansion coefficient properties as well as the phase composition and microstructure for the fabricated cordierite/anorthite composites were carried out. The results reveal that the increase in the cordierite content up to 20 mass-%, improves the sinterability and electrical properties. In addition, it increases the bending strength, hardness and decreases the thermal expansion coffecient. However, further increase in the cordierite content up to 25 mass% has negative influence on the physical, electrical and mechanical properties of the cordierite/anorthite composites.

1. Introduction

Many of ceramic materials have a wide range of applications in several industrial fields, due to their unique properties. Anorthite ($CaO{\cdot}Al_2O_3{\cdot}2SiO_2$) is one of the ceramic materials, which has a great potential for using in many industrial applications, due to its low thermal expansion coffecient $4.8{\times}10{-}6\ K^{-1}$, low dielectric constant value 6.2 at 1 MHz and good wear resistance [1]. It can prepared from chemical starting materials or natural resources such as kaolin [2], gabbro [3] and sugar beet filter cake [4], through out several methods of preparation such as sol gel [5], mechanochemical treatment [6] and hydrothermal processing [7].

Recently, some authors examined the production of ceramic composites made up of anorthite and other ceramic materials, that having desirable properties suitable for many industrial application fields. Lin, et al. [8] fabricated porous anorthite/ mullite composites by foam-gel casting. They studied the effect of mullite content on the physical and mechanical properties and found that mullite has great effect on the microstructure and compressive strength of the fabricated composite bodies. Naga, et al. [9] showed that the increase of Al_2O_3 content (from 5 to 20 mass-%) of anorthite- alumina composites improved the sintered bodies bulk density as well as their bending strength.

Cordierite ($2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2$) has low thermal expansion coefficient $1{\times}10^{-6}\ K^{-1}$, low dielectrical constant, high resistivity, chemical stability, high strength and low processing cost [10]. All of these properties encouraged the combination of cordierite with anorthite to form composite material that possesses superior properties. Ismail et al. [11] fabricated circuit substrates composed of cordierite – anorthite – boron base composite at low firing temperature. The prepared composite materials have high mechanical strength, thermal expansion coefficient close to silicon and low dielectric constant. Boudchicha, et al. [12] prepared dense anorthite/cordierite composite by mixing of 10 up to 20 wt% of hydrated dolomite powder with kaolinite in an aqueous media. The mixture was then fired at 1250 °C, followed by milling for 8 h. The produced powder was pressed and fired at 1200 and 1350 °C for 1 h. They reported that the obtained composites possess relative density 97% and are composed of anorthite and cordierite.

The main objective of this study is the utilization of some cheap local starting materials, such as sugar-beet filter cake and Egyptian talc-carbonate rocks for preparation of cordierite/anorthite composite ceramic bodies, which having the requirements necessary for kiln furniture industrial application. Investigation the benefit of addition of 10–25 mass-% cordierite to anorthite on both the thermal expansion coffecient and bending strength, together with the physical and electrical properties, phase composition and microstructure, is an another goal of the study.

2. Experimental procedure

2.1. Materials

Filter cake obtained as a by-product from the sugar beet industry

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Table 1
Batch composition of the cordierite samples, mass%.

Samples	Talc-Carbonate	Tieh kaolin	Al_2O_3	$Mg_2B_2O_5$
Cordierite	39.84	76.25	9.55	6.47

Table 2
Batch composition of the prepared cordierite/anorthite composites.

Batch composition	Anorthite, Mass-%	Cordierite, mass-%
C1	90	10
C2	85	15
C3	80	20
C4	75	25

was used to prepare anorthite powder [4]. Egyptian raw materials, mainly talc-carbonate rocks from Wadi Attalla in Egypt's Eastern Desert and kaolin from El- Tieh plateau in south Sinai Peninsula [4,13] together with chemically pure boric acid A.R. (H_3BO_3, 99%, Leicestershire, LE169EJ. United Kingdom), aluminum oxide (99.98 mass-% pure, provided by AlmatisGmbh Ludwigshafen/RH, Germany) and magnesium chloride hexahydrate ($MgCl{\cdot}6H_2O$, El-Nasr Pharmaceutical chemicals CO., Egypt), were used to prepare cordierite powder as show in Table 1 [13].

2.2. Preparation of the cordierite/anorthite composites

Four cordierite-anorthite batches were prepared by mixing finely ground anorthite and cordierite. Powder constituents were passed through 120 μm sieve in the proportions given in Table (2). The batches were mixed using a 3D- mixer for 2 h. Disks with 2.0 cm diameter and 0.5 cm thickness and 6 mm×6 mm ×60 mm bar-shaped samples were pressed with addition of 1 wt% of water under a pressure of 220 MPa to measure the physical and mechanical properties of fired bodies. The samples were dried at 110 °C overnight before firing. The dried samples were fired at a range of temperatures from 1250 up to 1325 °C with a heating rate of 5 °C/min and soaking time of 2 h at the peak temperature.

2.3. Characterization

The bulk density and apparent porosity densification parameters of fired samples were evaluated by the liquid displacement method (ASTM C20). The different phases developed during firing were determined by X-ray analysis (XRD) using a Philips PW 1730 X-ray diffractometer with a Cu target and Ni filter. A scanning electron microscope (SEM, JEOL JSM-T20) equipped with energy dispersion spectroscopy (EDS) was used to examine etched fracture surfaces of sintered samples. The samples were etched by immersion in 10% HF solution for 30 s. The sample surfaces were then coated with a thin layer of gold to impart electrical conduction. Bending strength was measured by a three point bending test on a universal testing machine (Lloyd LRX5 K of capacity 5 kN) at a crosshead speed of 0.05 mm/min, and support distance of 25 mm. 10 specimens with dimensions 6 mm×6 mm ×60 mm were measured for each data point. Electrical properties of the samples in terms of conductivity and dielectric constant values were determined. The applied voltage was increased from zero at uniform rate until puncture occurs (the electric strength is based on the highest voltage). Specimens' thickness near the puncture point was measured with a micrometer, and dielectric strength was calculated in KV/mm. Measurements were performed on compact disks of different samples during heating between 20–140 °C usingLCR Hioki 3532 HiTESTER instrument (Japan), at constant frequency 10^4 Hz and 1.5 test signal voltage, using 2-probe terminals fixed on the 2-sides of smooth surfaces disk sample. The thermal expansion coefficient in the temperature range from 25 up to 1000 °C was measured using an automatic Netzsch DIL402 PC (Germany), dilatometer over the range between room temperature and 1000 °C at a heating rate of 5 K/min using rectangular bars.

3. Results and discusion

3.1. Cordierite / anorthite composite bodies

3.1.1. Physical properties

The apparent porosity and the bulk density of the Cordierite /Anorthite composite bodies fired at 1250, 1275, 1300 and 1325 °C for 2 h are shown in Figs. (1) and (2) respectively. The figures indicate that the sinterability of the specimens was sharply affected by the firing temperature. The lower apparent porosity and higher bulk density values were observed at 1300 °C for all cordierite /anorthite composite specimens. On the other hand, with increasing the firing temperature up to 1325 °C, the specimens are deformed. Gibbs [14] reported that cordierite bodies has a short sintering range of 10–20 °C. Such short firing range produces a body sensitive to sintering. Any increase in the firing temperature will deform the body.

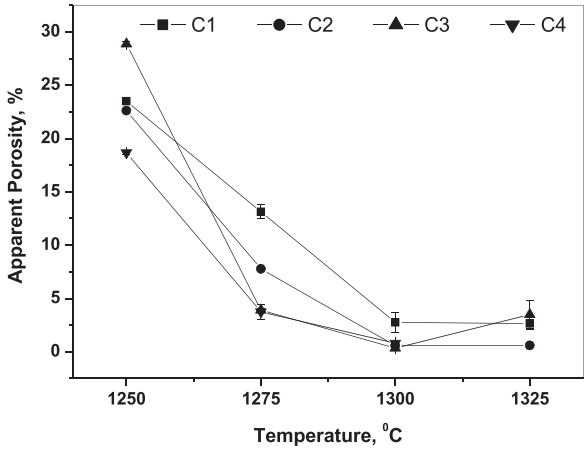

Fig. 1. The apparent porosity of different cordierite/ anorthite batch composite samples (C1: 10 mass-%, C2: 15 mass-%, C3: 20 mass-%, C4: 25 mass-% of cordierite) fired at different firing temperatures for 2 h.

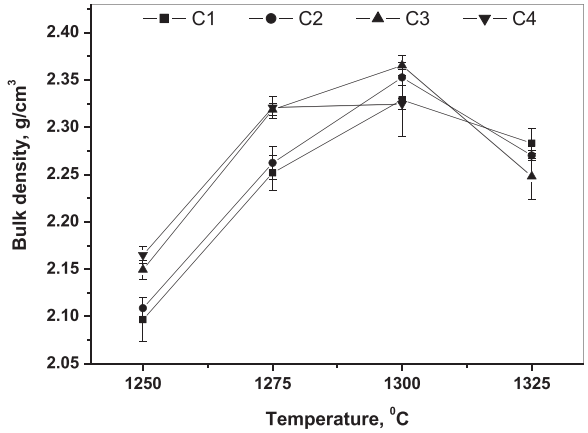

Fig. 2. The bulk density of different cordierite/ anorthite batch composite samples (C1: 10 mass-%, C2: 15 mass-%, C3: 20 mass-%, C4: 25 mass-% of cordierite) fired at different firing temperatures for 2 h.