



Effects of two mixtures of kaolin-talc-bauxite and firing temperatures on the characteristics of cordierite- based ceramics

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ABSTRACT

Cordierite ($2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$) is a thermal resistant ceramic presenting both low thermal expansion and electrical conductivity along with good chemical and mechanical properties. Thereby, it is suitable as material for manufacturing electric insulators, catalysis, refractory and porous ceramics. Solid-state reaction is the most common method for cordierite preparation. For this purpose, different mixtures including clay, alumina, talc, sand, diatomite and gibbsite are used. The present study is devoted to the preparation of cordierite-based materials using two mixtures of kaolin, talc and bauxite. Hence, prismatic specimens were shaped and tested to uniaxial compressive strength and heated in the range of 1200–1400 °C. The fired specimens were investigated via X-ray diffraction, Fourier transform infrared spectroscopy and scanning electron microscopy. Also, physical (firing shrinkage, water absorption, bulk density) and mechanical (bending strength) and dielectric properties of the fired bodies were measured as a function of temperature. The results showed that the fired bodies of the mixture composed of 50% by mass of kaolin, 20% by mass of talc and 30% by mass of bauxite together with high sintering temperature (1400 °C) resulted in the formation of abundant amount of cordierite in conjunction with mullite, cristobalite and pseudorutile. Also, there was increase of firing shrinkage, bulk density and bending strength. These changes were essentially linked to amount of new phases that were formed. Water absorption declined with increase of sintering temperature which was related to the reduction of porosity due to the formation of vitreous phase. The mixtures of kaolin-talc-bauxite which were fired at the range of 1300–1400 °C exhibited dielectric constant values varying between 20.3 and 2.8 along with dielectric loss tangent which varied between 0.1316 and 0.0002 at room temperature of the laboratory. The two mixtures can be considered as promising materials for both ceramic and electronic applications.

1. Introduction

Cordierite ($2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$) is one of the most important components within the $\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ phase diagram due to its unique and outstanding chemical, thermo-mechanical, thermal shock resistance, dielectric and low thermal expansion properties [1–5]. It can be used as substrate in production of microelectronics, firing tray in furnace or as support in many catalytic reactions [1–5]. Taking into account that it is not abundantly present in the nature, cordierite has to be synthesized. Many authors have reported preparation of cordierite according to various raw materials and techniques [6–10]. A great number of studies have been done on the synthesis of cordierite bodies from natural raw materials (talc and kaolin; andalusite and stevensite; kaolin, quartz and sepiolite; kaolin, talc and hydromagnesite) or from raw materials and additives (kaolin, talc, silica and alumina; talc,

kaolin, silica and feldspar; phosterite, silica and quartz; Al-rich anodising sludge, talc, diatomite) [4,5,11–16]. Several methods are proposed for the synthesis of cordierite ceramics including solid-state reaction [17], wet chemical methods such as sol-gel processes, hydrolysis, spray-pyrolysis and combustion synthesis [6,18–20]. It was shown that the formation of cordierite and its transformation from μ -cordierite to α -cordierite are related to the type of starting raw materials [21]. Also, it was observed in the $\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ phase diagram that μ -cordierite is often formed at lower temperature and the latter is transformed into α -cordierite with increasing temperature. α -cordierite can directly be formed from amorphous phase and it possesses both very low dielectric constant and low dielectric loss. However, the values of these latter constants vary depending on the processing parameters, particle size distribution, initial raw materials, stoichiometric compositions, phase contents, etc. [6]. Some authors

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studied the effect of mixtures of raw materials (kaolin and talc) on thermal expansion coefficients and dielectric properties of cordierite ceramics [16,22]. Little attention has been paid on effects of mixtures of kaolin- talc- bauxite versus sintering temperatures on microstructure, physical and dielectric properties of cordierite-based ceramics along with the reaction of their formations.

The present study reports the synthesis of cordierite bodies using kaolin, talc and bauxite as raw materials. The characteristics of two mixtures of these raw materials and sintering temperatures on microstructure, physical and dielectric properties were examined. The reaction during the synthesis is also proposed.

2. Materials and methods

The basic natural raw materials for preparation of cordierite ceramics were talc (T), kaolin (K), and bauxite (BX). These materials originated from three localities of Cameroon including Boumnyebel, Mayouom and Minim-Martap [23–25]. Their chemical compositions were determined thanks to inductively coupled plasma and optical emission spectroscopy (ICP-OES) using a Perkin-Elmer spectrometer (Optima™ 7000 DV ICP-OES) equipped with a CCD sensor. The chemical and mineralogical compositions of the raw materials are given respectively in Tables 1 and 2. Two mixtures of raw materials denoted respectively FO1 and FO3 were carried out and their compositions are given in Table 3. Suspensions of the mixtures were prepared and oven dried (105 °C) till constant mass. The dried mixtures were ground for 1 h thanks to a planetary ball mill and sieved (100 µm). The chemical compositions of the mixtures inferred from balancing amount of constituents of Table 1, are given in Table 4. Powdery mixtures were uni-axially pressed at 30 MPa using water (2% mass of mixture) as binder to get rectangular prisms 50 mm x 10 mm x 6 mm. The pressed specimens were oven dried at 105 °C till constant mass then fired in an electrical programmable furnace (Nabertherm RHF 1500) at 1200, 1300 and 1400 °C respectively for 2 h at a heating rate of 5 °C/min. X-ray diffraction (XRD) patterns of sintered products were obtained using a PHILIPS PW 3040 diffractometer, with Cu anode (K_{α} = 1.5418 Å) while Fourier Transform Infrared Spectroscopy (FTIR) was performed using a BRUKER VERTEX 70 spectrophotometer in the range 4000–400 cm^{-1} . Scanning Electron Microscopy (SEM) was achieved using a JEOL JMS 5500 microscope equipped with LINK-OXFORD XLII EDAX system. Also, test specimens were subjected to thermal analyses (DSC and TG) using a LINSEIS STA PT-1600 device. Thus, mixtures were heated from 20 to 1100 °C in self-generated atmosphere at heating and cooling rates of 10 and 20 °C/min respectively using α -alumina as crucibles. Water absorption, total porosity, firing shrinkage, bulk density and flexural strength of fired specimens were measured according to the methods previously used by Ergul et al., [26] and Njoya et al., [27]. Dielectric properties were obtained using an impedance analyzer (Hewlett Packard 4284A) by measuring both

Table 1

Chemical composition of the used raw materials. (LOI: Loss On Ignition).

	% mass		
	T	K	BX
SiO ₂	58.74	46.59	0.36
Al ₂ O ₃	0.79	34.46	54.69
Fe ₂ O ₃	6.68	1.05	5.91
MnO	0.11	< ld	< ld
CaO	< ld	< ld	0.03
MgO	28.51	< ld	0.06
Na ₂ O	< ld	< ld	0.05
K ₂ O	< ld	0.92	0.01
TiO ₂	< ld	4.05	4.81
P ₂ O ₅	0.09	0.32	< ld
LOI	4.78	12.53	31.86

Table 2

Mineralogical composition of the used raw materials.

T	K	BX
Talc	Kaolinite	Gibbsite
Chlorite	Illite	Anatase
Goethite	Quartz	Goethite
Chromite	Anatase	
	Apatite	

Table 3

Compositions of the mixtures (% mass).

Formulation	FO1	FO3
K	50	30
T	20	40
BX	30	30

Table 4

Chemical compositions of the mixtures (% mass).

Formulation	FO1	FO3
SiO ₂	43.0	45.0
Al ₂ O ₃	41.2	32.1
MgO	7.0	13.7
Fe ₂ O ₃	4.3	5.7
TiO ₂	4.2	3.2
K ₂ O	0.5	0.3
Total	100.2	100

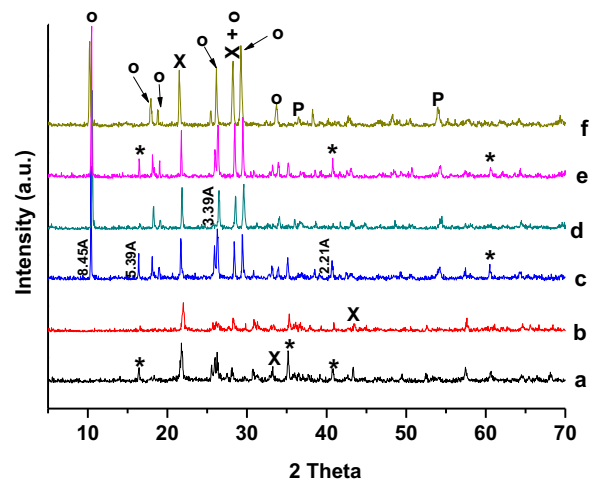


Fig. 1. XRD patterns of the ceramic bodies. (a=FO1, 1200 °C; b=FO3, 1200 °C; c=FO1, 1300 °C; d=FO3, 1300 °C; e=FO1, 1400 °C; f=FO3, 1400 °C (o=cordierite; *=mullite; P=Pseudorutile ; X=cristobalite).

capacitance and dielectric loss from room temperature to 500 °C at the frequencies of 1, 5, 10, 50, 100, 500 kHz respectively. To this end, specimens were polished to parallel surfaces and electrodes were silver painted. The values of dielectric constant (ϵ_r) were obtained from measurement of capacitance using the following equation: $\epsilon_r = \frac{C \cdot e}{\epsilon_0 \cdot S}$, where C is the capacitance (F), ϵ_0 the vacuum permittivity (F / cm), e the thickness (cm) and S the surface area of the sample (cm^2).

3. Results and discussion

3.1. Microstructure of fired specimens

The XRD patterns of fired bodies are given in Fig. 1 which indicates

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