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ScienceDirect
Journal of the European Ceramic Society 30 (2010) 1785–1793
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Utilization of recycled paper processing residues and clay of different sources for the production of porous anorthite ceramics

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Received 15 September 2009; received in revised form 15 January 2010; accepted 27 January 2010
Available online 23 February 2010

Abstract

Production of porous anorthite ceramics from mixtures of paper processing residues and three different clays are investigated. Suitability of three different clays such as enriched clay, commercial clay and fireclay for manufacturing of anorthite based lightweight refractory bricks was studied. Porous character to the ceramic was provided by addition of paper processing residues (PPR). Samples with 30–40 wt% PPR fired at 1200–1400 °C contained anorthite ($CaO{\cdot}Al_2O_3{\cdot}2SiO_2$) as major phase and some minor secondary phases such as mullite ($3Al_2O_3{\cdot}2SiO_2$) or gehlenite ($2CaO{\cdot}Al_2O_3{\cdot}SiO_2$), depending on the calcite to clay ratio. Anorthite formation for all clay types was quite successful in samples with 30–40 wt% of paper residues fired at 1300 °C. A higher firing temperature of 1400 °C was needed for the fireclay added samples to produce a well sintered product with large pores. Gehlenite phase occurred mostly at lower temperatures and in samples containing higher amount of calcium (50 wt% PPR). Compressive strength of compacted and fired pellets consisting of mainly anorthite ranged from 8 to 43 MPa.

Keywords: Firing; Porosity; Refractories; Anorthite ceramics; Paper processing residues

1. Introduction

Anorthite ($CaAl_2Si_2O_8$) is one of the most important members of the plagioclase feldspar family. It is a rare constituent in magmatic and metamorphic rocks. The theoretical composition of anorthite is 20.2% CaO, 36.6% Al_2O_3 and 43.2% SiO_2 on a weight basis. According to $CaO–Al_2O_3–SiO_2$ phase diagram (Fig. 1), pure anorthite exhibits a melting point of 1553 °C.[1] Its theoretical density is 2.76 g/cm^3 and it has triclinic crystal structure. Anorthite is chemically most nearly related to celsian ($BaAl_2Si_2O_8$), and crystallographically most similar to albite ($NaAlSi_3O_8$) and orthoclase ($KAlSi_3O_8$). Its unit cell is primitive, with a 14 Å *c*-axis; the *c*-axis is twice that of albite.[2] Anorthite crystals may occur as euhedral (well-formed with sharp) and tabular crystals.[3,4]

Dense anorthite ceramics are promising materials for substrate applications in electronics industry due to their good physical properties such as thermal expansion coefficient of 4.8×10^{-6}/°C and low dielectric constant of 6.2 at 1 MHz.[5] Their thermal expansion coefficient is close to mullite (5.3×10^{-6}/°C). Anorthite based glass–ceramics may also be used in a wide range of applications such as supports of catalysts for the conversion of combustion gases from engines in industrial heat exchangers for gas turbines due to their low thermal expansion coefficient, high thermal shock resistance and low dielectric constant.[6] The fluorapatite–anorthite binary system can be promising in biomedicine too, as material for joint prostheses or dental roots.[7] Because of these desirable properties, anorthite ceramics have attracted attention and several studies were carried out in order to decrease the firing and crystallization temperature below 1000 °C.[8–10] For example, anorthite ceramics for substrate applications require co-firing with inexpensive conductive metals at low temperatures.

Synthesis of anorthite was extensively studied by using different methods such as sintering of mixtures of calcium carbonate, kaolinite, alumina and aluminum hydroxide in addition to mechano-chemical treatments or employing different sintering aids.[8–12] Kobayashi and Kato[8] have reported the fabrication of dense anorthite ceramics by sintering around 1000 °C of kaolin and finely milled calcite mixtures. They concluded that

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doi:10.1016/j.jeurceramsoc.2010.01.038

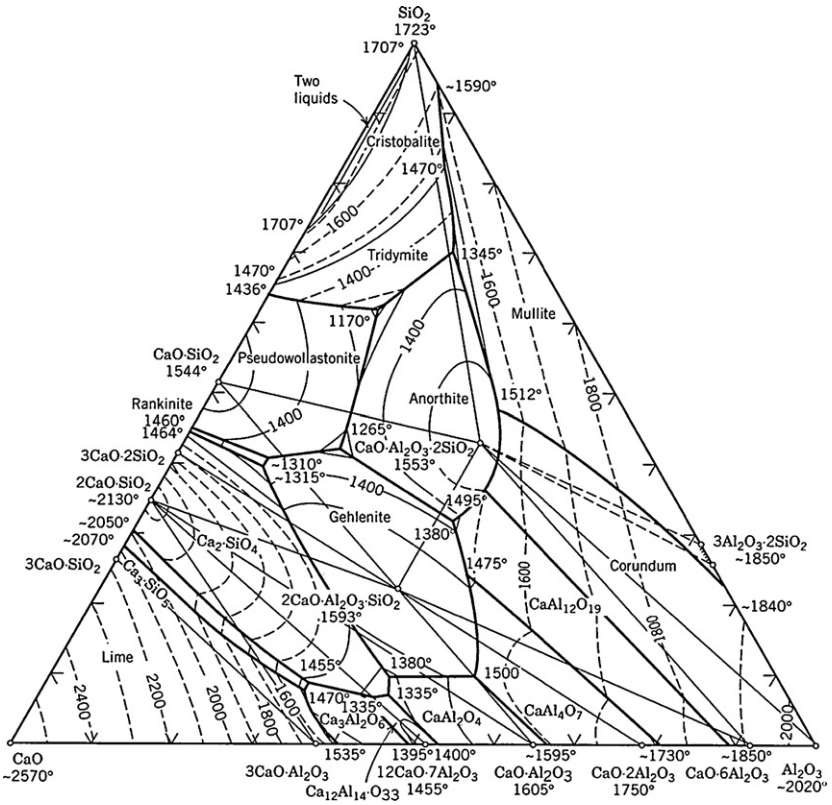

Fig. 1. $CaO–Al_2O_3–SiO_2$ phase diagram.[1]

reduction to 1.5 μm of the particle size of calcite led to the production of dense anorthite ceramics with a relative density of 94% at 950 °C. Mergen and Aslanoglu[9] have reported that single phase anorthite ceramic with 87% theoretical density could be obtained from sintering of raw materials with coarse particles at 950 °C by using boron oxide addition. Kavalci et al.[10] investigated the process variables such as temperature, soaking time, amount and type of additives and mechano-chemical treatment on synthesis of anorthite ceramics. They found that anorthite formation temperature decreased down to 900 °C by the combined effect of additive usage and intensive grinding. Okada et al.[11] observed a layered $CaAl_2Si_2O_8$ and anorthite formation by grinding effect in the samples fired at 900 and 1000 °C, respectively. Also the effect of different sources of CaO such as $Ca(OH)_2$, $CaCO_3$, marble powder and gypsum mould waste was investigated by Kurama and Ozel[13] in order to produce anorthite ceramics. They showed that anorthite could be produced as the main phase above 1200 °C with a maximum density of 80% in samples with $Ca(OH)_2$. Above mentioned studies aimed to produce dense anorthite ceramics from different sources of calcia and aluminum silicates. Recently, paper processing residues are used as a new source of raw material in the production of porous brick and porous ceramic composite consisting of the cordierite, mul-

Table 1
Experimental results of samples containing aluminum silicate and PPR (s: strong, vs: very strong for XRD peak intensity).

Temperature (°C)	PPR content (%)	XRD peak intensity[a]	Loss on ignition (%)	by Archimedes method (ASTM C20)			Compressive strength (MPa)
				Apparent porosity (%)	Bulk density (g/cm^3)	Apparent specific gravity	
1100	30	A, M, G	25.2	41.0	1.46	2.48	–
	50	A, G (s)	33.7	54.7	1.33	2.95	–
1200	20	A, M	20.9	29.0	1.75	2.46	–
	30	A (s), M	25.2	35.5	1.49	2.31	–
	40	A (s), G	29.5	49.9	1.34	2.68	–
	50	A, G	33.7	48.1	1.29	2.48	–
1300	20	A, M	20.9	6.4	1.94	2.07	41.4 ± 8.3
	30	A (vs), M	25.4	36.2	1.53	2.40	28.0 ± 6.8
	40	A (vs), G	28.3	44.8	1.39	2.53	15.6 ± 2.2
	50	–	34.2	30.4	1.71	2.47	–

[a] Decreasing dominance of phases from left to right.