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Materials Science and Engineering A 437 (2006) 222–225

MATERIALS SCIENCE & ENGINEERING A

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Characterization of cellular ceramics made by porcelain tile residues

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Received 15 March 2006; received in revised form 4 June 2006; accepted 21 July 2006

Abstract

This work deals with physical, structural and mechanical characterization of cellular ceramics obtained from porcelain tile polishing residues expanded with silicon carbide abrasive residues [A.M. Bernardin, et al., Proceedings of the VIII World Congress on Ceramic Tile Quality, vol. 3, 2004, pp. 195–199]. In a previous work it was studied the expansion process, that means, SiC decomposition simultaneous with the polishing residue melting, both at ∼1200 °C. Starting at 1000 °C SiC particles decomposes into SiO_2 and CO_2, the last one used as an expanding agent, promoting the expansion of the melt (porcelain tile residue) formed at 1200 °C. Now, the microstructure, expansion, density and mechanical properties (flexural tests) were determined to characterize the product. Cellular ceramics can substitute polymers (expanded polystyrene) and wood in internal partition walls and linings, and cellular concrete in the building industry.

Keywords: Polishing residues; Porcelain tile; Cellular ceramics; SiC; Abrasives

1. Introduction

Recycling was established with the Industrial Revolution, when the available metals were continuously processed. Nowadays recycling is an international industry. All kind of materials are collected, separated, processed and commercialized according rigid specifications, resulting in standard materials that can be traded around the world. The use of standard materials is, in theory, circular: primary substances extracted or collected are transformed in products that eventually are redundant and can be recycled in the manufacturing process [2,3].

Without recycling the process is not circular, becoming a sequence of events without a logical resolution. Potentially useful materials become a menace, not a resource [4]. The use of secondary, that is, recycled materials results in a great energy saving related to the primary production. Among the several raw materials that can be recycled are the industrial solid residues from the ceramic industry [5–8].

Currently there is no recycling of the solid residues from the tile ceramic industry in Santa Catarina State, South of Brazil. The region is the second tile ceramic producer in Brazil, with approximately 30% of the overall tile production and the first exporter. The ceramic residues are discarded directly on landfills, without any kind of separation [9–11]. The polishing ceramic residues, locally named "mud", are the remaining portions of the "grés porcellanato" polishing process containing abrasive particles detached from the abrasives used to polish the tiles, normally chlorine–magnesium cement impregnated with silicon carbide or diamond particles.

The residue is collected, stored and filtered in effluent treatment stations that remove the residual water, producing mud as a subproduct. The mud is stored on landfills, causing environmental impact [12,13]. An alternative to the discard of ceramic solid residues is their use to make new products [14,15]. Specifically in this study the porcellanato polishing residues were used to form low density ceramics. As presented by Bernardin et al. [1], low density ceramics can be used as building materials according their thermal and acoustic characteristics.

As previously stated, the polishing residues are the rest of porcelain tiles, mixed with water and organic substances. Porcelain tiles are characterized by a dense microstructure with low and close porosity. This product present a minor crystalline phase formed by mullite and quartz crystals immersed in a vitreous phase. The vitreous phase is formed by a siliceous glass containing alkaline and earth alkaline oxides, mainly potash, soda and magnesia, with a low melting

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doi:10.1016/j.msea.2006.07.130

Table 1
Chemical analysis (wt.) of the sample residues

Samples	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	LOI
Porcelain residue	59.5	17.3	0.7	0.3	1.6	5.3	2.8	3.6	5.6
Abrasive residue	10.5	1.6	1.6	0.1	4.1	34.8	0.1	6.3	40.2

point as the porcelain tiles, or "grés porcellanato", are fired at 1200 °C during 40–50 min. Combining a glassy material with a relative low melting point allows its recycling in new products.

In its turn, the silicon carbide that is present in the polishing abrasives can be decomposed above 1000 °C in presence of oxygen. Its decomposition results in silica and carbon dioxide according: $SiC + 2O_2 \rightarrow SiO_2 + CO_2$. Therefore, the mixture of a vitreous material that melts at the same temperature of SiC decomposition can result in a cellular ceramic material because of gas formation, in this case, carbon dioxide.

The amount of expansion is related to the number and particle size of SiC particles present in the vitreous material. After cooling, the structure formed is a vitreous material containing large and rounded pores, as obtained and discussed in a previous study [1].

In this study, the mechanical and physical properties of the cellular ceramic are related to the amount of abrasive added to the residue from an effluent treatment station. The results show good mechanical resistance with very low density and a microstructure formed by rounded and large pores.

2. Materials and methods

Samples from porcelain tile polishing residue and from SiC abrasives were submitted to physical–chemical characterization to determine their chemical, phase and particle size distribution analyses. In addition, a thermal analysis was carried out. The chemical analysis was carried out by X-ray fluorescence (Phillips PW2400, molten sample) and the phase analysis by X-ray diffraction (Phillips PW1830, Cu Kα, 0–75°, analysis with X'Pert HighScore software). The particle size analysis was carried out by LASER diffraction (CILAS 1064, 60s ultrasound). Finally, the thermal analysis was determined by differential thermal analysis (BP Engenharia RB 3000, 20–1200 °C, 10 °C/min, air atmosphere).

After characterization, polishing residue samples were dried (110 °C, 24 h) and sifted (200 mesh) forming a residue powder. The abrasives used were the part not used of SiC abrasives; they were disaggregated in a hammer mill, dried (110 °C, 24 h) and sifted (200 mesh) forming an abrasive powder. In sequence, the abrasive powder was added to the residue powder in mass fractions of 0.5%, 1.0%, 1.5%, 3.0%, 6.0% and 12.0% forming six formulations. The formulations were mixed with 6% of water (mass fraction) and pressed (300 kgf/cm^2) in cylindrical specimens (5 cm diameter, 1 cm height), five specimens for each formulation.

The compacts were sintered during 20 min at 1180 °C with 30 °C/min heating rate and cooled in the furnace (laboratory muffle oven). After heat treatment the expanded specimens of all formulations were submitted to linear expansion, volume density and mechanical resistance determination. The density was determined by immersion in mercury and the mechanical resistance was determined by the flexural test (Ceramic Instruments MOR3E, 10 mm/min).

3. Results and discussion

Table 1 shows the chemical analysis of the samples (porcelain tile polishing residue and abrasive residue) used in this study; Fig. 1 shows the phase analysis. As observed the major part of the abrasive residue is composed of chlorine–magnesium cement used to form the abrasive. It was not possible to identify the silicon carbide (SiC) because of the procedure used to analyze the abrasive samples: the samples were calcined at 1000 °C during 3 h, causing total conversion of the SiC present in the samples.

Regarding the porcelain residue, it is formed by quartz, albite and zircon, the major phases of a porcelain tile paste. The amount of alkaline and earth alkaline oxides present in the porcelain residue (13.3 wt%) shows the good vitrification of this system.

The thermal analysis essay of the abrasive sample (Fig. 2) shows endothermic peaks between 260 and 500 °C, probably regarding the decompositions of hydroxides (mainly portlandite and clinochlore) present in the sample. The carbonates (calcite, magnesite and dolomite) were not identified, probably due its low content. Between 1020 and 1030 °C it can be seen endothermic and exothermic peaks, probably related to the dissociation of the silicon carbide into silica and carbon dioxide.

The thermal analysis of the porcelain tile residue (Fig. 3) shows endothermic peaks at 60 and 400 °C approximately, probably due thermal decompositions of the organic substances present in the residue obtained from the effluent treatment. At

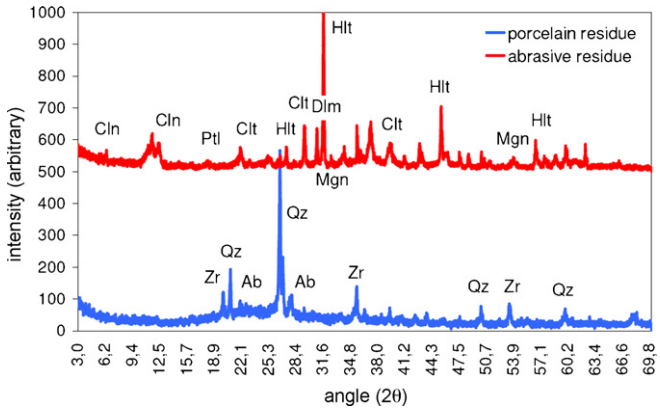

Fig. 1. Phase analysis of the porcelain and abrasive residues. Qz is quartz; Zr is zircon ($SiO_2{\cdot}ZrO_2$); Ab is albite; Hlt is halite (NaCl); Dlm is dolomite; Clt is calcite; Mgn is magnesite; Cln is clinochlore; Plt is portlandite ($Ca(OH)_2$).