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Obtainment of porcelain floor tiles added with petroleum oily sludge

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Abstract

This study focuses on the processing of vitrified floor tiles incorporated with a petroleum oily sludge. Floor tile formulations containing up to 5 wt% of the petroleum oily sludge in replacement of kaolin were prepared. The tile formulations were granulated by the dry process, pressed, and fired at temperatures between 1200 and 1250 °C using a fast-firing cycle. The specimens were characterized before and after firing. XRD was used to identify the crystalline phases present during sintering and SEM was used to show how the structure changes during densification. Three parameters were used to describe densification: linear shrinkage, water absorption, and flexural strength. The results showed that the petroleum oily sludge could be used as an alternative raw material in the floor tile formulations. The densification behavior of the floor tile pieces is influenced by the petroleum oily sludge addition and firing temperature. The vitrified floor tiles produced reached the technical characteristics of porcelain floor tiles, depending on petroleum oily sludge content and firing temperature.

Keywords: A. Firing; B. Porosity; E. Structural applications; Oily sludge

1. Introduction

Every year the petroleum industry generates large amounts of by-products (oily sludges) worldwide [1–3]. These oily sludges are basically complex mixtures of hydrocarbons (oil), water, inorganic materials, and traces of heavy metals [3,4]. For this reason, the oily sludges are considered to be hazardous waste materials. The management of these oily sludges has been over the years a major concern of the petroleum industry and environmentalists. In Brazil, the oily sludges have been mainly disposed in pounds, dykes, and landfarms (biodegradation). More recently, these oily sludges have been disposed in sanitary landfills after treatment with bentonite clay [5,6]. However, these options are usually expensive and environmentally unsustainable. In addition, Brazil is now increasing the regulatory pressures on these management options, thus the development of new management methods for this waste material is very important.

The oily sludge treated with bentonite clay is characterized as a petroleum waste material composed of clay minerals, quartz, barite, calcium sulpfate, calcite, and hydrocarbons [6]. Thus, it has some potential to be used as ceramic raw material. In fact, several works have shown promising results on the reuse of petroleum oily sludge in the production of clay bricks [7–12]. However, insufficient attention was devoted to the use of petroleum oily sludge in vitrified floor tiles [13]. Floor tiles are vitrified ceramic products of low porosity with excellent physical and mechanical properties. These materials are produced via powder technology: raw materials preparation (dry or wet grinding), dry uniaxial pressing, drying, and single-fast-firing cycles [14–16].

Brazil is currently the second worldwide producer of ceramic tiles, ahead of India, Italy and Spain, and behind China [17]. In 2009, Brazilian ceramic tile production totaled 715 million square meters, which corresponds to about 8.4% of the world production. This production can grow still more due to the high internal demand and opportunities for exportation. In fact, the domestic market is the second largest tile consumer in the world with 645 million square meters (7.6% of the world consumer). The need to increase

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production to meet the increasing demand has triggered academic and technological researches focused primarily on the development of new deposits of raw materials. In this context two important aspects should be considered: (i) the tile industry faces scarcity of good quality raw materials; and (ii) the tile formulations are strongly affected by locally available raw materials. Thus, the reuse of waste materials into tile formulations seems to be one of the best alternatives to reduce the extraction of virgin raw materials, preserving limited natural resources.

This paper discusses, in detail, the preparation of vitrified floor tiles using petroleum oily sludge. The densification behavior of the tile formulations containing petroleum oily sludge was investigated. Emphasis is given to the formulation characteristics, their effects on the technological properties of the end product, and the microstructural evolution of the fired specimens.

2. Experimental procedure

Different floor tile compositions were formulated (Table 1) using mixtures of kaolin, Na-feldspar, quartz, and petroleum oily sludge. The oily sludge was added up to 5 wt% in gradual replacement of kaolin. A standard composition (40 wt% kaolin, 47.5 wt% Na-feldspar, and 12.5 wt% quartz), referred to as MC0 formulation, was used as ref. [18]. Commercial kaolin, Na-feldspar, and quartz were used. The petroleum oily sludge was collected in the Brazilian oil company. Table 2 gives the chemical compositions of the raw materials and the prepared formulations.

Table 1
Ceramic floor tile formulations (wt%).

Raw materials	Formulations			
	MC0	MC1	MC2	MC3
Kaolin	40.00	38.75	37.50	35.00
Oily sludge	0.00	1.25	2.50	5.00
Na-feldspar	47.50	47.50	47.50	47.50
Quartz	12.50	12.50	12.50	12.50

The raw materials were dry-ground and mixed using a laboratory mill, and then passed through a 325 mesh (45 μm ASTM) screen. The tile compositions prepared by the dry process were mixed, homogenized and granulated using a high intensity mixer (Eirich, type R02) with moisture content of 14% (moisture mass/dry mass). After reducing the moisture content to 7%, the granulated powder is sent to the sieve to eliminate agglomerates coarser than 2 mm.

Mineralogical analysis of the tile formulations was done by X-ray diffraction (URD-65 Diffractometer, Seifert), using copper radiation (Cu-Kα=1.54056 Å). Scanning speed was set to 1.5°(2θ)/min. JCPDS-ICDD cards were used to identify the crystalline phases. Thermogravimetric analysis (TGA and DrTGA) of the tile powder sample was performed within the 25–1200 °C temperature range under air atmosphere with a heating rate of 10 °C/min. The size distribution of the granulated powders was determined by procedures according to the NBR 7181 standard. The plasticity was determined by the Atterberg method according to the NBR 6459 and NBR 7180 standardized procedures. The real density was determined by the picnometry method according to the NBR 6508 standard. The morphology and the surface topography of the granules were observed by scanning electron microscopy (SEM). The Hausner index and screening residue have been also determined.

The powders were uniaxially pressed in a 11.5 cm × 2.5 cm rectangular die at 50 MPa, and dried at 110 °C. The samples were fast-fired in a laboratory kiln at temperatures varying from 1200 to 1250 °C. The whole firing cycle lasts less than 60 min.

The densification behavior of the tile formulations was described by the linear shrinkage, water absorption, and flexural strength. Linear shrinkage values upon drying and firing were evaluated from the variation of the length of

Table 2
Chemical compositions of the raw materials and tested formulations (wt%).

Compounds	Raw materials				Formulations			
	Kaolin	Sludge	Na-feldspar	Quartz	MC0	MC1	MC2	MC3
SiO_2	49.07	41.73	69.55	98.97	65.06	64.97	64.88	64.69
Al_2O_3	33.74	10.93	18.82	0.41	22.49	22.21	21.92	21.35
Fe_2O_3	0.22	7.63	0.14	0.01	0.16	0.25	0.34	0.53
TiO_2	0.01	0.52	0.02	0.02	0.01	0.02	0.03	0.04
Na_2O	0.52	0.44	9.63	0.13	4.80	4.80	4.80	4.79
K_2O	1.97	0.95	1.47	0.18	1.50	1.49	1.48	1.45
CaO	0.30	7.76	0.17	0.01	0.20	0.30	0.39	0.58
MgO	0.06	5.87	0.09	0.01	0.07	0.14	0.21	0.36
MnO	–	0.02	–	–	–	–	–	–
P_2O_5	–	0.09	–	–	–	–	–	–
BaO	–	5.03	–	–	0.00	0.06	0.13	0.25
SrO	–	0.29	–	–	0.00	0.00	0.01	0.01
LoI^+	14.01	18.74	0.32	0.26	5.79	5.85	5.91	6.03

LoI^+—loss on ignition.