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Densification behavior of floor tiles added with sugarcane bagasse ash waste

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Abstract

In this work, the effect of sugarcane bagasse ash waste on the densification behavior of vitrified floor tiles was investigated. Four tile formulations containing up to 5 wt. % of sugarcane bagasse ash waste as a replacement of quartz were prepared. The floor tile manufacturing route consisted of the following steps: powder preparation by the dry process, uniaxial pressing, and firing at temperatures between 1190 ºC and 1250 ºC using a fast-firing cycle. The densification was measured by three parameters: linear shrinkage, water absorption, and flexural strength. The microstructure was evaluated by XRD and SEM. The experimental results indicated that the densification behavior of floor tile formulations was influenced by both the amount of sugarcane bagasse ash waste and the maximum firing temperature. Microstructural variation occurred during firing. However, the use of sugarcane bagasse ash waste had little effect on phase evolution during the fast-firing cycle. An optimum amount of sugarcane bagasse ash waste (up to 2.5 wt. %) for the replacement of quartz allowed for the highest quality production of floor tile materials.

Keywords: sugarcane bagasse ash; waste; floor tile; densification; microstructure.

1. Introduction

Industrial activities generate huge amounts of a variety of solid wastes, which cause considerable environmental and economic problems. For this reason, industrial solid waste management in an ecological and economical way has become a matter of high global interest. Currently, the strategies of solid waste management are focused mainly on the reuse instead of elimination or storage of waste. The ceramic industry for building materials is therefore a well-established field for reuse of solid wastes [1]. This approach has environmental and economic advantages because the solid waste is incorporated into ceramic formulations in place of non-renewable natural raw materials.

The sugarcane industry is based on the production of sugar and ethanol, which produces huge amount of sugarcane bagasse ash (SCBA) waste worldwide. SCBA waste is considered a non-biodegradable solid waste material, which has become a negative factor for the sugarcane industry and ecologists. The SCBA waste is mainly disposed of as soil fertilizer [2], but this negatively impacts the environment. SCBA waste has quartz (SiO_2) as a major component, and minor amounts of Al_2O_3, Fe_2O_3, K_2O e CaO [3-5]. Thus, SCBA waste has a high potential to be used in ceramic building materials as replacement of virgin raw materials.

Floor tiles are vitrified ceramic materials with excellent physical, mechanical and tribological properties. These tile materials are primarily formulated from a triaxial mixture with natural raw materials such as kaolin, plastic clay, feldspars, quartz, and feldsphatic sands [6]. On firing, floor tile formulations undergo a series of physical and chemical reactions at different temperature ranges, resulting in a heterogeneous microstructure composed of high-temperature silicate phases embedded in an abundant glassy phase. The tile

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industry in many countries is facing scarcity of viable raw materials in locations close to the plants. This means that there are significant opportunities for research in this field, mainly using solid wastes as a low-cost alternative for raw materials. The literature [7-12] review shows that the use of different solid wastes in the manufacturing of floor tiles has been extensively investigated. However, very little research has been focused on the effects of the SCBA waste addition on the processing properties and sintered microstructure of floor tile formulations [13, 14]. In particular, the densification behavior of floor tile formulation added with SCBA waste is still to be investigated.

The aim of this paper is to report and discuss the densification behavior of floor tiles incorporated with SCBA waste. Special emphasis is given to the tile formulation characteristics, their effects on the densification behavior and microstructural evolution of the fired specimens.

2. Experimental Procedure

Four floor tile compositions were formulated (Table 1) using triaxial mixtures of kaolin, albite, and quartz + SCBA waste. In this study the quartz was replaced with increasing amounts of SCBA waste. The SCBA waste sample was collected from a sugarcane plant located in south-eastern Brazil. The collection of the representative SCBA sample (10 kg) was done during boiler cleaning step of the sugarcane plant. The chemical composition of the SCBA waste has been published elsewhere [4]. Commercial kaolin, albite, and quartz used were supplied by the Armil Mineração do Nordeste Ltda, whose chemical compositions have been published elsewhere [15].

Table 1. Vitrified floor tile formulations (wt.%).

Formulation	Kaolin	Albite	Quartz	SCBA waste
MS0	40.00	47.50	12.50	0.00
MS1	40.00	47.50	11.25	1.25
MS2	40.00	47.50	10.00	2.50
MS3	40.00	47.50	7.50	5.00

The reference floor tile formulation (MS0) consisted of 40.0 wt.% kaolin, 47.5 wt.% albite, and 12.5 wt.% quartz. Table 2 gives the chemical compositions of the floor tile formulations. The raw materials were dried at 110 ºC, dry ground separately in a laboratory grinder, and then passed through a 325 mesh (45 μm ASTM) sieve. The tile formulations (Table 1) were mixed, homogenized, and granulated by the dry process. The granulated tile powder was sent to the sieve to eliminate agglomerates coarser than 2 mm.

Table 2. Chemical compositions of the tile formulations (wt.%).

Compounds	Formulations			
	MS0	MS1	MS2	MS3
SiO_2	65.03	64.57	64.11	63.17
Al_2O_3	22.38	22.46	22.53	22.67
Fe_2O_3	0.16	0.25	0.35	0.53
TiO_2	0.02	0.03	0.05	0.08
Na_2O	4.80	4.79	4.78	4.77
K_2O	1.51	1.58	1.66	1.81
CaO	0.24	0.31	0.37	0.49
MgO	0.07	0.08	0.09	0.13
MnO	-	-	0.01	0.01
P_2O_5	-	0.01	0.02	0.05
SO_3	-	0.01	0.01	0.02
LoI$^+$	5.79	5.91	6.04	6.27

$^+$ LoI – loss on ignition

XRD analysis of the tile formulations was performed in a conventional diffractometer (Shimadzu, XRD-7000) using Cu-Kα radiation (λ = 0.154 nm) at a scanning speed of 1.5º (2θ)/min. JCPDS-ICDD cards were used to identify the mineral phases. The grain-size distribution of the tile powders was determined by sieving. The plastic index was determined by the Atterberg method according to NBR 6459 and NBR 7180 standardized procedures. The Hausner ratio was determined as the ratio of tap density to apparent density of the granulated tile powder.

The tile formulations prepared by the dry process were tested at a laboratory scale, simulating the industrial floor tile-making process. The tile powders were moistened (7 wt. % water), uniaxially pressed at 50 MPa into test bars (11.50 cm x 2.54 cm), and then dried in an oven at 110 ºC. Green tile pieces (five test specimens for each composition) were fast-fired between 1190 ºC and 1250 ºC in a laboratory kiln (Fortlab, FQR-1300/3) with a heating rate of 70 ºC/min from room temperature up to 500 ºC, 25 ºC/min between 500 and 600 ºC, and 50 ºC/min up to the maximum firing temperature with 6 min of soaking time. The cooling rate was 120 ºC/min for maximum firing temperature up to 600 ºC, and 25 ºC/min for 600 ºC up to room temperature. The entire fast-firing cycle