Characterization of Granulometric Fractions of Ash from Boiler Burnt Sugarcane Bagasse

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Abstract. In the municipal area of Campos dos Goytacazes–RJ several ceramic industries are involved with a significant production of bricks and tiles. These ceramic products can serve as matrices for the incorporation of industrial residues such as the ash of sugarcane bagasse used as fuel in the boilers of the sugar and alcohol plants. The incorporation of ashes in ceramics is a solution that eventually can cause an improvement on the properties of the material. The objective of this work is to characterize granulometric fractions of sugarcane bagasse ash with particle sizes less than 149, 75 and 44 µm aiming at the ash incorporation into red ceramics. Chemical, mineralogical and microstructural characterization were carried out in the granulometric fractions. The results showed that the granulometric fractions present as main crystalline phase the cristobalite and that the ashes with smaller particle sizes can improve the densification of the ceramic body by the formation of more liquid phase during firing, due to the presence of less silica and more alkaline- and alkaline-earth oxides than the original ash.

Introduction

Campos dos Goytacazes is a town located at the Northern part of Rio de Janeiro state, Brazil. The main economical activities are sugar and alcohol production, from sugarcane, as well as bricks and roofing tiles production from kaolinitic clay [1].

The main fuel of the sugar and alcohol production plants is the proper sugarcane bagasse that is burned in boilers. The burnt of the bagasse generates large amounts of ashes deposited at the bottom of the boiler. These bottom ashes have relatively high contents of silica, potassium and phosphorus.

Solid wastes are becoming a matter of increase world concern due to their amount as well as difficulty and cost of final disposal. The ceramic products can serve as matrices for
incorporation of industrial residues such as the ash of burnt sugarcane bagasse, giving an option for the solid waste disposal with a possible increase in the properties of the clay ceramic artifacts.

The incorporation of wastes, including ashes, from several industrial activities into clay ceramic products is a technological alternative to reduce the environmental impact due to their indiscriminate disposal [2]. The firing stage during the clay ceramics process can promote the elimination of potentially toxic constituents present in the solid residues through their volatilization, chemical changes and stabilization in the vitreous phase formed by the aluminosilicates and fluxes [3-5].

The objective of this work was to characterize the granulometric fractions of sugarcane bagasse ash with particle sizes less than 149, 75 and 44 µm aiming at their incorporation into red ceramics. The characterization was carried out by chemical and mineralogical analyses, as well as morphology investigation by scanning electron microscopy.

Experimental Procedure

The raw material used in this work was the ash obtained from the burning process of sugarcane bagasse in boilers. The ash was manually crushed and screened using sieves with different apertures: 149 µm (100 mesh), 75 µm (200 mesh) e 44 µm (325 mesh). The fractions of the ash that passed through these sieves were denominated as Ash(#100), Ash(# 200) and Ash(#325), respectively.

Chemical composition of the ash and ash fractions was determined by X-ray fluorescence spectrometry (XRF) using a Philips model PW 2400 spectrometer.

X-ray diffraction analysis (XRD) was carried out by a Bruker-AXS D5005 diffractometer operating with Co-Kα radiation and a scanning angle (2θ) from 5 to 80°. The following crystalline phases were identified in the ash: potassic feldspar, mullite, hematite e calcium phosphate [6].

Thermogravimetric analyses (TGA) were carried out in a TA Instruments model 2960 SDT V3.0F that operates in an air stream (100 mL/min) and a heating rate of 10°C/min up to a maximum temperature of 1200°C.

Morphology of the ash particles was investigated by scanning electron microscopy (SEM) in a ZEISS equipment, model DSM 960.

Results and Discussion

Table 1 shows the chemical composition of the sugarcane bagasse ash and ash fractions. The ash is basically formed by high amounts of SiO$_2$. This elevated amount of SiO$_2$ is associated with quartz crystalline phase. When ash is added to the clay, the high free silica contents (~65 to 78 wt%) may contribute to change the plasticity and improve the drying step of the red clay. However, an excess of quartz may difficult the extrusion of the ceramic artifacts and reduce the mechanical resistance. At the firing step, the major part of the quartz behaves as an inert charge and may generate micro cracks during the cooling down step due to the allotropic transformation of the quartz around 573°C [7]. The high amounts of K$_2$O (~5.5 to 6.0 wt%) and MgO (~3.0 to 7.0 wt%) may act as a flux material. The low loss on ignition (LoI) is appropriate to the firing stages. Traces of other elements such as Na, S, Cr, Ni, Rb, Sr, Y, Ru, Rh, Ce e Nd were also present.

Chemical analyses have also shown that, as the ash particle size decreases, the amount of silica also decreases, and the alumina, alkaline and alkaline-earth oxides, P$_2$O$_5$ and LoI
increase. The combination of less silica and more alkaline and alkaline-earth oxides contributes to the formation of more liquid phase. The presence of SO$_3$ was observed in the ash fractions for all three granulometries.

XRD patterns of the ash fractions are shown in Figure 1. The main crystalline phase for the different granulometries is cristobalite. Ash(#100) also presents diffraction peaks corresponding to quartz, mulite, Fe-Mg silicate, and Mg-silicate. Ash(# 200) and ash (#325) do not present the diffraction picks corresponding to iron and magnesium silicate. The Ash(#325) also presents quartz, magnesium phosphate, potassium and calcium aluminosilicates. Cristobalite is formed at 1470°C and melts at 1713°C [8,9]. However, it may be formed at lower temperatures when silica is present in high concentrations. During firing, quartz acts as an inert and non-plastic charge, and potassium and calcium aluminosilicates are beneficial to the ceramic processing because they behave as fluxes.

Table 1 – Chemical composition of the raw materials (wt. %)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Ash</th>
<th>Ash (#100)</th>
<th>Ash (#200)</th>
<th>Ash (#325)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>77.5</td>
<td>73.8</td>
<td>69.7</td>
<td>64.6</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>4.7</td>
<td>5.6</td>
<td>5.7</td>
<td>6.4</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>3.8</td>
<td>2.5</td>
<td>2.9</td>
<td>3.2</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>0.3</td>
<td>0.3</td>
<td>traces</td>
<td>traces</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>5.4</td>
<td>5.5</td>
<td>6.2</td>
<td>6.1</td>
</tr>
<tr>
<td>MgO</td>
<td>3.0</td>
<td>4.2</td>
<td>5.4</td>
<td>6.9</td>
</tr>
<tr>
<td>CaO</td>
<td>2.3</td>
<td>3.3</td>
<td>4.1</td>
<td>4.9</td>
</tr>
<tr>
<td>MnO$_2$</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>2.3</td>
<td>3.1</td>
<td>3.7</td>
<td>4.8</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>-</td>
<td>0.4</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>ZrO$_2$</td>
<td>0.06</td>
<td>0.06</td>
<td>traces</td>
<td>traces</td>
</tr>
<tr>
<td>SrO</td>
<td>-</td>
<td>0.04</td>
<td>traces</td>
<td>traces</td>
</tr>
<tr>
<td>LoI</td>
<td>0.3</td>
<td>0.8</td>
<td>0.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Fig. 1 - XRD pattern of the ash fractions. S = iron and magnesium silicate, Q = quartz, C = cristobalite, M = mulite, I = magnesium silicate, F= magnesium phosphate, A = potassium aluminosilicate, N = calcium aluminosilicate

The thermal behavior of the ash and its fractions is presented in Figure 2. The following points are worth observing: at 180°C a small mass loss occurred by elimination of water; in the 650 to 740°C range a mass loss occurred probably related to an endothermic peak of Al₂PO₄(OH)₃ (augelite) coming from the hydroxyl elimination [10]; at 950-960°C a loss of mass occurred probably related to an endothermic peak of the dehydroxylation of magnesium silicate (talc, Mg₃Si₄O₁₀(OH)₂) and its transformation to enstatite (magnesium-iron pyroxene (Mg,Fe)₂Si₂O₆) [11], and also the formation of the spinel phase and mulite [12].

Fig. 2 - Thermogravimetric curves for sugarcane bagasse ash and ash fractions.
The morphology of the sugarcane bagasse ash particles are shown in Figure 3. SEM Fig. 3(a) shows round-shaped quartz particles. Figure 3(b) shows round-and tubular-shaped porous aggregates formed by a partial diffusion reaction of silica, alumina and alkaline and alkaline-earth oxides present in the ash. As the particle size of the ash decreases there is an increase of the tubular-shaped porous aggregates, Fig. 3(c). Through analysis by EDS, was observed in the porous aggregate, Fig. 3(b), the presence of Mg, Al, Si and K and in the tubular aggregate (Figure 3c) the presence of Si, Mg and Ca. The porous aggregate is probably composed of magnesium and potassium aluminosilicate.

Conclusions

The ash is basically characterized by high amounts of SiO$_2$. It also presents high amount of K$_2$O and MgO.

The fractions ash #100, ash #200 and ash #325 present as main crystalline phase the cristobalite.

The ashes with smaller particle sizes – Ash(#200) and Ash(#325) - can improve the densification of the ceramic body by the formation of more liquid phase during firing, due to the presence of less silica and more alkaline- and alkaline-earth oxides than the original ash and Ash(#100). Low values of LoI also favor the firing step of the ceramic processing.

It was observed, through scanning electronic microscopy, a prevalence of aggregates with a tubular form, composed mainly of Si, for the ash with smaller particle size, ash(#325).

The bagasse ash is a promising material for the ceramic industry associated with the sugar/alcohol production industry.

The benefits of using the bagasse ash as flux in ceramic would be twofold: to give an economical and ecological destination to approximately 28.000 tons/year of ashes coming from the burnt of the sugarcane bagasse in the Campos dos Goytacazes area, and as an alternative raw material in the production of ceramics, replacing the clay in up to 20%, without deleterious effects in the properties [13].
Fig. 3. SEM photomicrographs of the sugarcane bagasse ash fractions. (a) Ash(#100), (b) Ash(#200), (c) Ash(#325).

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References