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Volcanic ash as flux in clay based triaxial ceramic materials, effect of the firing temperature in phases and mechanical properties

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Abstract

The study of possible incorporation of nontraditional starting powders is a contribution to the rational utilization of raw materials in the ceramic industry. The technological properties of solid waste problems (both urban and industrial) in many cases are not correctly studied and reported. The main objective of the present work is to study and demonstrate the applicability of the volcanic ash for the fabrication of clay based ceramic materials as the flux fraction for replacing feldspar. This paper deals with a particular raw material (volcanic ash) but the results can be extended to materials resulting from similar sources and properties. The milled volcanic ash was characterized and employed as a flux agent replacing feldspar in a model triaxial ceramic material (clay–quartz–flux) formulation. Previously, the volcanic ash was characterized. Differential Thermal Analysis and termogravimetry (DTA–TG) in order to establish the firing conditions were also carried out. Afterwards, the thermal treatments (900–1300 °C) conditions were studied: the firing temperatures were correlated with the shrinkage–porosity–density evolution.

The crystalline phase thermal evolution was also established and compared to the one observed in the model feldspar based material. Finally the mechanical properties of the obtained materials (flexural strength and dynamic elastic modulus) were evaluated. The results permitted to corroborate the applicability and establish some of the technological properties of ash based ceramic material.

Keywords: Triaxial ceramic materials; Non-traditional raw materials; Volcanic ash; Processing

1. Introduction

The principal crystalline phases of the starting powders used for manufacturing traditional ceramics, also known as triaxial, are clays, quartz and feldspars [1]. In many cases the second and third are impurities of the principal clay source. However there are a lot of other inorganic resources that can be used as additives in the fabrication of this wide range of materials [1–11].

The study and the incorporation of nontraditional starting powders, is a contribution to the rational utilization of raw materials in the ceramic industry [12–26]. The technological properties of solid waste problems (both urban and industrial) in many cases are not correctly studied and reported. It is often overlooked that some wastes or materials like the volcanic ash are similar in composition when compared to raw materials, containing materials that are not only compatible, but beneficial to the manufacture of ceramics. The fabrication of products from waste is an advantage that may give the manufacturer a highly competitive position in the market due to the economic issues involved and the marketing opportunities particularly in reference to ecological aspects.

Traditional ceramics, white ware, sanitary ceramics, bricks, roof and floor tiles and technical ceramics, such as porcelain and mullite bodies, are usually highly heterogeneous due to the wide compositional range of starting powders and the natural clays used as raw materials, and the.

Therefore, there is a great incentive to use large amounts of suitable waste products as raw materials. Today it is a well-known fact that some waste materials are similar in composition

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to the natural raw materials used in the ceramic industry and often contain materials that are not only compatible but also beneficial in the fabrication of ceramics. In view of the huge amounts of non-renewable mineral resources that the ceramic industry consumes, this similarity is of even greater significance. Although the volcanic ash is strictly a natural resource once it is deposited in the urban or sub urban areas during the volcanic eruptions it transforms into an urban waste with several effects in the human activities; and the approach should be things in common with other urban solid wastes.

There are several studies dedicated to describe the ceramic processes and properties of materials elaborated from industrial inorganic wastes [12–26]. These have been recently reviewed [12–14] but the application of some of these raw materials is usually found in more complex systems than bricks or red ceramic industry, like sanitary ceramics, porcelain tile, etc.

The Southern Volcanic Zone (33°–46°) of the Central Andes exhibits many volcanic systems which have been active during Upper Pliocene (< 3.5 Ma). Characterized as basaltic to andesitic stratovolcanoes, the Puyehue Volcano (40°35′S–72°08′W, in south-central Chile) and the Copahue Volcano (37°51′S–71°09′W, close to Argentina–Chile boundary) represent the latest evidences of explosive eruptions – strombolian and freatomagmatic types – which have delivered huge amounts of pyroclastic fragments affecting human communities as well as ecosystems. During the eruption west and northwest-winds prevailed, so that a fan-shaped area widening towards the east was deposited; this ash layer decreases in thickness as well as in grain size with increasing distance from the source [27–30].

On the 4th of July of 2011 the Puyehue Chilean volcano erupted, its activity produced a great amount of volcanic ash that deposited in the Argentinean territory and the south hemisphere; especially in the Patagonia, the ash deposit was significant and exceeded the 10 cm thick in much of the surrounding areas east of the volcano. In these cases ash is discarded and used at most as landfill. This paper proposes the use of this material in an application with more economic potential. The chemical, crystalline compositions and grain size distribution of the ash are not strictly homogeneous and are slightly variable within a range. This variation might be correlated with trajectory, distance to the origin and other characteristics of the deposit.

A recent article correctly describes these tephra [28] both geochemically and morphologically the volcano is described as well. The actual eruptive history, geochronology, and magmatic evolution of the Puyehue–Cordón Caulle volcanic complex was previously described [31,32].

The environmental impact of the Puyehue–Cordon Caulle 2011 volcanic eruption on Buenos Aires was exhaustively described in a recent article as well [29]. The characteristic of the eruption and the texture of the tephras were also exhaustively described recently [30].

The amount of ash usually deposited in this kind of events transforms it in a potential starting material for several applications. The application of the volcanic ash depends on several factors such as the mineralogy and chemical composition, so that the thorough understanding of physicochemical properties of the phases present in the raw materials can play a decisive role in the evaluation of their technological potential. Then the true potential should be evaluated by the utilization of a representative starting material at laboratory scale. The ash has been proposed for building material fabrication, concrete, arsenic removal, geopolymer, and for other environmental application [33–36].

The sintering behavior of a volcanic ash has been studied recently [37] and the possible geo polimerization was also reported [38]. Some preliminary studies on materials elaborated from clay–ash mixtures were carried out by other authors. Both thermal analysis and mechanical characterization of some materials were presented [39].

The results of other high glass content mineral sources might be similar to the ones expected for the volcanic ash utilization. These have been widely explored in literature for some decades [37–43]. And the expected behavior of materials based in this kind of starting powders showed is similar to other alkali containing sources [44–48].

The objectives of the present work are to study and re-demonstrate the applicability of the volcanic ash for the fabrication of clay based ceramic materials as the flux fraction for replacing feldspar, to evaluate crystalline and non-crystalline phases of materials processed in different firing conditions. Finally the mechanical properties evolution with the firing temperature of a model triaxial material elaborated with a volcanic ash as fluxing agent was studied. Although this paper deals with a particular raw material but the results can be extended to materials originated in other volcanoes.

2. Experimental procedure

The employed ash was picked from the western coast of the Traful Lake (−40.614148, −71.546758), Argentina, (40 km west of the volcano): 40 kg were picked from the surface. The thickness of the ash homogenous deposit was around 20 cm, 60 days after the eruption started.

The volcanic ash presents a silico-aluminous composition and comes from high temperature–pressure conditions hence it principally consists in an amorphous glassy phase accompanied sometimes with some crystalline phases devitrified during the cooling [28].

During the heating treatments (above 1000 °C) of triaxial ceramics, the initial phases, usually crystalline, clay, quartz and feldspars suffer a series of chemical and physical processes at different temperatures between 500 °C and 1300 °C. These processes include decomposition, with gas emission, crystalline transformations, fusion and recrystallizations. Some of the products of these processes are amorphous and others present different grades of crystallinity. The actual temperature and conversion ratio of these reactions and processes depend on the clay type and fluxing components, together with the heating rate and atmosphere [1–11].

The Rietveld method has demonstrated to be an effective tool for quantitative phase analysis in diverse materials from XRD analysis [40,46,49].

The quantitative analysis of the amorphous/crystalline ratio is one of the most investigated and frustrating challenges in the diffraction research. Particularly in silicate materials, like in