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Characteristics of clays and properties of building ceramics in the state of Rio de Janeiro, Brazil

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Abstract

The general characteristics and technological properties of four types of clays obtained from the same location at the north of the State of Rio de Janeiro, Brazil, have been investigated. These clays are intended for applications in ceramics such as bricks and roofing tiles. Clays were first analyzed by X-ray diffraction, chemical composition particle size distribution, thermal analysis and plasticity. Extruded samples were fired at temperatures varying from 850 to 1100 °C to determine the linear shrinkage, water absorption and flexural rupture strength. The results showed that three of the studied clays have adequate characteristics for brick fabrication. However, for two of these adequate clays it is necessary to add convenient materials to enhance the workability. The high porosity developed after firing impairs the use of these clays for roofing tiles. This is a consequence of the kaolinitic nature of the clays as well as their elevated loss on ignition.

Keywords: Clays; Characterization; Ceramics; Properties

1. Introduction

Worldwide, clays are the main raw materials exploited in the fabrication of diversified ceramic products for building construction. Due to inherently complex physical, chemical and mineralogical characteristics, clays usually have unique properties related to their own natural diagenesis [1–4]. Normally, for economic reasons, the building-related ceramic industry has to use clays from nearby deposits. As a consequence, the characterization and quality control of each clay is important for the technical performance of local products [5,6]. Moreover, a specific deposit may have distinct layers associated with different clays. This gives a regional industry the opportunity to mix different clays in order to adjust the properties of both the unfired ceramic body and corresponding final product.

Brazil is one of the world's largest producers and consumers of clayey ceramic. The northern region of the State of the Rio de Janeiro, southeast of Brazil, has an area of around 1000 square kilometers with abundance in alluvial clays formed by quaternary sediments carried by the Paraíba River [7]. Today, this has motivated the development of a ceramic sector for bricks and roofing tiles that comprises more than 100 small and medium size industries with a total production estimated at more than 100 million pieces/month. The regional industries rely on a large number of natural deposits from which to extract the clays. For the vast majority of existing deposits, only empirical knowledge is used to process the clay, which frequently result in products below specifications.

Since the microstructure and properties of any ceramic depends on the characteristics of the raw materials and processing parameters [8], to assure the quality of ceramic products, a complete characterization of the precursor clays as a function of the firing temperature is needed. The objective of the present work was to characterize the

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clays found in a micro-regional deposit located at the Fazenda Santa Helena (Saint-Hellen Farm) in the municipal area of Campos dos Goytacazes, northern Rio de Janeiro State. This is an important deposit comprising layers of four different clays locally named as: amarela (yellow), cinza (grey), preta (black) and tabatinga (and indian name for clay). These clays will be referred to, respectively, as Y, G, B and T.

2. Materials and methods

The four types of clays, Y, G, B and T, used for the fabrication of bricks and roofing tiles were extracted directly from the Saint-Hellen farm deposit. The clays were quarted to provide statistically valid samples. Initially, the samples were dried at 110 °C and desegregated through a 20 mesh (840 μm) sieve. Powder samples were characterized by X-ray diffraction (XRD), chemical analysis, particle size distribution, differential thermal analysis (DTA), thermogravimetric analysis (TGA), and plasticity measurement. Technological properties were evaluated for both, simply dried and fired specimens. In simply dried specimens, the bulk density and the drying linear shrinkage (DLS) were determined. Water absorption and flexural strength, were obtained in fired specimens. Post-firing linear shrinkage (FLS) was also determined.

The XRD was carried out in a Seifert, model URD 65 diffractometer operating with Cu-Kα radiation for a 2θ varying from 5° to 40°. The chemical composition was determined by X-ray fluorescence spectroscopy in a Philips PW 2400 equipment. The particle size distribution was determined by both, sieving and sedimentation methods, following the appropriate norm [9]. The DTA/TGA of the bodies was simultaneously conducted in a TA model SDT 2960 equipment, operating in static air and at a heating rate of 10 °C/min. The plasticity was obtained through the determination of the Atterberg limits. These are the plasticity limit (PL), and plasticity index (PI), according to the norms [10,11].

Unfired rectangular ($100 \times 25 \times 10$ mm) specimens, in lots of 10 for each clay, were molded using an extrusion apparatus. These specimen bodies were dried at room temperature for 72 h and then at 110 °C for 24 h in a stove. The firing stage was carried out in the temperature range from 850 to 1100 °C, at intervals of 50 °C. The heating rate of the electric muffle furnace used for firing was 3 °C/min with 1 h soaking at the maximum temperature. Cooling occurred by natural convection inside the furnace after it was turned off. The technological properties were evaluated, as followed, using all specimen bodies and, for each type of clay, calculating the mean value and standard deviation. The dry bulk density was measured dividing the mass by the external volume for each specimen. The water absorption was determined according to standard procedure [12]. Both, DLS and FLS were obtained by the relative variation in length of the samples using a Mitutoyo calliper (precision of ±0.01 mm). The flexural rupture strength was obtained using a three points bending test in an Instron 5582 universal testing machine, according to standard procedure [13].

3. Results and discussion

Fig. 1 presents the XRD pattern of the four types of clays investigated. It should be noted that all clays have their major peaks associated with kaolinite (K). This is in agreement with most clays found in the northern Rio de Janeiro [14]. In addition, all clays exhibit minor contributions of quartz (Q) and gibbsite (Gi). The Y and T clays, in particular, display diffraction peaks corresponding to goethite (Go), lepidocrocite (L) and muscovite mica (M). Pyrite (P) was only detected in the T clay. The presence of pyrite (FeS_2) is undesirable due to the formation of SO_2 or SO_3 during the firing stage [15]. The relatively high intensity of the quartz peaks in the Y clay, Fig. 1a, indicates a significant presence of free silica. This can be confirmed by the greater SiO_2/Al_2O_3 ratio and smaller loss on ignition (LoI) for the Y clay in Table 1.

Table 1 shows the chemical composition of the clays, where it can be observed that all clays present SiO_2 and Al_2O_3 as the most predominant oxides. These oxides are mainly associated with the kaolinite structure [1]. A minor part is due to the presence of muscovite mica. The SiO_2 content is also associated with quartz particles and the Al_2O_3 is associated with gibbsite. The relatively low SiO_2/Al_2O_3 ratio of all clays is an indication of expressive amount of kaolinite, which represents 46.5 wt.% of SiO_2 and 39.5 wt.% of Al_2O_3. The participation of kaolinite is more significant in clays G and B. Iron oxide, Fe_2O_3, is the main colorant in the clays, being responsible for the reddish color after firing [15]. According to Table 1, clays Y, G and T have a comparatively high amount of Fe_2O_3. Clay B presents the lower amount of Fe_2O_3, which confers, to this type of clay, a lighter color after firing. This is an important technological aspect that renders possible the use of clay B in the fabrication of products with a cream tonality, especially for use in roofing tiles and rustic floor tiles. Another important aspect with respect to the chemical composition of the clays is the low amount of K_2O that is considered the main flux agent of clayey materials [15,16]. Again, this can be associated with the kaolinitic predominance of the clays. The value of LoI is related to the dehydroxylation of the clay minerals, organic matter oxidation, decomposition of carbonates, sulfides, hydroxides, etc. [12]. The weight loss of the investigated clays will be discussed in details with the presentation of the DTA/TGA curves.

Fig. 2 presents an extrusion prognostic using the plasticity of the mixtures [17]. The plasticity limit, PL, corresponds to the amount of water necessary for the clay to reach a plastic consistency, which makes it possible for it to be formed by extrusion. The plasticity index, PI, is associated with the range between plastic and sludge consistency. For practical purposes, the plasticity index must be above 10% [15]. Clays that present values of PI lower than