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Research paper

# Sintering of red ceramics from yellow Amazonian latosols incorporated with illitic and gibbsitic clay

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ABSTRACT

Latosols are part of the soil group with the widest geographic distribution in Brazil. This soil type consists of a yellowish to reddish clayey material, and it has been widely studied for its applicability to agriculture in tropical zones. Because of the wide distribution and mineral composition of latosols, it is important to evaluate the technical feasibility of using these materials for the production of red ceramics. The raw materials were characterized using X-ray diffraction, thermogravimetric and differential thermal analysis, inductively coupled plasma mass spectrometry, inductively coupled plasma optical emission spectrometry, scanning electron microscopy, and a laser particle analyzer. To determine the physical and mechanical properties, 20 different mixtures of samples were produced with the latosols of Rondon do Pará and Mosqueiro combined with 0, 20, 30, and 40% illitic or gibbsitic clays; each composition was calcined at 950 and 1100 °C. The technological properties of the samples (linear shrinkage, water absorption, apparent porosity, apparent density, and flexural strength) were investigated. The Mosqueiro latosol consists of quartz and kaolinite with additional minerals of anatase and goethite, whereas the Rondon latosol contains kaolinite and quartz as the dominant minerals, as well as goethite, anatase, and gibbsite. Only the Mosqueiro latosol, without the addition of other materials, demonstrated technological aspects that were favorable for its use in the production of ceramic products. However, the addition of illitic and gibbsitic clays significantly improved the technological characteristics of the two latosols studied.

## 1. Introduction

Latosols are part of the soil group with the widest geographic distribution in Brazil. This soil type consists of a yellowish to reddish clayey material, and it has been widely studied for its applicability to agriculture in tropical zones (Costa, 1991; Horbe and Costa, 2005). The mineral compositions found in this soil are generally kaolinite, goethite, gibbsite, hematite, quartz, and anatase.

The latosols that occur in the Amazon region are generally overlapping ferruginous laterite crusts, such as those in Mosqueiro and Pará State (PA), or overlapping bauxitic laterite profiles, such as those in Paragominas, Rondon do Pará, the Lower Amazonas, and Pará State, Brazil, which, in the latter case, can reach zone thicknesses of up to 25 m (Costa, 1991; Horbe and Costa, 2005; Sombroek, 1966). The occurrence of this type of soil in the Amazon was first studied by Sombroek (1966), who described it as a kaolinitic soil, typically ocher in color, with a homogeneous texture and no visible stratification.

The widespread availability of this type of soil in the Amazon region, specifically in Rondon do Pará and on Mosqueiro, means that it is a potentially inexpensive raw material, which makes it an interesting raw material for the production of products used in the red ceramics industry.

However, the dominant presence of kaolinite means that the ceramic materials have low plasticity and refractory behavior, resulting in products with excessive porosity. This type of behavior is a consequence of the particle size of this clay mineral, which is relatively large compared to other clay minerals (Magagnina et al., 2014). An alternative production of good quality ceramic products can be achieved with kaolinite by adding melting materials, which enable the development of liquid phases that fill in the pores of the final product (Vieira et al., 2004).

Given the widespread availability of this type of raw material in the region, as well as its unique characteristics, the present study aims to evaluate the chemical and mineralogical differences between the latosols of Rondon do Pará and Mosqueiro, to investigate the efficiency of using yellow latosols for the production of industrial red ceramics, and to determine the influence of the inclusion of gibbsitic and illitic clays on the technological properties of the ceramic samples.

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**Table 1**
Compositions of the samples studied.

| | LR | LM | IC | GC1 | GC2 |
|---|---|---|---|---|---|
| A1 | 100 | – | – | – | – |
| A2 | 80 | – | 20 | – | – |
| A3 | 70 | – | 30 | – | – |
| A4 | 60 | – | 40 | – | – |
| A5 | 80 | – | – | 20 | – |
| A6 | 70 | – | – | 30 | – |
| A7 | 60 | – | – | 40 | – |
| A8 | 80 | – | – | – | 20 |
| A9 | 70 | – | – | – | 30 |
| A10 | 60 | – | – | – | 40 |
| B1 | – | 100 | – | – | – |
| B2 | – | 80 | 20 | – | – |
| B3 | – | 70 | 30 | – | – |
| B4 | – | 60 | 40 | – | – |
| B5 | – | 80 | – | 20 | – |
| B6 | – | 70 | – | 30 | – |
| B7 | – | 60 | – | 40 | – |
| B8 | – | 80 | – | – | 20 |
| B9 | – | 70 | – | – | 30 |
| B10 | – | 60 | – | – | 40 |

LR = latosol of Rondon do Pará; LM = latosol of Mosqueiro; IC = illitic clay; GC1 and GC2 = gibbsitic clays.

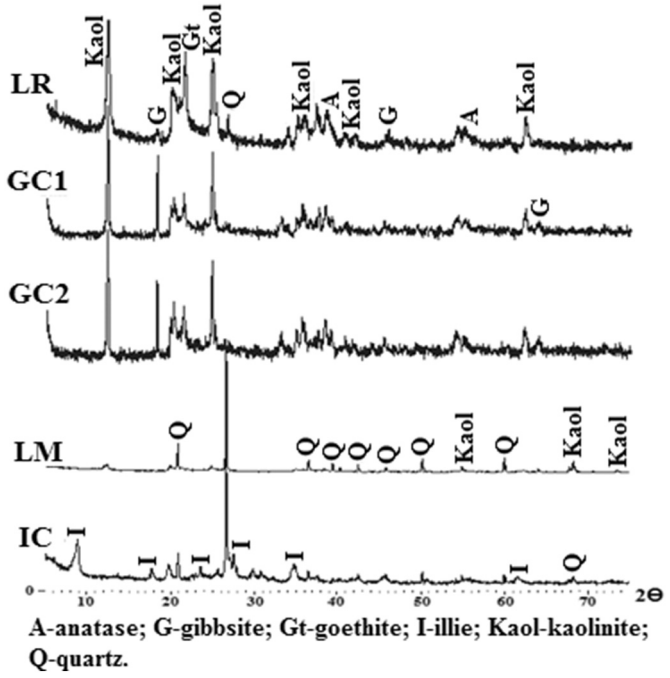


**Fig. 1.** X-ray diffractograms of the samples studied showing the main minerals identified.

**Table 2**
Chemical composition (% by weight) of the raw materials used.

| Sample | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $K_2O$ | $TiO_2$ | MgO | LOI | Others | Total |
|---|---|---|---|---|---|---|---|---|---|
| IC | 51.04 | 21.24 | 5.89 | 8.17 | 0.89 | 3.34 | 8.7 | 0.49 | 99.76 |
| LM | 69.48 | 15.15 | 5.06 | 0.50 | 1.20 | 0.19 | 8.1 | 0.16 | 99.84 |
| LR | 36.39 | 32.95 | 10.55 | 0.04 | 2.41 | 0.03 | 17.3 | 0.10 | 99.77 |
| GC1 | 29.03 | 38.03 | 12.48 | 0.01 | 2.18 | 0.01 | 17.9 | 0.11 | 99.75 |
| GC2 | 28.64 | 37.39 | 14.04 | < 0.01 | 2.55 | 0.01 | 17.0 | 0.09 | 99.72 |

IC = illitic clay of Alcântara; LM = latosol of Mosqueiro; LR = latosol of Rondon do Pará; GC1 and GC2 = gibbsitic clays of Rondon do Pará.

## 2. Materials and methods

### 2.1. Materials

The latosol samples used in the present study were collected in the Mosqueiro District of the municipality of Belém and in a pilot bauxite mine in the municipality of Rondon do Pará, from the area of the Alumina Rondon Project of the Votorantim Metals Corporation. Samples of gibbsitic clays, which were situated below the bauxite horizon, were also collected from the mine. The illitic clay used in the study came from Alcântara in Maranhão. All the raw materials were dried in an oven at 110 °C, disaggregated in an agate mortar, and then subjected to the analytical procedures described below.

### 2.2. Characterization of the raw materials and samples

The technological properties determined were the water absorption, linear shrinkage, apparent density, apparent porosity, and flexural strength. For the water absorption test, an adaptation of the standard NBR 15270-3 was used. The linear shrinkage was obtained using a Digimess digital caliper. The apparent porosity (AP) was determined in accordance with the (ASTM, 2006) C373-88 standard. The apparent density of the samples was obtained using the ratio between the apparent porosity and the apparent water absorption. The compressive strength test was performed using a WDW-100E universal testing machine (Arotec), with 100 kN load cell, at a crosshead speed of 0.5 mm/min and begin of the tests with 2 N, carried out at the laboratory of Federal Institute of Pará (IFPA), Brazil.

The studied raw materials and the calcined ceramic samples were manually careful gridded in agate mortar and submitted to powder X-ray diffraction (XRD) for mineralogical composition. The analysis were performed in a PANalytical X'Pert Pro MPD diffractometer (PW3040/60), equipped with a PW3050/60 goniometer (θ/θ), a PW3373/00 ceramic X-ray tube with a Cu anode (Kα1 = 1.540598 Å), a nickel Kβ filter and a 0.25° size slit. The detector used was an X'Celerator RTMS. The diffraction patterns were acquired from 5° to 75°2θ at 0.017°2θ steps under 20.3 s per step. The samples' preparation and XRD analysis were carried out in the Mineral Characterization Laboratory of Federal University of Pará (UFPA), Brazil.

The chemical composition and loss on ignition of the raw materials were determined at Acme Analytical Laboratories Ltd., in Canada. The major elements were determined by inductively coupled plasma optical emission spectrometry (ICP-OES) and the trace (REE) by inductively coupled plasma mass spectrometry (ICP-MS). For this, the pulverized samples were prepared by fusion with lithium tetraborate followed by dilution in nitric acid. The Loss on Ignition (LOI) was determined by gravimetry, which consists of the measurement of the mass following calcination at 1000 °C.

The particle size distributions were determined by laser diffraction using an Analysette Microtec Plus (Fritsch, Germany) laser particle size analyzer after prior disaggregation with sodium pyrophosphate. The micrographs of the calcined samples were obtained using a LEO-1430 scanning electron microscope (SEM) with a magnification of up to 50,000 ×. Both analysis were carried out in the Laboratory of Applied Mineralogy and Geochemistry, located in the UFPA.

Thermogravimetric and differential thermal analysis (TG-DTA) was performed using the TG/DTA320U apparatus (SEIKO) with a simultaneous thermal analyzer at a heating rate of 10 °C/min and an $N_2$ flow rate of 50 ml/s, located in the Martin-Luther Halle-Wittenberg Universität, Germany.

### 2.3. Specimens preparation

The samples were prepared in steel molds in the shape of prismatic plates (50 × 20 × 10 mm) at 50 kgf/cm$^2$. Twenty different compositions were formulated (Table 1) composed of latosols, latosols with