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A laboratory-scale experimental investigation on the reuse of a modified red mud in ceramic materials production

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HIGHLIGHTS

- The compressible stacking model makes it possible to optimize the granular structure.
- Mechanical properties of ceramics decrease with the increasing MRM content.
- Vacuum extrusion allows to have ceramic materials with higher mechanical characteristics.
- Firing temperatures play an important role on properties of ceramic products.

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ABSTRACT

The management of bauxite residues causes serious environmental problems worldwide due to their physico-chemical particularities. In this research, a bauxite residue collected from Gardanne Alumina Plant (France), renamed modified red mud (MRM) after dewatering treatment, was investigated for its reuse in the making of ceramic materials such as roof tiles or bricks. After physico-chemico-mineralogical investigations, formulations were tested by substituting natural clays with MRM at rates ranging from 0 to 30% and applying two firing temperatures at 950 °C and 1015 °C. Ceramics samples were characterized for their chemical, mineralogical, and mechanical properties. It was found that the addition of up to 30 wt% of the MRM allows the production of acceptable ceramic products such as tiles.

1. Introduction

To date, more than 95% of the alumina produced worldwide comes from bauxite ores after extraction by the Bayer process. Bauxite is the main raw material from which alumina is derived because it is easy to extract through the Bayer process and contains oxy-hydroxides of alumina in large quantities ranging from 30 to 65%. The Bayer process consists of chemical and physical treatments of bauxite ore and produces alumina. On the other hand, it also produces large amounts of substances that are not desirable: red mud (RM) residue, a muddy solid waste with high water content. Each ton of alumina produces from 1 to 1.5 tons of RM [1]. The global quantities of RM are estimated to be around 70 million tons per year [2], and some authors indicate 150 million tons per year [3]. This industrial by-product is usually disposed of into landfills, which are not environmentally sustainable management solutions. Also, Bauxite naturally contains heavy minerals. Among these, zircon ($ZrSiO_4$) is a mineral naturally radioactive by replacement of Zirconium atoms by Uranium. Hence some authors underlined the possible radioactivity risk of RM. That's why this parameter must be taken into account in case of a large industrial scale development [4].

The company Alteo has developed an innovative process, which allows the sodium hydroxide used in the alumina extraction process to be recovered by first washing with water and then reducing the water content of the residues using press filters. This process makes it possible to obtain a new solid residue called modified red mud (MRM) that contains less sodium hydroxide and might

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be suitably shovelled. This greatly facilitates its incorporation into building material formulations.

Over the last years, numerous studies have explored the reuse of RM residues as secondary raw material for different applications: as adsorbent to remove inorganic pollutants from wastewater [5–9] or as filters to clean waste gases [10], lightweight aggregates [11], cementitious materials [12], geopolymers [13], and ceramics products used as construction materials [14–18]. This latter option could be a viable solution for RM residues and has the benefit of saving natural clay resources while reducing the amount of RM stored inshore. Three techniques are well-known for ceramics manufacturing and are functions of the initial water content in the materials: dry, plastic or wet [19]. Generally, the moisture value given is arbitrary and depends on the different cases. In this article we treated the problems of incorporating RM in the formulation of ceramic products by determining precisely the parameters controlling the consistency of the ceramic pastes. Formulations including up to 30 wt% of RM were tested, and for each of them a quite precise optimal packing density was defined. For this purpose, a model was used to predict the packing density of the mixtures, based on the physical characteristics of each constituent (particle size distribution, density and packing density). The ceramic samples were formed with a 950um extrusion device (double-screw), by means of a vacuum pump connected to the tank into which the wet material was introduced, to eliminate micro-bubbles of air in the materials as used in the industrial process of the clay provider. Two sintering temperatures were fixed at 950 °C and 1015 °C, the selection of those two temperatures was based on the panel of temperatures exposed by the literature and the temperature used in the industrial process (1015 °C). The lower 950 °C temperature was based on previous study of Pérez-Villarejo et al. [20], it was selected to evaluate a potential energy gain. Ceramic samples were characterized by mechanical, mineralogical and pollutant leaching analysis in order to determine the impact of the reuse of MRM in ceramic products.

2. Materials and methods

2.1. Materials

The material used in this study was supplied by Alteo Gardanne, a French company located in the south of France (PACA Region). This industrial plant produces alumina from Guinean bauxite ores using the Bayer process. Each year, Alteo treats 635,000 tons of raw bauxite to produce 460,000 tons of alumina. Hundreds of thousands of tons of bauxite residues are produced each year and stored inshore in specific installations.

The clay used in this study is provided by a Monier plant, which is a French tile manufacturer located near the Alteo site.

2.2. Methods

2.2.1. Ceramic specimens preparation

Modified red med (MRM) and clay samples were dried and ground separately into particles <100 μm. The clay was mixed with different amounts of MRM ranging from 0 to 30% of the solid weight. Water was added to the powder mixtures and shearing mixed to obtain a plastic mass which was used to produce prismatic samples (4x4x16 cm) and flat tile samples (15 × 11 × 1.5 cm) (Fig. 1). According to EN 13006 technical standard prescriptions for tiles making, clays used in light-firing and dark-firing bodies are fairly well discriminated by a Fe_2O_3 content of approximately 3% wt, because iron oxides induce: a) dark colour of the tiles body, b) forms low melting zones and causes blisters, and c) changes the thermal conductivity. The ceramic specimens were obtained with a vacuum extrusion device which was used to eliminate micro-bubbles of air in the materials, which tends to reduce the effect of excess iron. For every formulation, 14 pieces were prepared (total of 112 pieces) (Table 1). The formed samples were fired at 950 °C and 1015 °C (ramp 100 °C/h) for 2 h in the electrical furnace. The obtained ceramic materials had a surface

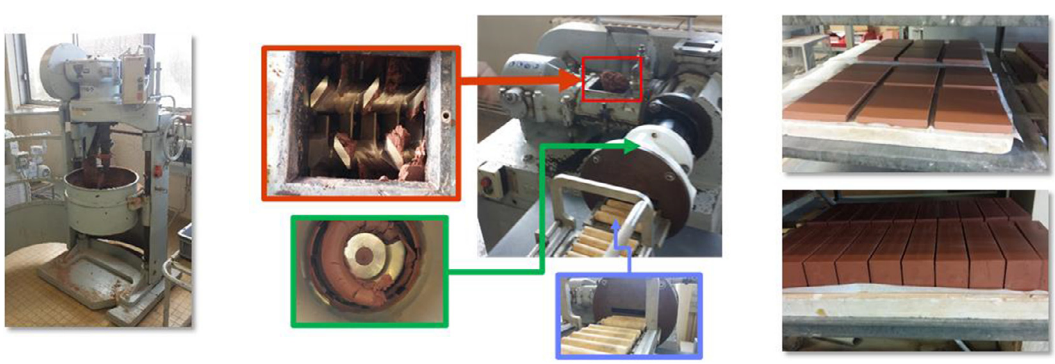

Fig. 1. Prismatic samples preparation.

Table 1
Different case studies and dimension of prepared samples.

	Sintering at 950 °C	Sintering at 1015 °C
Clay 100%	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm
MRM 10% – clay 90%	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm
MRM 20% – Clay 80%	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm
MRM 30% – Clay 70%	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm	10 prismatic samples 4 × 4 × 16 cm 4 flat tiles 11.5 × 15.0 × 1.4 cm