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Improving of the mechanical and rheological properties of slip of ceramic

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HIGHLIGHTS

- Amelioration of the mechanical and rheological properties of a slip of ceramic.
- Chemical analysis of slip modified by bentonite.
- Mechanical and rheological tests.
- The yield stress and the consistency index of slip of ceramic modified are increased.
- Increase of mechanical resistance of slip of ceramic.

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ABSTRACT

This work is a contribution to the amelioration of the mechanical and rheological properties of a slip of ceramic used in the ceramic fabrication process. A study of characterization of slip of ceramic modified by bentonite has been accomplished chemically, mechanically and rheologically. Chemical analysis showed that the slip modified by bentonite consist essentially of silica with a ratio of (SiO_2/Al_2O_3) average equal to 3.5 and the ratio of clays (Al_2O_3/SiO_2) is relatively stable with increasing percentage of bentonite in the slip, with an average of 0.28. The mechanical and rheological tests were showing that increasing the percentage of bentonite in the base slip caused an increase in the mechanical resistance, the yield stress and rapid increase in density of the slip.

1. Introduction

Today the production of ceramics by casting is widely applied in the ceramic industry for making household and fancy majolica, porcelain, and faience products. According to Dondi et al. [1] and Lim et al. [2] the production of ceramic tiles is growing worldwide at a rate of 300 million m^2/year and has already passed 10 billion m^2 in 2012. For this reason many additives have been added to ceramic slip such as the electrolytes [3–6] for improving their rheological behavior such as thixotropic and sludge of wastewater treatment [7,8] in order to improve the mechanical proprieties of ceramic. For improving the rheological and mechanical properties of porcelain Andreola et al. [9] added fourteen types of bentonite to clay from Sardinia Island, Italy. It was demonstrated that the adding the bentonite to clays improve the plastic components and this caused amelioration of the rheological behavior of mixture, such as the increasing the viscosity and the thixotropy. Moreover, Kizinievic and Kizinievic [10] used wood ash from biomass for amelioration the quality of ceramic. It was shown that the incorporating percentage from 5% to 60% of wood in formation of ceramic cause reduction of drying and burning shrinkage, density, thermal conductivity and increasing water absorption and porosity. Likewise, the authors demonstrated the incorporation of wood ash from biomass in formulation of ceramic has an influence on the ceramic body as a natural pigment that brightens the ceramic body. Moreover the effects of different chemical materials such as sodium tripolyphosphate, sodium hexameta phosphate, sodium polymethacrylates, ammonium phosphate, sodium citrate, polysulfonate on the rheological behavior of clay particles in aqueous systems used in ceramic have been investigated by [11–13].

According to Tsetsekou et al [14], the solids particles should not settle fast under the effect of gravity, but they should be able to remain in suspension, because otherwise segregation may occurred which causes density inhomogeneity. In order to control

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the density and rheology of the slip and to facilitate demolding the tiles of ceramic the thickening organic agents are added to slip of ceramic. These organic additives, removed during sintering, have a particularly important role since its conditions largely the arrangement of the medium dispersed in the mold [15].

The objective of this paper is to improve the physicochemical and mechanical characteristics of the slip of ceramic used by the company CERAL to this effect we tried to replace the clay used by bentonite of Maghnia (Algeria) without modifying the percentage of the others composition (Schist 1, Schist 2 and Sandstone).

2. Materials and methods

2.1. Materials

The raw materials used in this study are from the "CERAL" Company of Hassi - Amer- Oran Algeria. This company uses clays at fixed percentages by adding deflocculants to facilitate mold release from the plaster molds. Table 1 presents the various materials used by the company CERAL for the manufacture of ceramics and the Table 2 shows the percentage of mixtures [16].

2.2. Samples preparation

In the first step, several body formulations were prepared. Each mixture was wet ground in a jet mill long enough until the residue on 63 μm sieve was reduced to require values. In second step, a rectangular samples were carried out using the press (ceramic Instruments Srl) SASSUOLO-ITALY, the maximum pressure of this apparatus is 250 bar and a bending apparatus FLEXI 1000 LX GABTEC, to the company CERAMIR from HASSI AMER Oran. We introduced 100 g of the samples into the press apparatus and a pressure of 80 bar was applied to make tiles with a thickness of 7.8 mm, a length of 100 mm and a width of 45 mm. We then introduced the tiles in a drying oven at 110° C for 2 h. After completion of the tiles and drying, flexural tests were carried out. After 2 h of drying at 110° C, the tiles of ceramic were fired at constant temperature of 1140 °C for 45 min in an electric furnace and 45 min of soaking time.

2.3. Mechanical characterizations

The biaxial flexure tests were carried at room air and temperature by using the method of the three points bending was conducted in and using a universal testing machine (FLEXI 1000 LX GABTEC Italy) according to ISO6872 [17].The three points bending strength was calculated using the following equation:

$$R_e = \frac{3Fb}{2Lt_e^2} \quad (1)$$

where R_e is the flexural strength, F is the breaking load, b is the specimen support span, L is the specimen length and t_e is the thickness of specimen.

2.4. Rheological measurements

The rheological measurements were performed by using a torque controlled rheometer (RS600 from Thermo-Fischer) connected to a temperature controlled water bath and equipped with a plate-cone geometry (diameter: 60 mm; angle: 2°; gap: 105 μm). A solvent trap was placed around the measuring device in order to minimize solvent evaporation. After the bending tests, the samples are recovered and ground and then passed through the 100 μm sieves in order to make granulometric tar compatible with the cone/plane geometry used for the rheological measurements. The slip in powder form is then dispersed under magnetic stirring for 3 h in distilled water at a concentration by weight of 58%. The suspension obtained is left to stand for 24 h.

The evolution of shear stress τ as a function of the shear rate $\dot{\gamma}$ at different concentration of bentonite added in ceramic slip was investigated to obtain some information about the stability. In order to avoid any memory effect, the sample was pre-sheared at a constant shear rate of 200 s^{-1} during 60 s. After this pre-shearing, the sample was kept at rest during 600 s prior to measurements in order to allow the material to recover, at least partially, its initial structure. The imposed shear rate range depends on the quantity of added in ceramic slip. Consequently, the flow experimental procedure consists of a linear ramp of increasing shear rate from 0.05 to 200 s^{-1} over 20 min at constant temperature (20 ± 0.2 °C).

The creep and recovery tests were conducted after a rest time of 600 s. Creep and recovery tests were performed by first applying a constant shear stress of 10 Pa during 180 s to the samples of ceramic slip and then removing the shear stress during 180 s in order to obtain the time dependence of the compliance.

Table 1
Materials used by the company CERAL for the manufacture.

Materials	Percentage
Schist 1	61%
Schist 2	10%
Sandstone	17%
Clay	12%

Table 2
Percentage of mixtures used in this study.

Bentonite (%)	0	3	6	9
Schist 1 (%)	61	61	61	61
Schist 2 (%)	10	10	10	10
Sandstone (%)	17	17	17	17
Clay (%)	12	9	6	3

3. Results and discussions

3.1. Size distribution of bentonite and clay

Fig. 2 shows the particle size distribution of bentonite and clay suspension used by company CERAL measured by the light scattering technique with a Malvern Instruments Mastersizer 2000 system. In order to avoid the formation of aggregates during the measurements, the sample was submitted to ultrasound excitation. We observed in Fig. 1 the particle sizes of bentonite ranging between 1 and 138 μm were found with a symmetric distribution centered at about 46 μm and particle sizes of clay used by company CERAL ranging between 1 and 138 μm were found with a symmetric distribution centered at about 25 μm. We also observed the maximum volume of bentonite is greater than of maximum volume of clay that means a bentonite is more swelling compared to clay used by company CERAL.

3.2. Chemical analysis

Chemical analysis of the samples carried out at the laboratory of the LAFARGE company. Table 3 shows that the slip of ceramic modified by bentonite consists essentially of silica with average ratio of SiO_2/Al_2O_3 equal to 3.5. According to Robert and Tessier [18] in clays, because of numerous substitutions, the values of the ratio of SiO_2/Al_2O_3 are generally ranging between 2 and 4. It is also observed that the clay ratio of Al_2O_3/SiO_2 is relatively stable with the increase the percentage of bentonite in the slip of ceramic, with an average of 0.28. The iron oxide content is quite high in the slip of ceramic modified by bentonite. We also observe that the increase the quantity of bentonite in slip of ceramic causes a decrease of CaO.

3.3. Improvement of the mechanical characteristics of the slip of ceramic by bentonite

3.3.1. Effect of bentonite on density of slip

Fig. 3 shows evolution the density of slip as a function of bentonite concentration added to slip. We observed the density is increased with increase the percentage of bentonite in slip of ceramic. This increase can be explained by the increase in the volume of the bentonite suspensions caused by the swelling of the bentonite [19].

3.3.2. Effect of bentonite on flexural strength of slip

The Fig. 4 shows the variation of flexural strength of slip as a function of the concentration of the bentonite added to slip of ceramic after baking at 110° C and firings 1140 °C. We observed in the