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Changes in the physicomechanical characteristics of a ceramic paste during drying

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This paper is a contribution to the determination of the variations of the physical and rheological properties of a ceramic paste during drying. The ceramic's density was determined as a function of moisture content using the Archimedes' Principle. The shrinkage was derived from the experimental density data and also determined by measuring the variation of the sample's dimensions during drying. Compression tests were performed at different deformation rates in order to identify the linear and non-linear viscoelastic domains of the material. Relaxation tests were carried out and the results of fitting showed that the generalized Maxwell model could be used to describe the viscoelastic behavior of the samples. Rupture tests were also made to measure the strength of the material for different moisture contents and to study the influence of temperature on the strength of the dried product.

1. Introduction

Controlling the drying process of ceramic bodies is of great interest in order to limit the formation of defects that occurs in the products. There are a lot of properties that are usually examined for the prediction of the quality of the dried material and for process design calculation. The characterization of these properties may improve the understanding of drying mechanisms.

The particular structure of the material and the mechanical characteristics of its elements at equilibrium define the sample's volume and determine its size and shape. When water is removed from the material, a gradient of pressure is produced between the interior of the material and the external pressure, generating contracting stresses that lead to material shrinkage, changes in shape and occasionally cracking of the product.

Density is one of the main properties that should be identified because it intervenes in many equations (heat, mass, momentum) and calculations of characteristics. This property, as most properties of a hygroscopic material, varies with the moisture content in the product. Also, controlling shrinkage is an important criterion, especially in the case of manufactured building products (bricks, faience, and tiles), because excessive shrinkage causes the deformation of the items during firing [1]. Density and shrinkage were investigated in many papers. For food products, it has been shown that density peaked at low values of the moisture content, and then decreased with increasing moisture content. This behavior was observed for apple, potato, calamari, and garlic [2,3]. And in this case, drying is accompanied with an important shrinkage that decreased

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almost linearly when moisture content decreased. For clay materials, it has been shown that shrinkage does not continue till the end of drying. Thus, density increased at the beginning of drying under the effect of shrinkage and then, in a second stage, the volume of the sample does not change with further loss of water [4,5].

In the case of ceramics and wood industry, the knowledge of only shrinkage and density data occurring during dehydration is generally scanty. Mechanical properties are the main properties qualifying materials because the mechanical deterioration of dried materials is the most undesirable change. Mechanical resistance of some products to compression has been studied by many authors [1,6] in order to predict the strength variation.

Rheological modeling is also used to predict the physical response under various conditions of stress and strain and consequently enables one to decrease damage risks. Wet products can generally be considered as viscoelastic materials [7]. The stress relaxation test is often used to measure the viscoelastic properties. These properties are expressed as a function of time and there are no works reporting their dependency on moisture content [8,9].

Our objective in this study is to determine the variation of the shrinkage and of the density of porcelain with moisture content. Compressive tests will be investigated to determine the linear and nonlinear viscoelastic domains. Relaxation tests will be carried out in order to forecast the different rheological properties and their variation as a function of moisture content. Ultimate strength will be studied as function of moisture content and the influence of the drying temperature will also be examined.

2. Materials and methods

For all the experiments the ceramic samples are prepared by wetting a porcelain powder with water. The composition of the porcelain powder was: 50% kaolin, 25% quartz and 25% feldspar. The samples were dried in a convection oven operating at 40 °C.

2.1. Density

The Archimedes method was used to measure the samples' density [4]. Spherical samples with a radius of 5 mm were placed in the oven at 40 °C and were weighted every 15 min in order to obtain a large range of moisture content ranging from 0 to 0.4 kg/kg d.b. To ensure sealing of the surfaces, each sample was covered with a thin layer of parafilm. The apparent density ρ can be determined as follows

$$\rho = \frac{W_{\mathrm{a}}[\rho_{\mathrm{fl}} - \rho_{\mathrm{a}}]}{0.99983\,G} + \rho_{\mathrm{a}}\ \left(\mathrm{kg/m^3}\right) \tag{1}$$

where

- ρ_{a} is the density of the air under standard conditions;
- ρ_{fl} is the density of the fluid;
- $G = W_{\mathrm{a}} - W_{\mathrm{fl}}$ is the buoyancy of the immersed solid;
- W_{a} and W_{fl} are the weight of the solid in the air and in the fluid, respectively.

Finally, the samples are dried at 105 °C for 24 h in order to determine the mass of the dry sample m_{s} (dry basis) and to consequently determine the moisture content w expressed as:

$$w = \frac{m - m_{\mathrm{s}}}{m_{\mathrm{s}}}\ (\mathrm{kg/kg\ d.b.}) \tag{2}$$

2.2. Plastic limit

The plastic limit PL is defined as the lowest moisture content at which a clay material can be rolled into threads one-eighth inch in diameter without breaking into pieces. This is also the moisture content at which the material changes from a plastic state to a semisolid state.

The plastic limit tests were performed by following the conventional ASTM D4318 [10]. It consists in forming a small ball of porcelain paste that is rolled on a flat non-porous surface.

The PL is reached when the thread breaks apart at a diameter of 3.2 mm.

2.3. Shrinkage

Shrinkage of the ceramic material was examined by using two methods.

2.3.1. Direct measurement

Shrinkage was determined experimentally by monitoring the variation of a porcelain sample dimensions during drying. A cylindrical sample having an initial diameter $d = 20$ mm and a height $h = 24$ mm was used. Each 15 min, the sample