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Microwave processing of porcelain tableware using a multiple generator configuration

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HIGHLIGHTS

► We present a microwave oven capable of processing porcelain tableware.
► Material dielectric properties are critical due to its natural inhomogeneity.
► Thermal runaway can be controlled by the field distribution during the sintering.
► Samples show equivalent properties compared with conventional fired porcelain.

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ABSTRACT

In this work we developed a microwave oven capable of processing porcelain tableware, with different sizes and shapes. We used a multimode cavity fed by 6 magnetrons with 1 kW each one, operating at 2.45 GHz, as the only heating source. Controlling the radiation power, in each stage of the process, we can create a more homogeneous electromagnetic field, avoiding the natural inhomogeneity which is a critical problem in the sintering process with microwave radiation.

To characterize the quality of the sintered porcelain we measured the rupture energy, impact resistance, porosity, water absorption and concentration of undesired elements. These measurements have been compared with the obtained in similar porcelain pieces prepared by conventional methods, showing equivalent features and with parameters in the acceptable limits. It was observed that the sintering process is faster, with consequent lower costs and lower local emissions of harmful gases into the atmosphere.

1. Introduction

The greatest advantages of using microwave radiation to sinter porcelain materials are the lower emissions of harmful gases into the atmosphere and the reduction of processing time. Replacing the conventional heating sources by microwave generators, it is possible to diminish some pollutants emissions resulting from the combustion process. Combining both gas and microwave radiation it is possible to reduce some percentage of that emission. In a hybrid furnace, that is, a microwave assisted gas approach, at least 25% of the energy is provided by microwave generators [1].

As a result of the introduction of microwave radiation in the process, it is possible to ensure a more uniform controlled temperature, having a fast firing. The reduction in the time needed to the sintering is important, particularly in the industries that use clay as their basic material, since it contains significant quantities of impurities which can be emitted to the atmosphere during firing, like fluorine. The use of microwave radiation reduces substantially these emissions due to two reasons: i) the amount of fluorine released is directly related to the time that the clay is at temperatures above 800 °C; ii) 90% of the fluorine released during the firing process comes from the decomposition of raw materials, and forms hydrofluoric acid by reaction with water transported by flue gases from the kiln. In contrast with the conventional technology, where the heat is transported to the material by conduction, convection and infrared radiation, most of the water will be released below 800 °C because the material processed by microwave radiation is heated through the interactions with the radiation that penetrates into the material and heat it in a more volumetrically way [1]. Because of this intrinsic property of the microwave heating, the

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Fig. 1. Two possible sets to implement in the MWMM oven.

processing in various areas of investigation, such as, food, mining and chemical industries can be accelerated [2]. As well, due to its localized electromagnetic field, it is possible to concentrate the energy into a manner that we can join materials with a better heating control than conventional processing [3].

The form which the radiation interacts with the material depends on the frequency of the radiation, the position of the microwave generator relatively to the cavity, the geometric form of the load, the dielectric properties of the material [4], the thermal conductivity, the specific heat, the density [5] and the electromagnetic and thermal behaviour during the heating process [6].

One of the crucial challenges for researchers is the uniformization of the electromagnetic field inside cavities or ovens, in order to avoid overheating points that can destroy the material at a local level [6]. To overcome the inhomogeneous heating there are a few techniques. Between them, it can be cited turntables, mode stirrers, and others much more complex ones that consists of varying the design of the waveguide or the path through which the microwave energy field is introduced into the oven. It is also possible to include a system that dislocates the cavity walls, changing the resonant frequency and therefore the position/distribution of the hot and cold regions through the space of the cavity [7]. The most complex and effective invention is the Travelling Wave Tube (TWT), which is capable of sweeping a range of frequencies resulting in a uniform heating [8,9]. Another approach relatively simple and effective, with a proper design, it is a multiple generators system with an accurate control of the power supplied to the sample [10].

In our previous work [11], we have shown that, with a turntable and a stirrer, the microwave sintering of porcelain tableware is a real alternative. However, the introduction of a turntable and/or stirrers in an furnace bring some technical and practical difficulties and the homogenization of the electromagnetic field is not adequate to sinter multiple ceramics pieces, particularly at an industrial scale. In this work we have studied the multiple generators approach, and we have compared the properties of the porcelain sintered by microwave radiation with gas-fired porcelain, with promising results.

2. Experimental

To heat the material, the microwave radiation must be absorbed by it, and that capability is given by the absorbed power density [12] which can be expressed by

$$P = \frac{1}{2}\left[\left(\sigma_{dc} + \omega\varepsilon_r''\right)E^2 + \omega\mu_r''H^2\right] \quad (1)$$

where σ_{dc} is the dc electrical conductivity, ε_r'' and μ_r'' are the imaginary parts of the permittivity and permeability, respectively. E and H are the electric and magnetic fields. For nonmagnetic materials, as the porcelain, the second term of this equation is not necessary.

At the macroscopic level, the dielectric properties control the microwave processibility of a wide range of nonmagnetic materials through the depth of penetration (D_p) [13],

$$D_p = \frac{\lambda_0}{\sqrt{2\pi(2\varepsilon_r')}}\left(\sqrt{\sqrt{\left(1+\left(\varepsilon_r''/\varepsilon_r'\right)^2\right)}-1}\right)^{-1} \quad (2)$$

where, $\lambda_{0,}$ is the free space wavelength of the microwave radiation and ε_r' is the real part of permittivity.

The D_p, for many ceramics in the microwave range, is usually much greater than their cross-section, so all the samples stacked inside an oven are exposure to the microwave radiation and a more uniform and rapid heating can occur.

Considering the time dependence and the heat loss by radiation and convection, the temperature in one point of the sample is expressed by the following equation [14]

$$\rho V C_p \frac{dT}{dt} = PV - \left[h(T_s - T_\infty) + \eta\sigma\left(T_s^4 - T_{viz}^4\right)\right]A_s + q''_{int}A_s \quad (3)$$

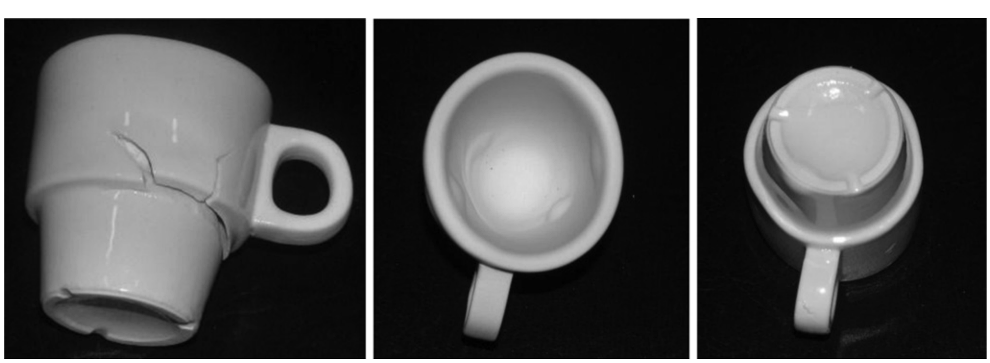

Fig. 2. Porcelain cups with a few defects caused by the uncontrolled electromagnetic field.