Microwave Sintering of Ceramics in Large Volumes

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In spite of wide international interest in microwave sintering, large mono-volume heating types have not been researched sufficiently yet. In channel induction furnaces, ceramic refractory material is used as an essential part of the furnace construction. These large mono-volume ceramics define the channel of the molten metal and also take the temperature gradient from the channel to the surroundings. Simulations are carried out based on numerical modeling in commercially available software. Dielectric properties of the ceramic material are used as inputs to the numerical model. After a basic numerical model has been established, the value of the transmitted power can be calculated. The final objective of the study is optimization of the geometry and the position of antennas and reflectors in order to determine a sintering process based on microwave heating with the prospect of shorter processing time, more energy efficiency, and longer lifecycle of the sintered refractory.

Introduction

Sintering is a thermal process in which powder is transformed into a dense material without pores. In the last 50 years, microwave sintering has seen a wide range of applications, such as the heating of food, drying of paper, textile and wood, etc. Only in the last two decades has microwave energy been increasingly applied in the area of materials (ceramics, composites and metals). In parallel with this trend, there has been a lot of investigation into sintering of ceramics with microwave heating. This innovative heating technique offers many advantages compared to classical heating techniques [1]-[3]. Microwave sintering is an actual and intensively studied research topic in some international research centers. In spite of wide interest, microwave sintering of large monovolumes has still not been researched sufficiently.

A large monovolume of refractory (consisting of ceramic material) is, for example, an essential part of a channel induction furnace, which is used for melting metals. The ceramic refractory material defines the channel of the molten metal. The refractory also limits the temperature gradient to the surroundings. Sintering is the most important production step in making the refractory. In the classical technique the heat needed for the sintering process is generated by means of electrical resistance. The heat needs to be transferred by conduction through the ceramic. The problem of resistance heating is the low thermal conductivity of the ceramic, which causes temperature gradients and, as a consequence, inhomogeneous sintering in the entire volume of the ceramic. This causes weak spots in the formed solid material because the powder has not transformed everywhere optimally to solid material. This poor sintering leads to quality loss of the refractory which causes early cracks and erosion in the refractory [4]. Sintering with resistance heating is also not very advantageous from an energetic point of view.

The proposed investigation intends to study if and how it should be possible to replace the traditional sintering process with resistances by a sintering process with microwaves in the processing of the refractory. The most important advantage is that materials heat volumetrically with microwaves. In this way the heating and sintering of the ceramic material can be made more homogeneous. Weak points in the material will be avoided and the lifetime of the refractory will increase, causing a huge cost reduction because the replacement of the refractory of a channel induction furnace is expensive. By means of an adapted design, the intrinsically more efficient energy transfer can be further optimized. This causes a higher efficiency and a better use of the energy than can be achieved by resistance heating.

Technique

The main purpose in this research is to answer the question: *Is microwave sintering of ceramic in large volumes more efficient than the commercial methods that already are used in the industry?* The investigation will smooth the path toward design of an industrial installation for the sintering of ceramics with microwaves, to serve as a refractory in a channel induction furnace. This is innovative because the investigation of the sintering of *big volume* ceramics with microwaves has not been done yet. In the first part, we present a review of the commercial methods for ceramic sintering in large volumes in industry. Currently, the most important one is resistance sintering which has its own problems and limitations, such as non-homogeneous heating that leads to some pores and cracks in the final ceramic product. Power consumption is another aspect which should be considered in this way. Next, abilities of microwave sintering are explained. Tests and simulations are carried out in order to verify these potentials in sintering of ceramics in large volumes.

Dielectric properties of the ceramics used in the project (Didolit 20-T) are extracted. Penetration depth of microwaves in the operating range should be calculated. Using this parameter, initial MW antennas will be designed. According to these, simulations are done by COMSOL Multiphysics software (ver. 3.5), with the goal of achieving the most homogeneous heating of the material in simulations, in order to maximize quality of the final ceramic. The effect of each of the following parameters is examined in the simulations to reach this goal:

- Frequency (896, 915 or 2450 MHz)
- Ceramic material
- Diameter and length of the antennas
- Position and distance between the antennas
- Applied power, which can be adapted by adapting the amount of pulses each second (without changing the frequency)
- Position of the metal around the ceramic (the metal serves as a reflector of microwaves)

Variations of the resulted heating are presented in terms of the mentioned parameters. These curves could be standards for comparison with the commercial methods of ceramic sintering. The final objective of the study is optimization of the geometry and position of antennas and reflectors in order to determine a sintering process based on microwave heating with the prospect of shorter processing time, more energy efficiency, and longer lifecycle of the sintered refractory.

References

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