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Title: Analysis of Electromagnetic Mechanism for Microwave Sintering of Powder Metal

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Text: Microwave sintering of powdered metals has been successfully realized in multimode microwave systems and the experimental proof of the major role of magnetic field losses has also been performed at MRI Pennsylvania State University[1,2]. However, the experimental proof has been performed in a single-mode microwave system with small size samples, which has a little difficulty to explain why powder metals can also be sintered in a multimode microwave system. This paper discusses the electromagnetic mechanism of microwave sintering of powder metals, which shows the major role of magnetic field losses in a multimode system. A model of the interaction of microwaves with powder metals has been established, which has been used to study the physical process of the microwave sintering of the powder metals.

The variations of the attenuation coefficient with the parameters, like frequency, electric conductivity, and permittivity, have been calculated. The results show that the attenuation coefficient is usually very small for modes far away from the cut-off. For example, the value of the TE_{01} mode far from cut-off has about the magnitude order of 10^{-5}~$10^{-4}m^{-1}$. However, the attenuation of higher order modes is higher than that of a lower order mode. If any mode is near to cut-off, its attenuation coefficient can even increase by a factor 10^3 ~10^5. Usually, the attenuation coefficients will decrease with the increase of the operating frequency, but increase with the enhancement of the frequency for a mode near to cut-off frequency. The higher the order of the mode near to cut-off, the larger its attenuation coefficient, and usually the smaller its superposition coefficients of the field solutions become. It is very important for improving the field uniformity for the microwave heating of powder metals in the oven because the cut-off frequencies of many modes are very close each other, which means a lot of modes have higher attenuation.

As a simple application of the interaction model, the superposition coefficients of the field solution only for two lower order modes TE_{01} and TE_{02} have been obtained for studying the relation of the heating rate and heating conversion efficiency with operating frequency, electric conductivity, and permittivity. The calculations show that, the heating rate and heating conversion efficiency is very low for the modes far away from cut-off. If the TE_{02} mode is near to cut-off, a heating rate of 350~480 °C/min can be reached for an electric conductivity in the range of $(0.01\sim1.00)x10^6$ S/m at the frequency of 2.45 GHz, and the heating conversion efficiencies are all over 20%. Usually, in powder metals, the heating rate and conversion efficiency decreases with the increase of operating frequency, electric conductivity, and permittivity. However, in our example, almost the same high heating rate can be reached as soon as the TE_{02} mode operates near to cut-off for various different permittivities when the same average power flow density is kept along the coaxial guide, which can explain why the heating rate presented in the article [2] can be so high without insulation around the sample.

[1] R. Roy, et al, "Full sintering of powder-metal bodies in a microwave field", Nature Vol. 399, P668, June 17, 1999.

[2] J. Cheng, et al, "Experimental proof of major role of magnetic field losses in microwave heating of metal and metallic composities", J. Mats. Sci. Lett. Vol.20, P1561-1563", 2001.