Microwave Heating and Pre-sintering of Copper Powder Metal Compacts in Separated Electric and Magnetic Fields

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Abstract

We present a systematic study of the heating and pre-sintering behavior of porous copper powder metal compacts. We employ a TE102 single mode microwave system to position the samples in the separated electric field (E) or magnetic field (H) anti-node of the cavity. We observe significant differences in the heating, pre-sintering, and microstructure evolution of the samples due to the individual fields. We note that sample history (whether heated first in the E-field or H-field) greatly effects a difference in heating trends and subsequent heating behavior and does not appear to be solely a thermal process.

Keywords : microwave heating, sintering, powder metallurgy

1. Introduction

In 1999, Roy and coworkers reported that a porous, powder metal compact could be heated and sintered in a microwave field [1]. They found that some metals heated better in the E-field, others in the H-field, and copper equally well in either. More recently, Saito observed that microwave-assisted sintering (using a susceptor) enhances shrinkage compared to conventional sintering, yet in most cases, with no effect on activation energy [2]. Gupta and Wong found that microwave-assisted sintering improved the tensile strength of various metal-powder compacts when compared to the same materials sintered conventionally [3].

However, there is little data in the present literature addressing the details of the direct interaction of microwaves with powder-metal compacts for interpreting the mechanisms of microwave heating and subsequent sintering of these materials. This study focuses on the influence of some important physical parameters, such as whether the sample is heated in the E- or H-field, field heating history, particle diameter, and relative density of the green compacts.

2. Experimental and Results

To heat the samples, we use a 2.45GHz microwave system with a two-port, half wavelength applicator, and sliding short circuit. Samples can be heated separately in the in the E-field or H-field. We maintain maximum forward power (typically 400W) using a 3-stub tuner.

We use a rigid die to produce compacts 0.250” diam. by 0.25” high. These were exposed to microwave fields for periods ranging from of 5 to 15 minutes to achieve equilibrium temperature and observe the development of pre-sintering microstructure. During heating, average surface temperatures were monitored using infrared pyrometry. We examined the microstructure of the compacts using scanning electron microscopy (SEM).

When heated in either field, a temperature peak is always apparent in the first heating of green, copper powder compacts. This behavior is independent of the relative density or particle size (over the range studied). In subsequent heating runs, the heating rate and equilibrium temperature drops slightly as the number of heatings continues (likely indicative of slowly increasing densification).

We find that field heating history is important. Samples heated first in the E-field show an initial temperature peak that is not observed in subsequent heatings in the same field (Fig. 1, curves 1–3). However, by placing this multi-heated sample in the H-field we still see a temperature peak for the initial H-field heating run (Fig. 1, curve 4). Then for subsequent heatings in the H-field, the peak is quenched (Fig. 1, curves 5, 6). We do not observe the same behavior if the procedure is reversed by starting the heating in the H-field (Fig. 2, curves 1–3). That is, heating first in the H-field quenches the temperature peak permanently and the effect is not reversible (Fig. 2, curves 4 – 6, E-field heating).

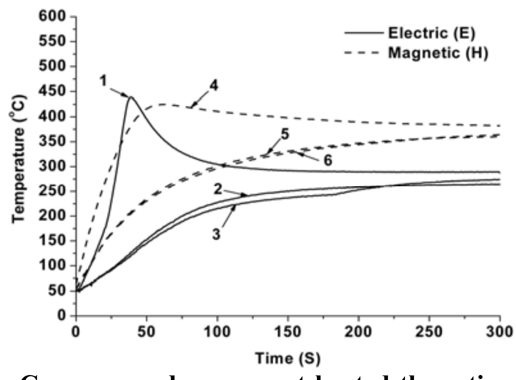

Fig. 1. Copper powder compact heated three times first in E-field and then three times in H-field.

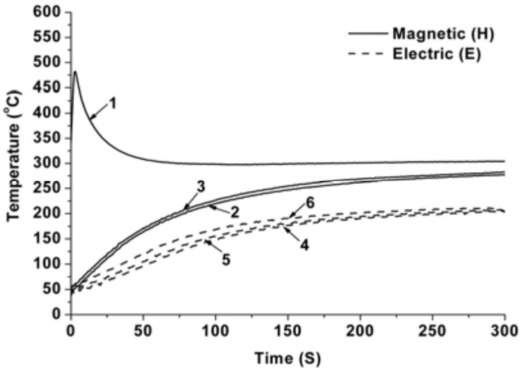

Fig. 2. Copper powder compact heated three times first in H-field and then three times in E-field.

SEM observations confirm the greater effectiveness of H-field heating; as Fig. 3 shows, heating is more comprehensive throughout the sample and the pre-sintering is more evolved.

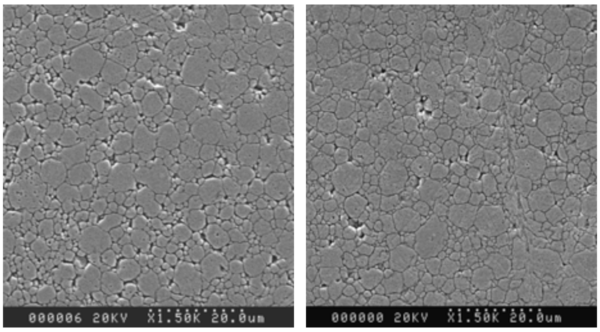

Fig. 3. Centers of two copper powder compacts heated 15min. in E-field (left) and in H-field (right).

For samples made with same relative density but varying particle size, greater E-field heating is clearly favored by particle diameters near or below the skin depth (Fig. 4). This trend is not observed in the case of H-field heating.

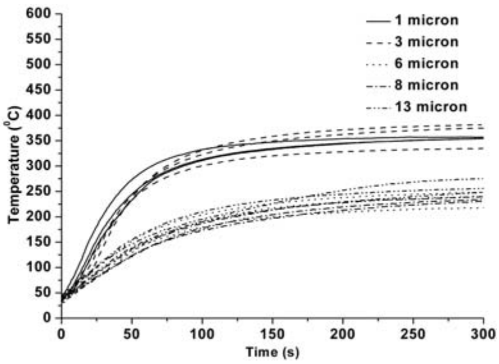

Fig. 4. E-field heating of different samples made with copper powders of varying particle diameter.

For compacts made from the same particle-size powders, heating in either field is more rapid and to higher equilibrium temperature with decreasing relative density, consistent with the skin effect (Fig. 5).

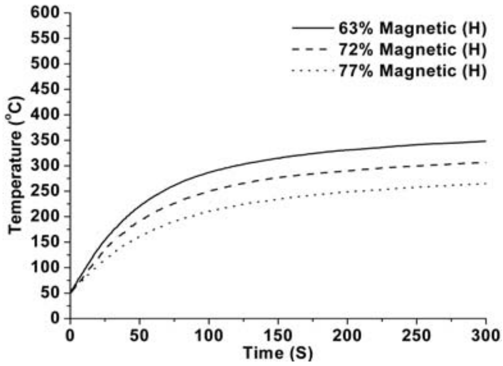

Fig. 5. H-field heating of copper compact samples of three different densities. E-field heating shows similar behavior.

3. Summary

A general implication one can draw from the results presented is that the heating and pre-sintering behavior of porous copper metal compacts depends significantly on whether the sample is initially subjected to the E- or H-field, the particle size, and the relative density of the compacts.

4. References

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