# Effects of microwaves on sintering processes

Georg Veltl, Frank Petzoldt, Fraunhofer-Institute IFAM, Wiener Str. 12,
D-28359 Bremen, Germany
Peter A. Pueschner, Pueschner MicrowavePowerSystems, Steller-Heide 14,
D-28790 Schwanewede, Germany

## Abstract

Microwave sintering has shown its applicability on ceramics and hardmetals and its potential impact on sintering of steels. However, all effects of the microwaves on the sintering of metal powders are not fully understood. This paper reports about microwave experiments on some arrangements of different powders like steel and bronze. As a model system steel bearing balls were used to examine and separate the transport mechanisms induced by the fields of the microwaves during the sintering process. In the investigations metallography, SEM and high resolution thermography were used to document the different mechanisms of microwave sintering. The effects deriving directly from the microwaves have been separated from the thermal effects by experimental means. The effect on sinter neck formation is shown.

## Introduction

Different recent studies on the microwave sintering of different materials, e.g. under the sponsorship of an EPMA consortium have taken place and have shown the beneficial effects of microwaves on the sintering process. Shorter sintering times and better properties at the same sintering temperatures as in conventional sintering have been reported. In Figure 1, the tensile strength, yield strength and ductility of a conventional PM-steel are shown. It is visible that strength and elongation to fracture are both improved by the application of microwaves.

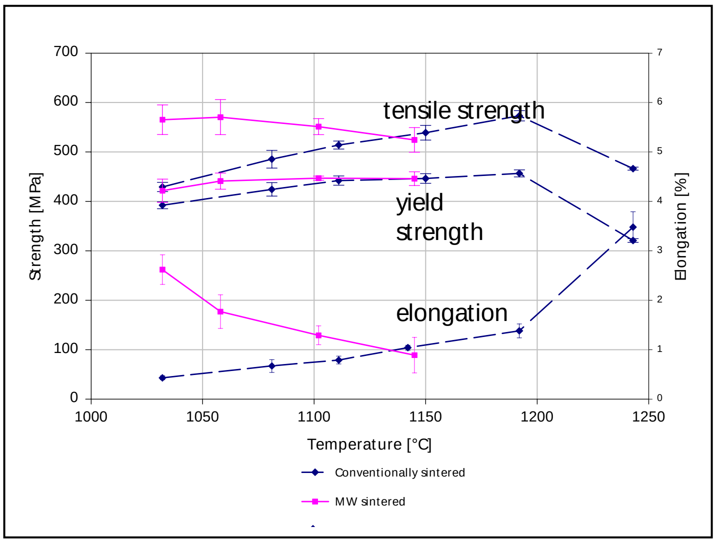


Figure 1: Comparison of properties of microwave sintered and conventionally sintered PM-steel MSP1.5 Mo [1.].

The high densities of the pressed powders make it difficult to elucidate the effects, which are purely caused by the application of the microwaves and to separate them from the effect of the microwave heating. For that reason, in this study some basic experiments have been performed to find out more about the microwave effects in sintering metallic material.

## Experiments and results

### Experimental

The microwave experiments were carried out in a gas and vacuum tight furnace of Pueschner Microwave Powersystems, Fig.2. Inside of the vacuum vessel a multimode cavity of 25x25x25 $cm^3$ is mounted in which the samples were treated. The installed microwave power is 1200W. All experiments have been carried out under flowing nitrogen as protective atmosphere. The sintering of the steel samples has been carried using a SiC-plate as susceptor heating element, on which the samples have been placed. SiC absorbs microwaves very well and acts in this way as additional external heating to the steel samples. In this way the system worked like a hybrid furnace combining conventional heating and microwave processing.

Figure 2: Microwave sintering device

Bronze powder has been used as model material to highlight the effects underlying the microwave sintering. Coarse bronze powders with a diameter of 350-500µm have been used to clarify some processes taking place during micro wave sintering. The powder was strayed on to a ceramic isolation material which did not absorb microwaves, so that only reactions of the powder arrangement to the microwave radiation were core of the experiment. A powder bed of 1mm height was formed and placed directly in front of the hollow wave guide.

Figures 3 shows the SEM-pictures of the surfaces of bronze powder particles, which have been processed with 1000W microwave power.

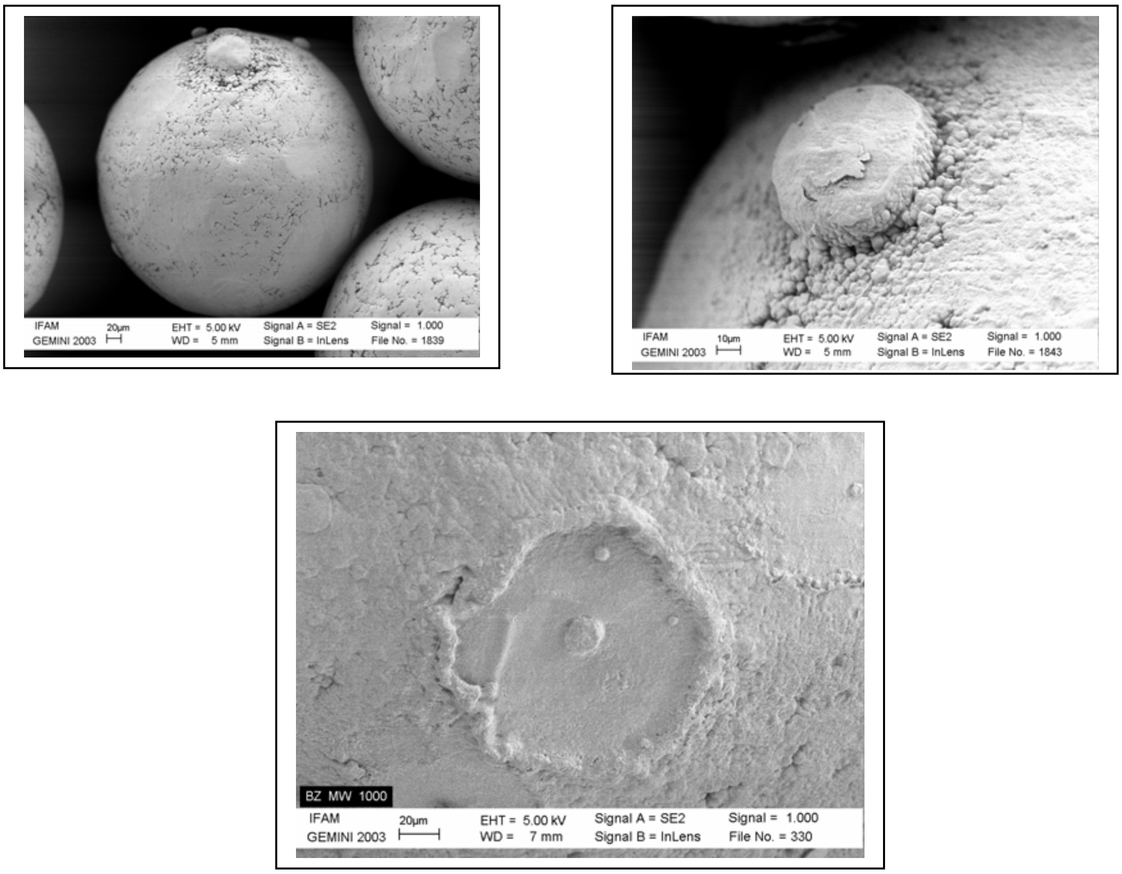


Figure 3: SEM pictures of bronze powder particles treated with microwaves

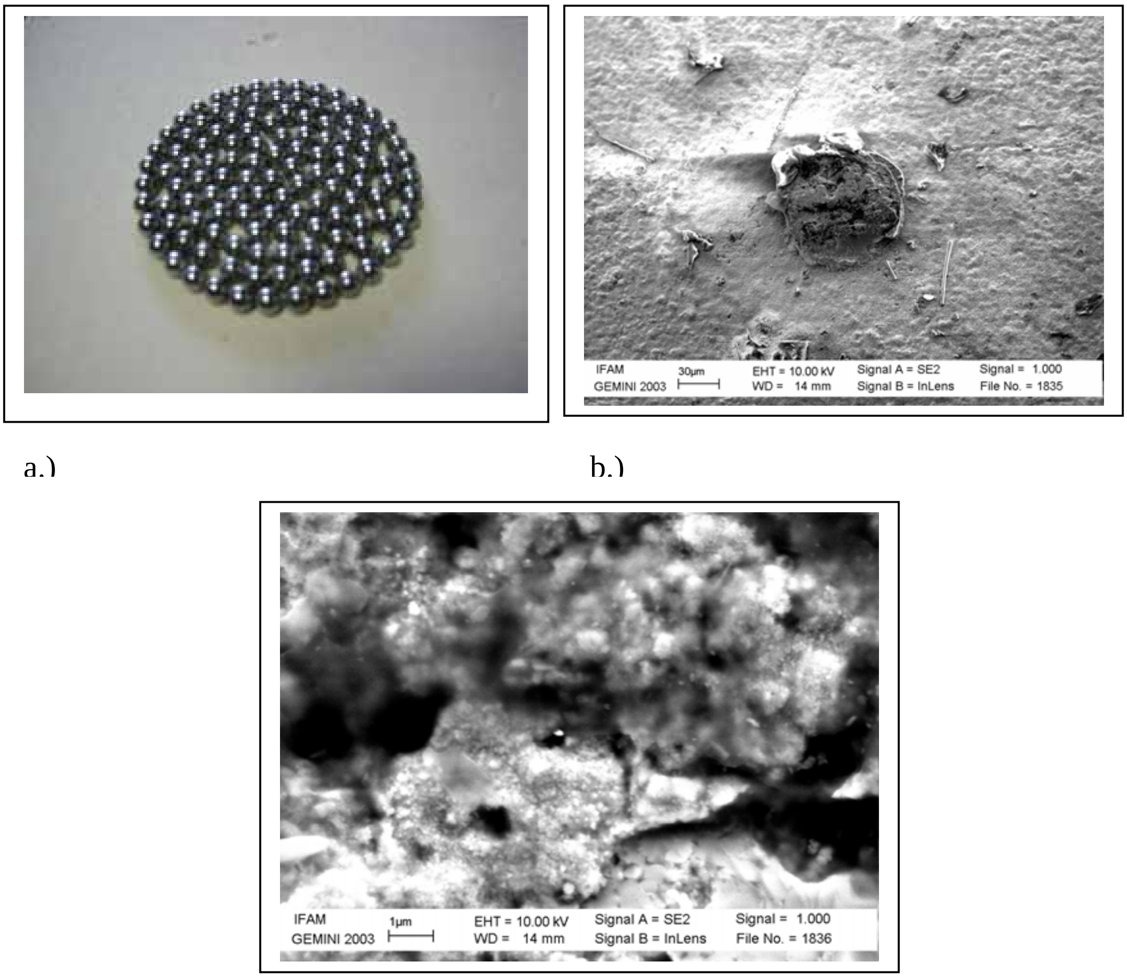
The pictures show that there was a material transport into the contact areas of the powder particles. There are seams of material around the former contacts as well as pile ups of material between two particles. The higher magnification picture reveals that the material consists of very fine particles below one micron size.

Although the picture visible in the experiments with the bronze powders is quite evident, another set of experiments was performed to clarify even more the “microwave effect“ in microwave sintering.

## Bearing balls as model material

In order to avoid any thermal effect of sintering a very coarse model powder was used with steel bearing balls of 6mm diameter. They are big enough to be far away from any thermal sintering and they provide a well defined surface which makes any change due to transport mechanisms along the surface clearly visible. The temperature was carefully controlled in these experiments and has been kept always below 700°C in order separate microwave effects from pure heating effects.

The SEM-pictures of the bearing balls treated with microwaves of 1200W power is shown in the following figure 4. Here it is also visible that a material transport has taken place into the area of the contacts between the bearing balls. A view with very high magnification shows that the seam around the contact consists of nano-particles, which have in their shape the typical appearance of sputtered layers, which have been produced under high atmospheric pressures.



a.)

b.)

c.)

Figure 4: Steel bearing balls in microwave experiment. a.) Experimental arrangement of bearing balls on a ceramic substrate; b.) Surface of bearing balls treated with microwaves;
c.) High magnification detail of contact area

## Cracks and microwaves

Microwaves show due to their long wave length a response on macroscopic details of parts as sharp corners, which act as field raisers, and also cracks which cause field concentrations [3,4,5]. To study the effects of these field concentrations, bending test samples have been pre-cracked in the green state to a crack length of half of their thickness. A part of the samples has been treated by microwave assisted sintering for 15min at 1050°C the other half of the samples was treated with the same time-temperature program in a conventional furnace. The sintered samples were examined in a 4-point bending test, in such a way that a constant bending momentum acted on the cracks and no further stress concentrations disturbed the results. The results of the tests are summarized in the following table, where the mean values of the measurements are listed.

Table 1: Bending strength values of pre-cracked samples treated conventionally and by microwave-assisted sintering.

| **Sample** | **Bending strength / N/mm²**<br>**Conventional sintering** | **Bending strength / N/mm²**<br>**Microwave sintering** |
|---|---|---|
| Distaloy AE<br>400 MPa compacted | 242 | 270 |

There is a significant increase in bending strength of the pre-cracked microwave sintered samples. This increase corresponds well with the former observation (see Fig1.) that especially at low temperatures the beneficial effect of microwaves is best visible. By SEM examination it was not possible to identify clearly the effect of the microwave treatment in the fracture surface and the ground of the fracture. It seems that the transport of material into the sharp ground of the green crack raises the fracture strength.

## Discussion of results

The experiments carried out with the model powder, bearing balls, clearly indicate that there is a pure microwave effect, which acts without the thermal effect of heating due to induced currents. The currents cause heating of the area close to the surface of the individual powder particles due to the skin effect acting at these high frequencies.

Additionally the electric high frequency fields between the individual powder particles generate local plasmas, which sputter material away from the pore area of the powder arrangement [2]. The transport into the contact area takes place via finest particles down to nanometer size in the gas phase. The transport occurs from the high energy area of the positively curved powder particle surfaces into the low energy area of the contacts. Those particles can influence the sintering in two ways. At first it may be that the transport of the fine sputtered particles is the microwave sintering effect by itself. It may also be the case that the fine powder particles are transported into the contact area and there they are subject to a normal sintering. As their size is so small, their sintering activity is so high that sintering around the contact areas is taking place at very low temperatures. This causes the impression that microwave sintering occurs at much lower sintering temperatures. Nevertheless, the principles may be independent from microwave, but the effect on the sintering process is fully depending on the action of microwave radiation.

In the conventional “thermal” sintering two particles are sintered together due to their surface energy. It is an absolute prerequisite that the particles have to be in contact with each other in order to be able to form a common surface, which has the capability to minimize itself. In microwave sintering two particles do not have to be in contact for sintering, they only need to be in close neighborhood. In consequence microwave sintering has the capability of a repair technique for cracks in green parts. In conventional sintering two crack boundaries never come together in sintering. The crack boundaries are free surfaces, which are more likely to move away from each other, and open a crack more widely. In microwave sintering, the field concentration at cracks fosters material transport in these areas especially by the higher fields and offers the possibility to lower the effects of cracks via sintering. This may be another big potential for microwave application on conventional PM-materials.

## Summary

The results presented here support the opinion that microwave does not only act by thermal effects and heating up metallic materials by induced currents but that fields acting between particles and parts generate plasma which fosters mass transport into the contact areas between particles by generating fine particles. It will be the subject of further investigations to find out, how the exact mechanism works and how it may be used for the sintering process of PM-parts.

The fact that microwave treatment reduces the effect of cracks in parts, requires further examination as this may become a very important feature and motivation for further use of microwaves in powder metallurgy.

## Acknowledgement:

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