Finite element analysis of spark plasma sintering: contribution to the reduction of temperature inhomogeneities in non conductive materials

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Highlights

- Both axial and radial temperature gradients were observed in the sample.
- Temperature heterogeneities were minimized considering an optimal partial insulation of the die.
- Misalignment of the axial pyrometer and a shift of the die relatively to the sample were identified as potential error sources for temperature measurements.

1. Introduction

Due to its exceptional benefits, including rapid heating rate and reduced sintering temperature and holding time, Spark Plasma Sintering (SPS) is becoming increasingly applied to a variety of advanced materials in a wide range of application fields [1]. The major drawback of the SPS sintering is the inhomogeneity of the material properties, due to the temperature uncertainty during the experiments or to the temperature gradients inherent to this process.

During the last decade, finite element modeling has contributed to investigate the influence of several experimental parameters on the temperature distribution within the SPS setup or the sintered materials [2-5]. However, most of the numerical studies lack of experimental validation and their accuracies depend on the simplifying assumptions. In this work, standard sintering experiments of alumina were performed and their results were used to develop faithful simulations used to propose a simple method to decrease the temperature inhomogeneities within the sample. The simulations were also used to discuss the effect of the experimental procedure on the temperature dispersion during SPS sintering.

2. Methods

Sintering experiments were performed with alumina using an SPS setup (FCT Systeme GmbH Germany) in a temperature-control mode. FEM modeling detail of which are described in [6] was employed to investigate the influence of various experimental parameters on the temperature distribution or dispersion considering two error sources: misalignment of the axial pyrometer and a shift of the die relatively to the sample.

3. Results and discussion

The finite element simulations showed that axial temperature gradients in addition to radial ones appear in the sample, as a result of asymmetrical cooling or asymmetrical positioning of the punches in the die. Both gradients increased with the sample dimensions. Figure 1 shows the temperature fields and the maximal temperature difference within a sample of diameter 40 mm. Instead of a total insulation of the die commonly used, partial insulation using graphite felts with an optimal height allowed to minimize the radial temperature distribution with little incidence on the axial gradient. Moreover, the simulations show that the temperature homogenization within the sample can be improved by combining a controlled upward displacement of the die with an optimal partial insulation (Fig. 1d).

Simulations of the temperature deviation induced by a misalignment of the axial pyrometer or by a shift of the die relative to the sample were performed. Both error sources induce comparable temperature deviations which are sensitive to the sample diameter in the case of a pyrometer misalignment.

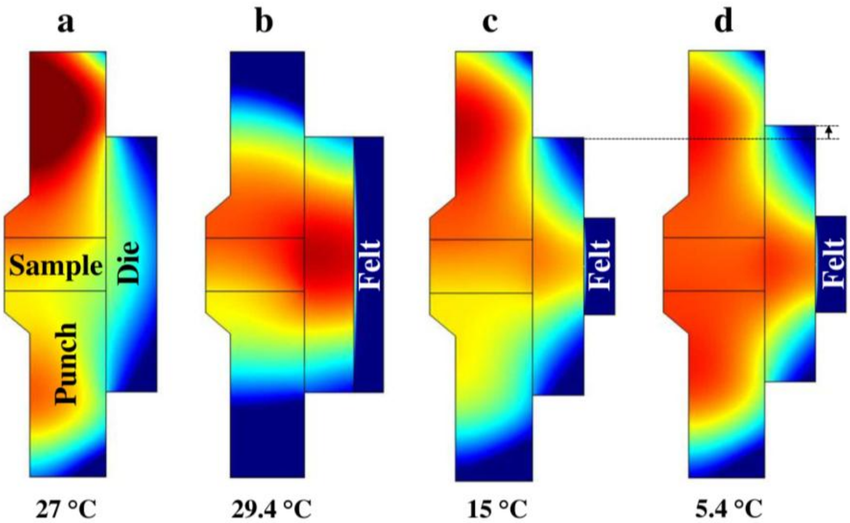

Figure 1. Temperature fields and maximum temperature difference for different configurations of die insulation: (a) without insulation; (b) total insulation; (c) optimal partial insulation and (d) partial insulation with upward die displacement of 2 mm.

4. Conclusions

Partial insulation of the die with an optimal height of felt allowed to minimize the radial temperature distribution, with little incidence on the axial gradient.

Misalignment of the axial pyrometer or asymmetrical positioning of the punches in the die are potential error sources that contribute to the temperature dispersion and inhomogeneities. Therefore, a carefully controlled experimental procedure is necessary to avoid the heterogeneity and the non reproducibility of material properties that represent a major barrier toward fully exploiting the unique benefits offered by the SPS technique.

References

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Keywords
Spark Plasma Sintering; temperature gradients; temperature dispersion; Finite element modeling.