# Modelling of powder sintering using the discrete element method

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Abstract

This paper presents numerical modelling of powder sintering. The numerical model introduced in this work employs the discrete element method which assumes that material can be modelled by a large assembly of discrete elements (particles) of spherical shape interacting among one another. Modelling of sintering requires introduction of the cohesive interaction among particles representing inter-particle sintering forces. Numerical studies of sintering have been supplemented with experimental studies which provided data for calibration and validation of the model. In the laboratory tests evolution of microstructure and density during sintering have been studied. Comparison of numerical and experimental results shows a good performance of the numerical model developed.

*Keywords: powder sintering, powder metallurgy, simulation, discrete element method*

## 1. Introduction

Sintering is a manufacturing process used for making various parts from metal or ceramic powder mixtures. Sintering consists in consolidation of of loose or weakly bonded powders at elevated temperatures, close to the melting temperature with or without additional pressure. This is a complex process affected by many factors. Modelling can be used to optimize and to understand better the sintering process and improve the quality of sintered components.

Modelling of sintering process is still a challenging research task. There are different approaches in modelling of sintering processes, ranging from continuum phenomenological models to micromechanical and atomistic ones. In this work the discrete element method is adopted as a modelling tool. This model employs a discrete model of sintered material and belongs to the class of micromechanical models. It allows us to determine interaction between the grains during sintering and rearrangment of grains during sintering. The numerical model is validated using the results of experimental studies of a sintering process.

## 2. Experiemental studies of a sintering process

Experimental studies of sintering have been performed in the laboratory of Institute of Electronic Materials Technology. Sintering has been carried out in a Thermal Technology Astro uniaxial hot press. Morphology of the NiAl powder used for sintering is shown in Fig. 1. Sintering has been performed under pressure of 30 MPa and at temperature of 1400$^{o}$C.

During sintering particulate material is converted into polycrystal. In the initial stage cohesive bonds (necks) are formed between grains. Microstructure at an early stage of sintering is shown in Fig. 2. When the sintering process is continued the necks between particle grow. Grain rearrangement and increase of grain compaction can be observed during sintering. With the advancement of grain growth, gradual reduction and elimination of porosity is observed.

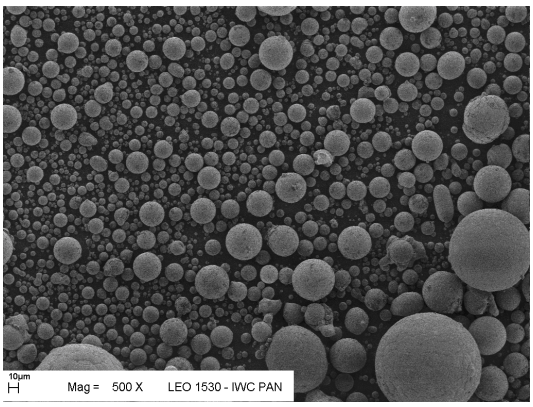



Figure 1: Morphology of the NiAl powder

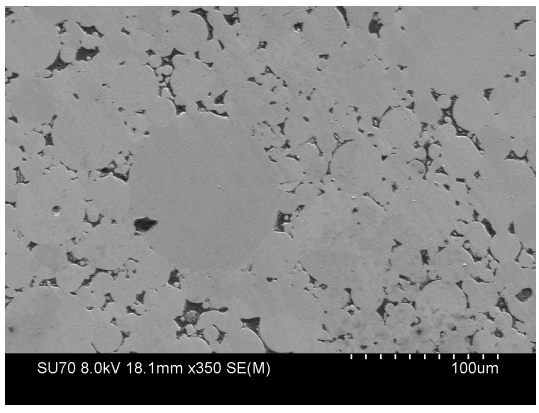



Figure 2: Microstructure at an early stage of sintering of NiAl

The kinetics of sintering can be evaluated by investigation of the bulk density change in time. The macroscopic shrinkage of the porous material during sintering leads to the increase of the bulk density. The evolution of the bulk density obtained in our studies will be used in calibration of the numerical model.

## 3. Numerical model of sintering

Growth of the neck connections between grains during sintering is a result of mass transport by different mechanisms [3]. The main mass transport mechanisms during sintering: surface, volume and grain boundary diffusion. As a result of the stresses in the neck and the surface tension the particles are attracted to each other leading to shrinkage of the system.

Considering the relationship between the diffusion and stress state Coble [1], Johnson [4], and De Jonghe & Rahaman [2] formulated mathematical models for sintering force between two particles. The discrete element method provided a suitable framework for more general application of these models [5, 7]. Discrete element method assumes that material can be represented as a collection of spherical particles interacting among one another, thus the discrete element model takes explicitly into account the particulate nature of the sintered material [6]. The numerical model of sintering has been implemented in the finite/discrete element code Simpact [6].

Modelling of sintering requires introduction of the cohesive interaction among particles representing inter-particle sintering forces. In our model the translational motion will be considered only, assuming that the rotational motion is negligible in sintering. The particle interaction model assumed for sintering employs the equation derived by Parhami and McMeeking [7]:

$$F_{\mathrm{n}} = \frac{\pi a^4}{8 D_{\mathrm{b}}} V_{\mathrm{n}} - \pi \gamma_{\mathrm{S}} \left[ 4R\left(1 - \cos\frac{\Psi}{2}\right) + a \sin\frac{\Psi}{2} \right] \tag{1}$$

where $F_{\mathrm{n}}$ is the normal force between two particles, $V_{\mathrm{n}}$ – the normal relative velocity, $R$ – the particle radius, $a$ – the sintering contact radius, $\Psi$ – the dihedral angle, $\gamma_{\mathrm{S}}$ – the surface energy and $D_{\mathrm{b}}$ – the grain boundary diffusion coefficient. The geometric parameters used in Eq. (1) are defined in Fig. 3.

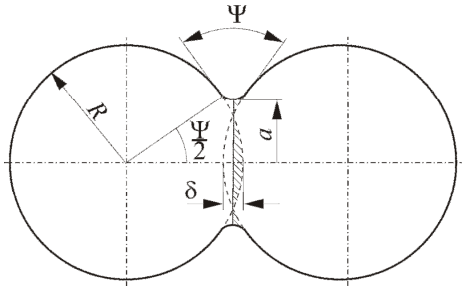


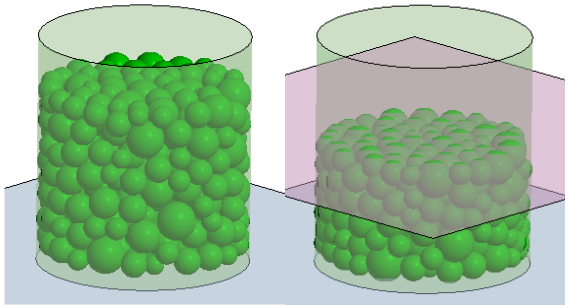

Figure 3: Model parameters definition

## 4. Simulation of sintering of a cylindrical specimen

The model implementation has been verified and calibrated performing simulation of a cylindrical specimen assuming that the kinetics of sintering is the same as in the laboratory test of sintering presented above. The initial configuration of the discrete element model consisting of 350 particles is shown in Fig. 4a. Figure 4b shows the specimen at the end of sintering. The shrinkage can be clearly observed. The model parameters have been determined by fitting the density evolution to experimental results (Fig. 5). It can be seen that the evolution of the density is reproduced properly in the simulation.

## 5. Concluding remarks

The discrete element method is a suitable tool to model powder sintering. Presented results show a big potential of the developed numerical model in modelling of sintering processes, although further developments and validation are necessary.



a) b)

Figure 4: Simulation of sintering: a) initial configuration, b) final configuration

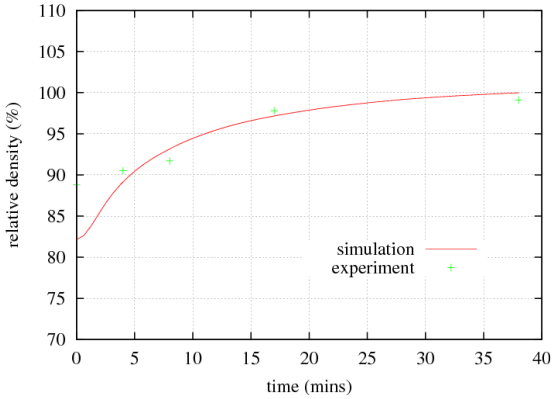



Figure 5: Evolution of relative density during sintering process

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