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Discrete element simulation of powder metallurgy manufacturing process of metal-ceramic composites

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ABSTRACT

The paper presents discrete element simulation of manufacturing of metal matrix composites using a powder metallurgy process. Powder metallurgy is the most common technique to fabricate metal matrix composites with ceramic reinforcement, advanced materials with many applications. As a technological process powder metallurgy consists of several stages including metal and ceramic powder manufacturing, preparation of metal-ceramic powder mixture, powder pressing and sintering. Sintering consists in consolidation 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. One of the main problems in sintering of metal-ceramic composite is possibility of crack initiation in the material due to difference in shrinkage of metal and ceramic phases.

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. In the discrete element method, material is represented as a large collection of particles interacting with one another by contact forces. It is a suitable tool to model granular and rock materials [1]. Modelling of sintering requires introduction of the cohesive interaction among particles representing inter-particle sintering forces. Following [**?**, 2] the discrete element model adopted in this work employs the following equation for the sintering interaction between powder grains:

$$F = \pi\gamma_S \left[4R \left(1 - \cos\frac{\Psi}{2} \right) + a \sin\frac{\Psi}{2} \right] + \frac{\pi a^4}{8 D_b} V \tag{1}$$

where V is the normal relative velocity, R – the particle radius, a – the radius of the interparticle grain boundary, Ψ – the dihedral angle, γ_S – the surface energy and D_b – the effective grain boundary diffusion coefficient. The geometrical parameters of the model are defined in Fig. 1. The first term on the right hand side of Eq. (1) represents the sintering driving force and the second one – the viscous resistance of the material. The model has been extended to include elastic and thermal effects. It enables modelling of a powder metallurgy process consisting of powder compaction, sintering and cooling of the sintered component. It allows us to study the grains during sintering and rearrangment of grains during sintering, material shrinkage and internal stresses.

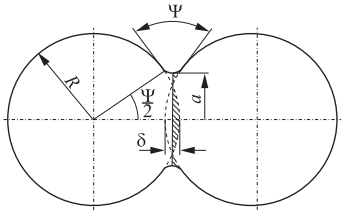

Figure 1: Two-particle model of sintering.

The numerical model has been applied to analyze sintering behaviour of different mixtures NiAl/Al_2O_3. Numerical simulations are combined with experimental studies of sintering. First, sintering of each phase, NiAl and Al_2O_3, is studied separately at different parameters: temperature, time and pressure. Finally, sintering of mixtures NiAl/Al_2O_3 will be performed at similar conditions. The kinetics of sintering is evaluated by investigation of the bulk density change in time. The evolution of the bulk density obtained in experimental studies is used in calibration and validation of the numerical model. Comparison of experimental and numerical results for sintering of NiAl powder at temperature 1300°C under pressure of 30 MPa is shown in Fig. 2a. Since experimental tests for mixtures NiAl/Al_2O_3 have not been finished yet, numerical results are shown only in Fig. 2b. With the parameters assumed the sinterability of the mixture NiAl/Al_2O_3 is worse than that of each phase separately as it is reported by Shinagawa [3], who investigated solid phase sintering of powder mixtures. This will be verified in further experimental work.

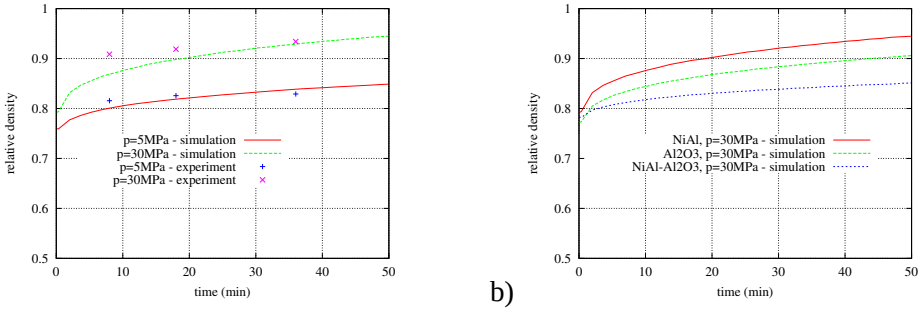

Figure 2: Evolution of relative density during sintering: a) numerical vs. numerical results for NiAl, b) numerical results for NiAl, Al_2O_3 and mixture NiAl/Al_2O_3.

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