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Viscoelastic cohesive contact formulation for discrete element model of powder sintering

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In the discrete element method (DEM), a material is represented by a large assembly of particles interacting among one another with contact forces. Particle interaction models are based on various contact formulations incorporating such physical phenomena as elasticity, viscosity, friction, as well as cohesion [1, 2, 3]. The contact law for the particle interaction in the DEM plays a role of a micromechanical material model. Taking an adequate contact formulation with appropriate contact parameters allows us to obtain required macroscopic behaviour of the material [4].

The DEM has become a popular method to model granular and particulate materials. It has also been shown to be a suitable tool to model powder sintering, cf. [5, 6]. Sintering is an essential stage of powder metallurgy processes consisting in consolidation of loose or weakly bonded powders at elevated temperatures, close to the melting temperature with or without additional pressure. Sintering requires a special constitutive model for particle contact interaction [7, 8]. In the present work, an original authors' contact model for sintering [9] will be presented.

The model developed in [9] is aimed to model the sintering as well as the preceding stage of powder compaction. The rheological schemes of the contact interaction for the both stages are shown in Fig. 1. The non-cohesive contact interaction at the powder compaction stage is represented by the Kelvin–Voigt scheme (Fig. 1a) while the cohesive contact during sintering is modelled by the Maxwell element connected in parallel with an element representing the sintering driving force (Fig. 1b). The tangential interaction is neglected in the contact model. Transition between the two viscoelastic model is smoothened by gradual activating one model and desactivating the other one [9].

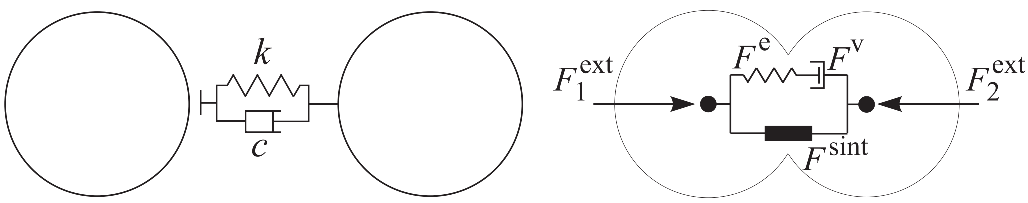

Figure 1: Rheological scheme of the contact interaction for the stages of:
a) powder compaction, b) sintering

The total contact force $F^{\rm cont}$ for the sintering model is a resultant of the sintering driving force $F^{\rm sint}$ and the force in the Maxwell element $F^{\rm Maxwell}$

$$F^{\rm cont} = F^{\rm sint} + F^{\rm Maxwell}. \tag{1}$$

For the Maxwell element, we assume the additive decomposition of the relative velocity between the particles at the contact point v_{r} into the elastic and viscous parts, $v_{\mathrm{r}}^{\mathrm{e}}$ and $v_{\mathrm{r}}^{\mathrm{v}}$, respectively.

$$v_{\mathrm{rn}} = v_{\mathrm{rn}}^{\mathrm{v}} + v_{\mathrm{rn}}^{\mathrm{e}} \tag{2}$$

The force in the Maxwell branch can be expressed either by the elastic or viscous force, F^{e} or F^{v}, respectively, which are equal:

$$F^{\mathrm{Maxwell}} = F^{\mathrm{e}} = F^{\mathrm{v}}. \tag{3}$$

The viscous force is written in the form:

$$F^{\mathrm{v}} = \eta v_{\mathrm{rn}}^{\mathrm{v}} \tag{4}$$

where η is the viscosity coefficient. The sintering driving force and viscosity are evaluated according the the classical models developed for two-particle sintering [10]

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