Modeling of elasto-plastic behaviour of granular materials using multi-particle finite element simulations

N. ABDELMOULA*, B. HARTHONG, D. IMBAULT and P. DOREMUS

* Université Grenoble Alpes, Laboratoire 3SR, F-38000 Grenoble, France
CNRS, UMR 5521 3SR, F-38000, Grenoble, France
E-mail: nouha.abdelmoula@3sr-grenoble.fr

ABSTRACT

Powder metallurgy is a common process for manufacturing complex-shaped components. Part of this process is the cold compaction stage in which ductile powders (iron, copper) undergo large plastic deformation. The mechanical behaviour of ductile powders is typically apprehended by the finite element method (FEM) using macroscopic (phenomenological) constitutive laws.

Constitutive laws used for that purpose in the powder industry are exclusively variants of the Drucker-Prager Cap model that are implemented in commercial FEM codes. These models are based on the concepts of yield surface and plastic potential. However, experimental measurements [1] [2] show that these models do not correctly reflect the evolution of stresses and/or strains during powder densification, in particular because they do not account for compaction-induced anisotropy. Improvement of these models is limited by the difficulty of experimental characterisation of yield surfaces and plastic flow since only a limited number of loading paths are accessible through laboratory tests.

In this work, the multi-particle finite element model (MPFEM) [3] [4] is used to get new insights on the mechanical behaviour of powder materials. In this method, grains are meshed and interact by mechanical contacts. Their constitutive behaviour is modelled by a continuum mechanics-based model, ensuring an accurate description of the change in shape of elasto-plastic grains undergoing large deformations. The response of a sample made of a limited number of grains under various loading paths is simulated using an explicit finite element solver. Under these assumptions, numerical simulations allow access to any kind of information inside grains or at contacts, and the averaged behaviour of the sample is also accessible. This method constitutes a powerful multi-scale tool allowing a deep and accurate analysis of the mechanical behaviour of assemblies of particles based on rigorous continuum mechanics assumptions on the grain behaviour.

An assembly of 50 spherical particles is used to derive yield surfaces and plastic strain increment vectors using a spherical stress probing technique. Results show part of the conditions under which the flow rule postulate is acceptable and whether the flow rule can be considered associated or not. The analysis essentially focuses on relating the incremental plastic behaviour to the evolution of the microstructure of the sample.

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