Numerical Simulation of Cold Compaction of 3D Granular Packings

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Abstract

During cold compaction processes loose powder is pressed under tooling action in order to produce complex shaped engineering components. Here, the analysis of the plastic deformation of granular packings is of fundamental importance to the development of computer simulation models. Powders can be idealized by packing discrete particles, where each particle is a sphere meshed with finite elements. The pressing of a body centered cubic packing was compared with numerical prediction and experimental data. The global response was expressed in force-displacement curve, and the accuracy of the numerical models analyzed for high relative densities up to 0.95.

Keywords : compaction, granular, simulation, elasto-plastic

1. Introduction

Powder densification can be analyzed in two ways: by modeling each particle or by modeling the compact at a macroscopic level [1]. The first approach is well adapted to granular material. This approach associated with micro-mechanics based models provides information on particle shape, size and contact distribution of the initial packing [2]. In order to model the compaction mechanisms, it is also essential to understand the mechanical behaviour of [3] for the contact of two spheres: the force-displacement law which links the contact load to the positions of particle during indentation, frictional model. Cold compaction of powders has been studied using discrete element method [4] for two-dimensional packing and [5-6] for three-dimensional packing, and by finite element model for two-dimensional packing [7]. In this paper, we demonstrate the ability of finite element 3D model (Abaqus) to describe densification from loose powder to high relative density.

2. Material Characterisation

Lead was characterised with casted cylinders of 20mm in diameter and 44mm in height. However, the viscous component of this material is not representative of iron powder which has an elastic-plastic behaviour. Thus, for simulating industrial powder compaction, experimental tests were performed in a way such that viscous effects were always avoided (low strain rate ranging from 10^{-3} to 10^{-4} s^{-1} and relaxation steps). Simple compression tests were performed, and in these tests, many relaxations steps took place. The elastic and plastic parameters were evaluated from stresses measured after relaxations (Fig.1).

In Fig. 1, elastic behavior is linear and fully determined by the Young's modulus E, Poisson's ratio υ and yield compression stress σ_Y measured in the field of small strains ε (ε ranged from 0 to 0.01).

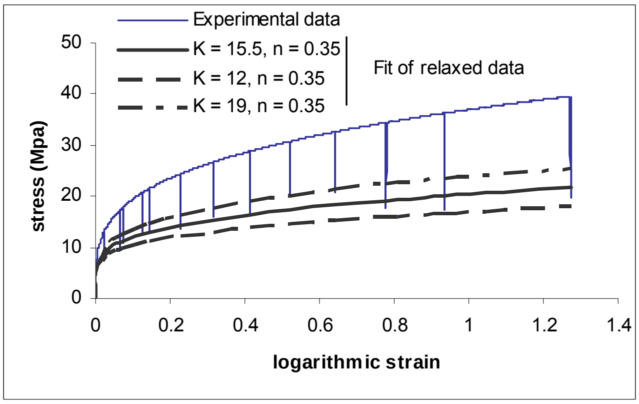

Fig. 1. Bold lines indicate the fit of the experimental data obtained after relaxation. All relaxed data are located between the two bold dashed lines.

The plastic behavior is a Von Mises with plastic strain as the hardening parameter. The hardening expression is given by:

$$\sigma = K(\varepsilon^{pl})^{n} + \sigma_Y$$

where $\sigma = F/S$ is the Cauchy stress, $\varepsilon = \ln(H/H_0) = \varepsilon^{el} + \varepsilon^{pl}$ the logarithmic strain, $\varepsilon^{el} = \sigma/E$ the elastic strain, ε^{pl} the plastic strain, S and H the true dimensions, K and n are material constants. Parameters K and n were measured from the results of 10 relaxations performed over a logarithmic strain ranging from 0.2

to 1.3. The plastic parameters hereafter are as follows: K = 15.5 and n = 0.35 and elastic parameters are E = 10Gpa, ν = 0.435 and σ_Y = 5Mpa.

3. Die pressing of a body-centered cubic packing

The experimental test and simulation consist in pressing a body centered cubic packing made of 9 identical spheres into a die with a fixed lower punch. The packing has initial height and diameter of 44.62mm (Fig.2(a)). The interest of this test is to achieve a high distortion of the spheres and to use an industrial process for the compaction. The displacement of the upper punch is 25.85mm which corresponds to a relative density of 0.97.

Several levels of mesh refinement were used in the models in order to achieve convergence of numerical predictions in terms of force-displacement response associated to large elastoplastic deformations and evolutive contact. With the adopted element size, numerical simulations were carried with remeshing procedure. It has been shown that remeshing procedure has no significant influence on the numerical results.

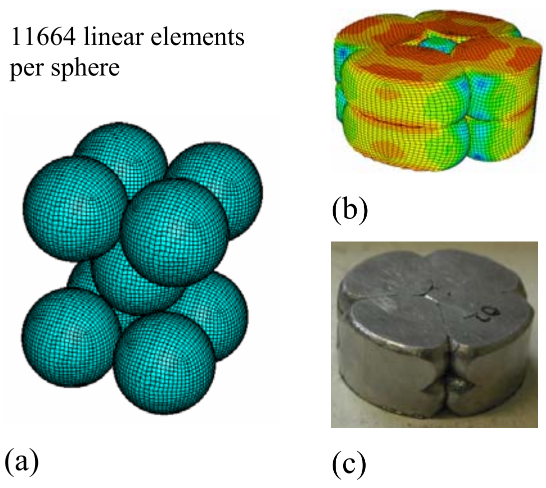

Fig. 2. (a): Initial bcc packing. (b): Simulated packing for 0.97 relative density. (c): Real packing as (b).

Three couples of friction coefficient μ were used, sphere/die = μSD and sphere/sphere = μSS. The all packing looks similar (Fig. 2(b) and 2(c)). The pressing force as function of the upper punch displacement is shown in Fig. 3 for the experimental test including relaxations and also simulated results. The friction between spheres μSS influences the pressing force. The best fit is obtained with coefficients: μSD = 0.25 and μSS = 0.1.

After a 10mm displacement of the upper punch the slope of the compacting curve suddenly increases slightly. This is due to the first contact of the four lower spheres and the four upper spheres. The corresponding displacement is 10.5mm for the simulation.

The increase in friction coefficients results in an increase in the predicted upper punch load (Fig .3).

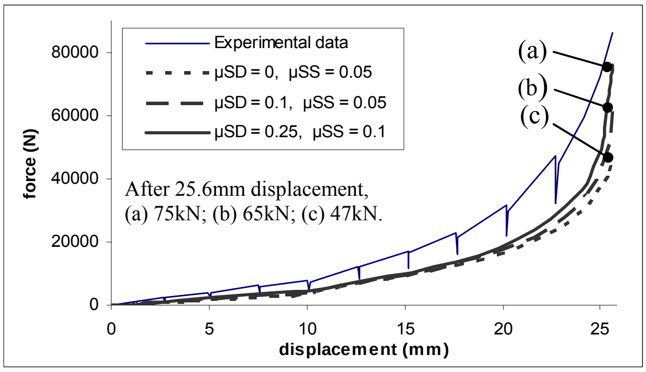

Fig. 3. Evolutions of the simulated pressing force on the bcc and the experimental data with relaxations.

4. Summary

Lead spheres were used to simulate powder particle. The material behavior of lead was experimentally determined and calibrated, and then incorporated into a modeling code to simulate compaction. Spheres were meshed and deformed under pressing force to cause the relative density to increase from 0.43 to 0.97. Pressing force that was applied on a body centered cubic packing was found to be in good agreement with experimental data. Moreover, the simulated spheres after deformation were similar to the real ones. The results of the experiment showed that friction between spheres as well as that between sphere and compaction tooling is an influenced parameter. This first work clearly demonstrates the applicability of meshed particles method for simulating simple packing densification.

5. References

1.Dienet modelling group, Eur. Powder Metall., **2**, pp.320, (2003).
2. P.L. Larsson, S. Biwa and B. Storåkers, Acta Metal., **44[9]**, pp.3655, (1996).
3. B. Storåkers, N.A. Fleck and R.M. McMeeking, J. Mech. Phys. Solids, **47**, pp.785, (1999).
4. P. Redanz, N.A. Fleck, Acta Mater., **49**, pp.4325, (2001).
5.P.R. Heyliger, R.M. McMeeking, J. Mech. Phys. Solids, **49**, pp.2031, (2001).
6. C.L. Martin, D. Bouvard, Acta Mater., **51**, pp.373, (2003).
7. A.T. Procopio, A. Zavaliangos, J. Mech. Phys. Solids, **53**, pp.1523, (2005).
8. Bharat Bhushan, Modern Tribology Handbook, CRC Press LLC, **1**, (2001).