Powder Mechanics

In general terms, the research at the Division of Solid Mechanics is mainly concerned with modelling and analysis of product functionality combined with modelling and simulation of manufacturing processes. The research is focused on industrial product development with respect to the combined effects of design and manufacturing on the product functionality.

Constitutive modelling

An important part of the work within the group is mainly concerned with constitutive modelling of cold or hot forming iron powder mixtures, tungsten carbide powder, minerals in powder form and iron ore pellets. For the purpose of the modelling, a cap-plasticity model has been developed by the group. Other models are also developed and used. The parameters of the models are established by minimising the error between the model response and the experimental results with respect to several load paths, so called inverse modelling. The experimental data is key information; we put a great effort to develop testing methods and controlling the testing needed. This is done in our labs in Luleå and in co-operation with other research laboratories e.g. INPL Grenoble and CIMNE/UPC Barcelona. Almost all references below contains, to some degree, constitutive modelling.

Powder flow

Flows of granular material such as die filling is an important stage in the manufacturing process of powder metallurgical components as proceeding stages are influenced by the powder distribution achieved by the filling process. In our work smoothed particle hydrodynamics (SPH) method is used to simulate shoe filling of metal powder into simple and stepped dies. An elastic-plastic material model is used as constitutive model where the material parameters are estimated using results from filling rate experiments and loose powder shear tests. The powder flow behaviour and packing density is simulated and compared with experimental results. The results shows that SPH simulations can capture major observed features of powder die filling. See references 58,59,62,63,64

Fracture modelling

The numerical modelling of fracture in pressed powder is based on an experimental investigation of the Diametral compression test performed for pressed metal powder. One of the main findings from the experimental work is that pressed powder seems to exhibit a cohesive behaviour upon tensile loading. Experimentally determined tensile strength and fracture energy as functions of density are also results from the study. A general energy dependent fracture model to control dissipated energy for pressed powder is developed by the division. A property of the potential function is that the derivative of the normal stress as function of the crack–width is zero for a closed crack. This grants function stability at the onset of fracture.

See references 48,54,55,66

High-pressure compaction

Mechanical properties for powders at high pressure are rare, this because it is difficult to attain material data in this region. The test apparatuses that are available are only working in the lower pressure region. Calcite (CaCO₃) is one mineral that can be used
in high-pressure processes. It is also a very common material in the earth core and therefore is of interest to the geo scientists. To be able to model processes that are working in the high pressure region the mechanical properties of the powder have to be known for the whole stress region, in our work from 0.05 to 5 GPa compressive mean stress. The objectives of the research carried out at our research group has the purpose to investigate the pressure/density relationship of the powder and also from novel experimental techniques correlate the relative density to elastic and strength properties. Further, to introduce a methodology to produce the foundation for an elastic-plastic model.

See references 65,67

High velocity compaction
The establishment of physically based constitutive models to describe loading paths and to understand the process of high velocity powder compaction requires a detailed knowledge of high-strain-rate mechanical behaviour of these materials. The research at the division introduces a method for characterization of powder in high velocity compression using a modified split Hopkinson set-up. The survey has been done with a simple tool preventing radial deformation of the tested materials. The obtained dynamic data has been compared with static results. The dynamic data has been used to estimate constitutive parameters for models of powder. The work shows the possibility to numerically study the geometric design and to optimize the densification behaviour of a complex high velocity compaction process.

See references 44,45,51,53,60,61

Hot isostatic pressing
The research regarding HIP performed at our group is about modeling and simulation of the process. Normally it consist of a steel container filled with steel powder, with or without internal core. Simultaneously heating and pressing (typically 200 MPa) until full density is reached. The constitutive models developed at our group are micro mechanical based or more traditionally macro mechanical based models.

See references 15,16,17,18,22,23,24,26,29,33,42

Simulation of industrial processes
The powder compaction simulations have mainly been performed with use of explicit time integration of the equations of motion. Implicit integration can be used as well but the very non-linear nature of the problem necessitates very short time-steps which make explicit methods very competitive with respect to computer execution times. There are also more advantages with explicit methods; it is relatively straightforward to test new or changed models for material behaviour or new models and methods for frictional contact. The methods used for contact detection and contact interface algorithms are based on earlier work with contact-impact problems. The contact forces are established with use of direct integration of the contact interface with the impenetrability condition as constraint. The friction is modelled with a variable friction coefficient which can be dependent of powder density and the velocity. This type of behaviour has formed the base for the modelling of friction between powders and surrounding walls.

International co-operation
The group is working in several international research co-operation programs. COST 512 established co-operations with Fraunhofer IWM Freiburg, INPG Grenoble and
Cea-CEREM Grenoble which has continued actively since beginning of the 1990’s. Prof. Mats Oldenburg is the coordinator of the Brite/Euram project “Inverse modelling for determination of non-linear constitutive relations” (IMCOR). The other partners in the IMCOR project are Höganäs AB, Aalborg University, Cambridge University and Rolls-Royce plc. The group is partner of the Brite/Euram project MC$^2$ together with Höganäs AB, Cea-CEREM, Federal Mogul, Cerametal, Ugimag, Ames, University of Cataluna, CS/SI, Fraunhofer IWM and University of Grenoble. Cea-CEREM is the main contractor.

The group is also partner of the thematic network DIENET “Network to Improve Powder Die Compaction using Computer Simulation and other Advanced Techniques” together with approximately 25 other European organizations. The main contractor is EPMA.

For the moment we have also bilateral co-operation with several universities around the world such as Technical University of Catalonia in Barcelona, University of Oxford in England, University of Swansea in Wales and Nagoya Institute of Technology in Japan.

**Powder Mechanics related publications, Division of Solid Mechanics**


64. Gustafsson G., Häggblad H.-Å. and Knutsson S., Experimental characterization of constitutive data of iron ore pellets. Powder Technology. 2009 ; vol. 194, nr. 1-2, s. 67-74
65. Berg S., Jonsén P. and Häggblad H.-Å., Experimental characterisation of CaCO₃ powder for high pressure compaction modelling, Powder Technology, accepted for publication, 2010
66. Häggblad H.-Å. and Jonsén P., Modeling of tensile crack formation in metal powder pressing, Steel Research Int., accepted for publication, 2010