# Thesis Abstract

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# Experimental and Discrete Element Modelling Investigation of Flow Behaviour of Cohesive Powders under Varying Consolidation States

*by*

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Abstract

Granular materials find use in many industrial processes, such as mixing, coating, granulation, milling, transport, and discharge. For these processes to work efficiently and without interruptions or stoppages, it is necessary to evaluate the flowability of the powders for the design and operation of the bulk solids handling equipment. Flowability of powders is generally evaluated using the methodology proposed by Jenike, which is often referred to as the shear testing methodology. The shear testing methodology involves first shearing a powder sample under a defined normal stress to a steady or critical shear consolidation state characterized by constant shear stress and bulk density, followed by measuring the strength of the powder by shearing the powder sample until failure under a lower normal stress. However, there are many handling scenarios in industry in which the powders might not be subjected to flow regimes leading to critical shearing states, such as in dosing, powder feeders for tableting, and small-scale silos/hoppers for storage and discharge. In such scenarios where the internal shearing deformation of the powders is limited during flow, the powders may not achieve the critical consolidation conditions and instead be only partially consolidated, it is plausible that the Jenike method of flowability assessment may not apply. This study considers the possibility of powders to be partially consolidated and investigates the impact of consolidation state on powder flowability. A flowability characterization procedure to test powder specimens under varying consolidation states was developed using the Schulze Ring Shear Tester (RST). Flowability of two cohesive powders at steady and partially consolidated states were characterized using RST, and flat-bottom model silo experiments were conducted to study the influence of consolidation in powder flow. The RST results showed that the extent of shear deformation and the resultant state of consolidation impacted the yield loci and the strength of the powders, and it marginally impacted the flow function and thus the flowability, the latter finding was also confirmed by the silo experimentation results. This study shows that the powder flowability evaluated at critical consolidation is a good approximation of the flowability at partially consolidated states.

To study the particle level phenomena underlying the bulk behaviour observed during shearing and flow, this research further investigated the powder flow in the shear tests using the discrete element method (DEM). As it is computationally prohibitive to simulate powder flow problems at the real particle scale for the micron-sized particles, a meso-scale or coarse-graining approach was adopted to scale up the particle size to reduce the number of particles in the system and to simplify the particle shape representation. Prior coarse-graining studies have not been able to reproduce the experimental flow function which is obtained by conducting the shear test at varying levels of pre-shear normal stress, requiring stress history dependent/sensitive behaviour of the modelled particle system. In this thesis, the meso-scale cohesive DEM model of the shear testing was developed using the EEPA contact model to reproduce the full flow function and to study the particle level phenomena. The DEM model was calibrated using the experimental data. A fractional Design of Experiments (DOE) study was utilised to explore the parametric space and a Multi Objective Genetic Algorithm (MOGA) was used to minimize the values of the objective functions in the calibration of the model parameters. The

calibrated DEM model obtained by the adopted meso-scale and calibration approach is able to reproduce the stress history dependent flow behaviour for the critical and partial consolidation states, and the full flow function for the critical state. The likely underlying factors causing the partially consolidated powder to have lower failure strength than the critically consolidated powder were also investigated using the upscaled DEM model. The bulk density, velocity and bulk stresses were evaluated from the discrete particle data and were used to study the particle level phenomena such as shear strain evolution, and principal plane orientation in the localized zones in the powder bed. The coarse-graining technique was found to be a useful modelling tool for conserving or reproducing the key characteristics of the original system and for studying the particle level phenomena whilst decreasing the computational costs.