MULTI-SCALE MODELLING OF SNOW MECHANICS

B. KABORE[1], B. PETERS[1], C. WILLIBALD[2], T. THIELE[2], and M. SCHNEEBELI[2]

[1] *University of Luxembourg, Luxembourg, Luxembourg*
[2] *Institute for Snow and Avalanche Research SLF, Davos, Switzerland*

e-mail: bricewendlassida.kabore@uni.lu

1. Introduction

Dynamic and static behavior of snow are of great importance in some engineering applications: *impact on civil infrastructures, avalanches prediction and protection, tire-snow interactions, icing of aircrafts and machinery...* Beyond density, the microstructural parameters of snow have received increasing attention in recent years as the density alone could not accurately represent the mechanical behavior of snow. A realistic modeling of snow dynamics requires a multi-scale approach. This work adopts the following hierarchical modeling approach: first, a mathematical modeling of the grain scale response featuring most of relevant micro-mechanical processes; second, an investigation of meso-mechanical response of representative volumes from structures observed through x-ray computed tomography; Third, upscaling meso-mechanical properties for macro-mechanical behavior.

2. Method formulation

The complex underlying physics at grain scale includes friction, creep, pressure or frictional melting and re-freezing of contact interface creating a bonded structure and a high energy dissipation during macroscopic flow and deformation. Most of these processes are function of the thermodynamic state of the snow. Similar processes are observed in powder metallurgy and additive manufacturing where strengthening and porosity reduction through sintering is accelerated by pressure [3]. From numerical modeling viewpoint, the granular phase can be characterized with frictional interaction of discrete particles and hysteretic energy dissipation. The solid phase is a porous media composed of meso-scale structures with evolving geometries and fracture properties. The inherent mechanical behavior of such structures can be captured using bonded particles for which according to the stress state at the contact area occur: instantaneous bonding or re-bonding due to visco-plasticity and melt-freeze mechanism for compressive stress; elastic deformation and quasi-brittle fracture of the resulting structure under destructive torques, tensile and shear stress. The micro-structure evolution is represented by coupling discrete particle model for the first mechanism and a network of Euler-Bernoulli microbeam model with fracture for the later. Model parameters are calibrated using snow rheology and strength measurement of bond created between contacting ice spheres at different time scales [2] [4].

The snow is considered as a viscoelastic material with a memory effect [1]. For two contacting ice particles we consider the force displacement relation of burger material which includes rate dependence and loading history in the following equation:

$$f^c + [\frac{\eta_d}{k_d} + \eta_i(\frac{1}{k_d} + \frac{1}{k_i})]\dot{f}^c + \frac{\eta_d \eta_i}{k_d E_i}\ddot{f}^c = \eta_i \dot{u} + \frac{\eta_d \eta_i}{k_d}\ddot{u} \tag{1}$$

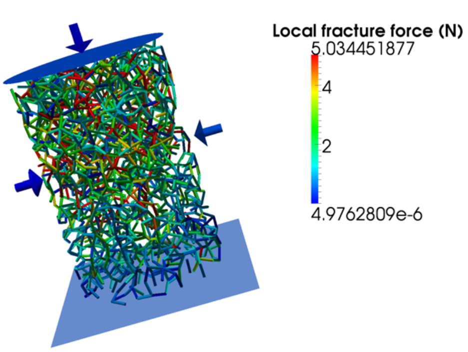
Where η_i and k_i are the instantaneous viscosity and stiffness constant, η_d and k_d the delayed viscosity and stiffness constant, $\dot{u}$ displacement rate, $\ddot{u}$ the acceleration.
The resulting bonding microbeam start thickening and the resistance force under tensile stress is calculated as follow :

$$f^b = \begin{cases} ku & \text{if } u < u_l \\ ku_l\Psi & \text{if } u_l \leq u \leq u_f \end{cases} \tag{2}$$

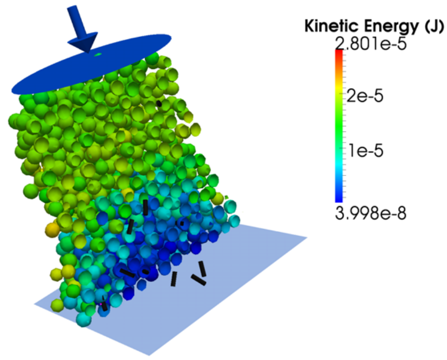
Where the bond stiffness k is function of the beam radius and length, u_l is the limit elastic displacement and Ψ is a damping function for fracture energy dissipation, u_f is a displacement limit depending on the fracture energy. The shear force, bending and torsion torques are computed according to the Euler-Bernoulli beam theory with a quasi-brittle failure and fracture energy dissipation to explicitly account for phase change.

3. Results and remarks

The micro-scale model allowed us to carry out detailed analysis of high strain and rate-dependent behavior and microstructure based fracture parameters. The following images show created microbeam structure under an isotropic compression and the flow of a granular phase after failure of the microbeam structure under high strain rate uni-axial compression. The Fracture force is calculated by multiplying the area of the created bond to the ultimate tensile strength of ice. The solid phase is characterized by the presence of microbeam. Under high



(a)



(b)

Figure 1: *Tests at -5^oC a) Tensile force required to fracture local microbeam structure after a moderate strain rate isotropic compression; b) ongoing damage under high strain rate loading.*

strain rate the brittleness of snow and granular phase is characterized by fracture and low microbeams density.

4. Conclusion

In an effort to simulate the flow of granular snow and fracture behavior of packed snow during large deformations, a hierarchical approach consisting of micro-scale characterization, meso-mechanical and macro-mechanical modeling have been adopted. Based on creep tests and grains bonding strength measurements, calibration and validation of the grain scale mechanical model was performed and meso-scale fracture behavior was investigated. Also mechanical behavior under high strain and different strain rates and pressure sintering of snow have been investigated and modeled.

Acknowledgments This work received the financial support of the Luxembourg National Research Fund and the Swiss National Science Foundation. Simulations were carried out on the HPC facilities of the University of Luxembourg

References

[1] J. Desrues, F. Darve, E. Flavigny, and P. Navarre. An incremental formulation of constitutive equations for deposited snow. *Journal of Glaciology*, 1980.

[2] H. Gubler. Strength of Bonds between Ice Grains after Short Contact Times. *Journal of Glaciology*, 28(100):457–473, 1 1982.

[3] Szymon Nosewicz, Jerzy Rojek, Marcin Chmielewski, and Katarzyna Pietrzak. Discrete element modeling and experimental investigation of hot pressing of intermetallic NiAl powder. 2017.

[4] Denes Szabo and Martin Schneebeli. Subsecond sintering of ice. *Applied Physics Letters*, 2007.