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Failure in snow as a multiscale process

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ABSTRACT

Failure in snow can only be understood by understanding the processes at multiple scales. Measurements of mechanical properties in the field and laboratory are complicated by spatial variability of snow cover both in vertical (stratification) and horizontal direction. Recent observations and measurements help to understand the complex interactions. Snow avalanche formation depends on a combination of critical material properties at different scales. To model the processes relevant for snow failure at each scale, and to relate the relevant processes between the scales will remain a challenging task.

1. Introduction

The failure of snow is a common phenomenon: Every year, snow avalanches causes many fatalities mainly among skiers in the Alps. On the other hand, traffic jams in winter time are caused by the failure of snow under the tires of cars. This illustrates just a small part of the wide spectrum snow failure can have in our daily life. Snow is an unusual material especially with respect to its high homologous temperature (T/T_{melt}). Under terrestrial conditions, the homologous temperature of snow is higher than 0.9, which can be considered as a material at very high temperature state. Snow is a sintered material of usually monocrystalline ice particles. Mechanical properties depend strongly on temperature and strain rate. The large changes in material properties are also caused by the large range of porosities and of grain sizes: the porosity can vary from over 90% to about 30%, where the pore-close off occurs. The grain size varies from about 10 micrometers to several millimeters. The scale dependence of the failure processes in snow are still poorly understood. Recent advances in microstructural imaging and simulation, macroscopic and slope-scale testing and in the development of theory improve our knowledge. Here, a short review of the current understanding will be given [1].

2. Failure at the microscale

The failure at the microscale is determined by elastic-brittle failure at high deformation rates. Microstructure is very important to the formation of stress concentrations, as smaller structures lead to less stored energy. Acoustic emission during deformation indicates that failure at the microscale is crucial for the damaging process. Mechanical simulations at the microstructural level also show stress concentrations [2]. The distance and extent of such stress concentrations is very dependent on the microstructure. However, no direct mechanical observations are yet available of theses processes. The upscaling from the microstructural behavior to a macroscale (continuum) property is in a very inital stage.

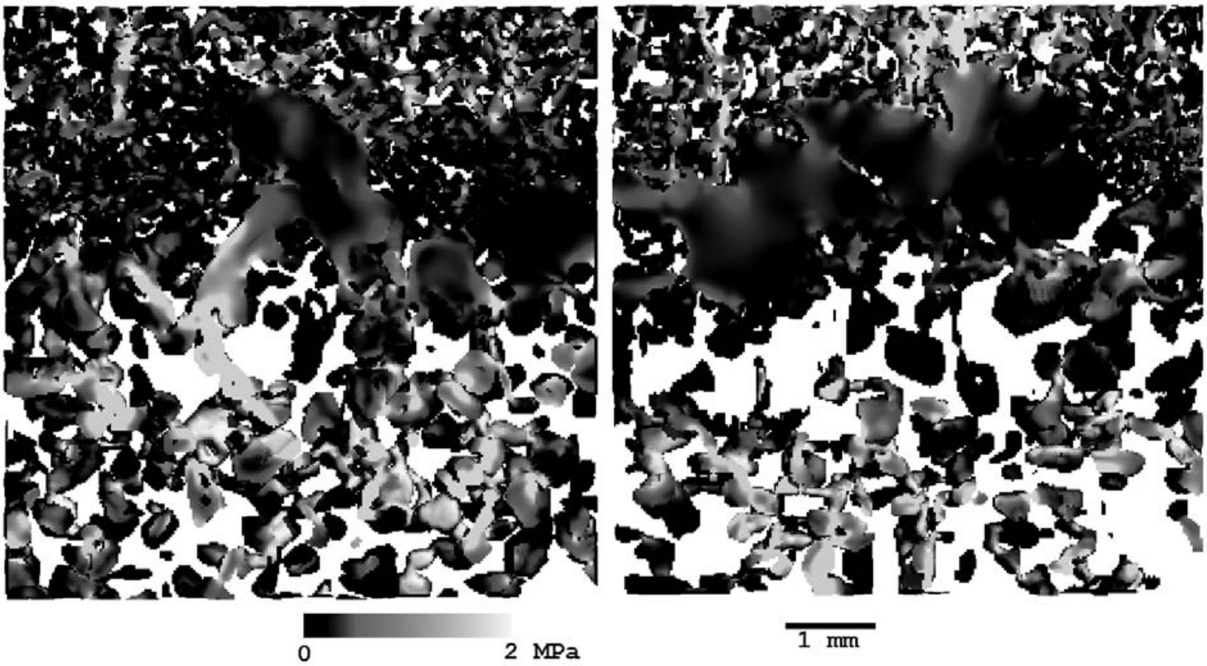

Fig. 1 Uniaxial vertical compression of snow with an applied strain of 0.1%. A purely elastic constitutive law was assumed. Von Mises equivalent stresses in the snow microstructure are shown. Although the porosity in the top and bottom snow are identical, much larger stress concentrations developed in the bottom layer. (from [2]).

3. Failure at the macroscale

Only recentlyexperiments of fracture mechanical properties of snow were conducted [1] [3]. These tests confirm that snow is an extremely brittle material. Size and shape effects have to be taken into account when results of laboratory-scaled experiments are extrapolated to the slope scale [4]. A weakness below a cohesive slab within the snow cover is necessary for slab avalanche release. The properties of the overlaying slab also need to be considered [5]. Laboratory and field tests indicate that the energy required to fracture a weak layer in the snowpack depends on the material properties of the weak layer, whereas the energy available for crack propagation depends mainly on the material properties of the overlaying slab and the slope normal collapse height of the weak layer [3]. A recently proposed analytical model for fracture nucleation in a collapsible stratification [6] is compatible with these oberservations.

4. Failure on the slopescale

Spatial heterogeneity is an inherent property of the snow cover in mountainous terrain. Wind and solar radiation are the main process drivers. While layers may be continuous at the slope scale, their properties exhibit spatial variability. [7]. Spatial patterns affect failure initiation and fracture propagation. Modelling the spatial variations of shear strength in a weak layer with a cellular automata model, suggests that fractures through snowpack weak layers with large-scale spatial structure are more likely to propagate over large areas than fractures through weak layers with smaller-scale spatial structure[8].

5. Conclusions

Failure in snow is complex process, which requires a combined cycle of experiment, simulation and model building. Direct imaging of the snow microstructure will improve process understanding in the future. Many of the actual problems involve non-linearities, spatial variation and size and temperature effects. Progress in the understanding of failure in snow remains challenging.

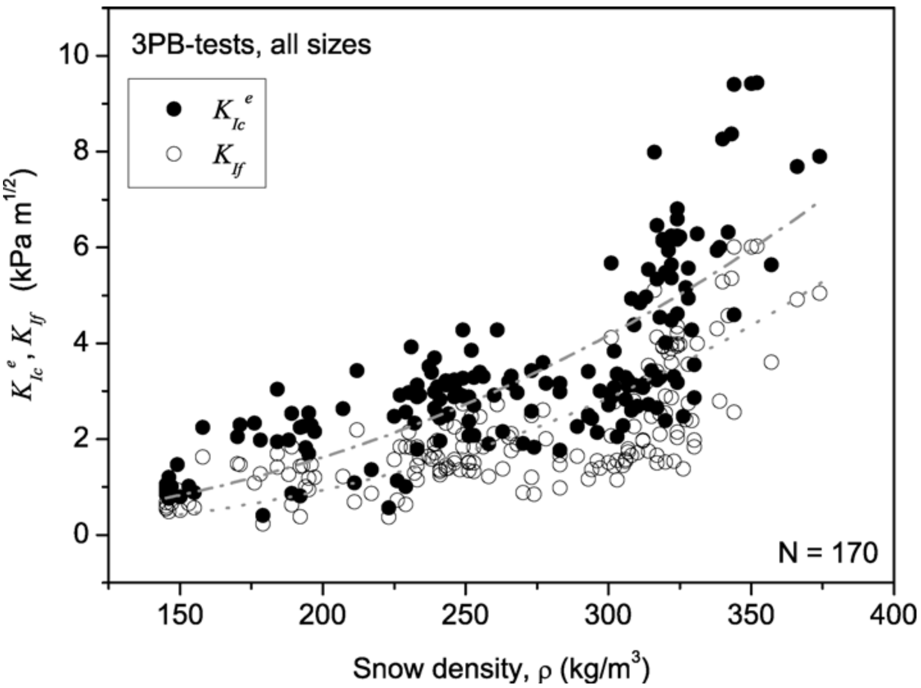

Fig. 2 Critical stress intensity factor, K_{If}, from laboratory-scaled three-point bending tests (white circles) and the same data corrected to a size independent equivalent fracture toughness, K_{Ic}^{e}, (black circles) in relation to snow density. Dotted and dash dotted lines are power law fits to the critical stress intensity factor and the equivalent fracture toughness data, respectively.

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