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On size and shape effects in snow fracture toughness measurements

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Abstract

Dry snow slab avalanche release is preceded by two fracture mechanical processes: shear failure of a weak layer or an interface within the snowpack, followed by tensile failure of the overlaying slab. For a slope stability analysis based on fracture mechanics, the fracture toughness of snow has to be known. The purpose of this work was to evaluate snow fracture toughness in mode I, to determine to what extent it is affected by the specimen size and shape and to search for adequate correction methods. Edge-cracked beam-shaped snow specimens cut from homogeneous layers of naturally deposited snow were subjected to three-point bending and cantilever beam tests. To describe the size dependence an empirical size effect law and the FAD (failure assessment diagram) approach were explored. By comparing the three-point bending with the cantilever beam tests a shape dependence of the toughness was found. The fracture process zone was estimated to be in the order of at least one centimetre. Due to the large size of the fracture process zone a dependence of the toughness on the specimen size has to be expected, as it is typical for non-linear, quasi-brittle materials. Experiments with four different specimen sizes clearly confirmed that toughness is size dependent, possibly up to the scale of a slab avalanche. Preliminary results suggest that the actual fracture toughness might be twice as large as the one determined experimentally. Therefore, size correction functions will be essential to transform toughness data of laboratory-scaled experiments to the scale relevant for snow slope stability models.

Keywords: Snow fracture toughness; Snow mechanics; Fracture mechanics; Avalanche formation; Size effect; Shape effect

1. Introduction

Before the release of a dry snow slab avalanche several damage processes occur. Damage accumulation in a weak layer of the snowpack or along an interface between two different snow layers leads to an initial failure in shear followed by fractures in tension, which finally releases the slab avalanche (Perla and LaChapelle, 1970, Schweizer et al., 2003). Both fracture processes can be described and understood by the theory of fracture mechanics. Thus, the corresponding material characteristics such

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as the fracture toughness in Mode I and Mode II have to be known (McClung, 1981). They are essential to well-founded and reliable slab release models.

The available data on fracture toughness of snow are still relatively few (Kirchner et al., 2000; Kirchner et al., 2002a,b; Faillettaz et al., 2002; and Schweizer et al., 2004). In all previous studies cantilever beam tests were used to determine fracture toughness. Assuming linear elastic fracture mechanics (LEFM) to be applicable, they obtained K_{Ic} values ranging from 0.1 to 1.5 kPa $m^{1/2}$, depending on snow type and density. However, Schweizer et al. (2004) pointed out that the standard size requirements for LEFM were not fulfilled for the specimens used (20 × 50 × 10 cm), which makes the application of the test results to snow slope stability models questionable.

Bazant et al. (2003) related fracture toughness to the avalanche release process by taking a size effect into account. They formulated a size effect law based on equivalent linear elastic fracture mechanics and found that fracture toughness in shear is approximately proportional to the thickness of the overlaying slab to the power of 1.8. Dempsey et al. (1999a,b) tested sea ice over a very large sample range from 0.1 up to 100 m and confirmed Bazant's empirical size effect law (Bazant and Planas, 1998) to be valid even over this large range. They calibrated the size effect law with experiments between 0.1 and 3 m and were then able to predict correct toughness values up to a size of 100 m.

The present paper introduces a new test method and reports on a preliminary study on the size and shape dependence of snow fracture toughness and on possibilities for corresponding corrections. The final aim is to extrapolate laboratory toughness data to the snow slab avalanche scale. For this purpose four different specimen sizes and three different specimen geometries were used: two types of cantilever beam tests with different protrusion, and a three-point bending test. Furthermore, attempts were made to estimate the size of the nonlinear fracture process zone.

However, regarding the variety of influencing parameters, the presented experimental data are not yet statistically sound. They have to be considered as preliminary and need to be confirmed by further tests.

2. Experimental methods

2.1. Three-point bending test

Three-point bending tests (3PB-tests) were performed on snow samples of naturally deposited snow with a standard testing apparatus (Fig. 1). The specimens were cut out of the snowpack in the surroundings of Davos (Switzerland) with beam-shaped aluminium cases. The density of the snow samples ranged from 140 to 380 kg/m^3. Four different sizes of cases were used (Table 1). The largest snow case was close to the limit of what can be handled in the field and transported to the laboratory without destroying the natural snow structure. The other sizes were chosen such that a size range of 1 : 4 was achieved and included the one used by Schweizer et al. (2004) (20 × 50 × 10 cm). The thickness w was the same for all specimen sizes in order to avoid a possible thickness effect ("2D similarity", according to Bazant and Planas (1998)).

All experiments were performed in the SLF cold laboratories at Weissfluhjoch and Davos (Switzerland) at temperatures between −7 and −15 °C in a standard material testing apparatus which is designed to measure compressive or tensile forces up to 20 kN with a resolution of 0.1 N. The snow specimens were supported by two aluminium cylinders with a diameter of 6 cm separated by a span s (Fig. 2a). Into the central cross section, a sharp cut of variable length a was introduced from below with a thin metal saw blade. The load was applied in

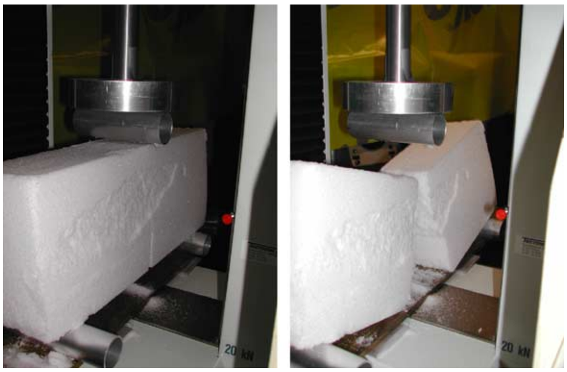

Fig. 1. Three-point bending setup before and after cracking. Snow specimen dimension: 20× 50 × 10 cm.