Preliminary Results Controlled Shear Experiments

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ABSTRACT.
Snow samples (115 mm in diameter, 16-18 mm in height) were taken from the field and shortly afterwards tested in a cold laboratory using a direct simple shear apparatus of Norwegian manufacture. The effects of strain rate and temperature on snow strength, stiffness and toughness were studied. The transition from ductile to brittle behaviour was found to be at a strain rate between 10^{-4} and 10^{-3} s^{-1} for the snow types and temperatures tested. Stiffness up to peak stress proved to be highly temperature dependent. Toughness is also significantly temperature dependent, while snow strength seems to depend only slightly on temperature. The dependence of the shear strength on temperature seems partly hidden by the scatter in strength data due to variations inherent in sampling and testing.

INTRODUCTION

The behaviour of snow under shear is believed to be one of the most important factors for describing slab avalanche formation and assessing the snow stability. Although most previous controlled shear experiments were done using slow displacement rates, field tests of snow strength or slab stability such as the rutschblock test involve rapid but less controlled loading and strain rates. Previous testing in shear under laboratory conditions was done by Ballard et al. (1965), McClung (1977) and Fukuzawa (1993). Some field studies: Roch (1966), Perla (1977), Föhn (1987) and Jamieson (1995). Recently Föhn and Camponovo (1996) have tried to measure shear strength in situ under controlled conditions.

METHODS

Tests were performed with a Norwegian type direct simple shear apparatus in the cold laboratory at Rogers Pass, Glacier National Park (British Columbia, Canada) (Fig. 1). The effects of shearing rate and temperature were studied. In particular, to establish the ductile to brittle transition, rapid tests at strain rate larger than 10^{-4} s^{-1} were performed.

Specimens (115 mm in diameter, 16-18 mm in height) were taken from relatively homogeneous layers of fine grained snow with densities between 220 and 340 kg/m^3, and hand hardness index: 3 (1 finger) to 4 (pencil). These were tested at -5, -10 and -15 °C for six different displacement rates: about 0.0073 mm/min, 0.074 mm/min, 0.17 mm/min, 0.29 mm/min, 0.50 mm/min, and 4.2 mm/min. For each of the displacement rates and temperatures about 5 tests were performed, resulting in a total of about 90 tests. Typically, samples were tested at a certain displacement rate on three consecutive days at the three temperatures. Accordingly, samples were stored typically between 1 and 5 days. This procedure may have slightly affected the results due to ongoing age-hardening.

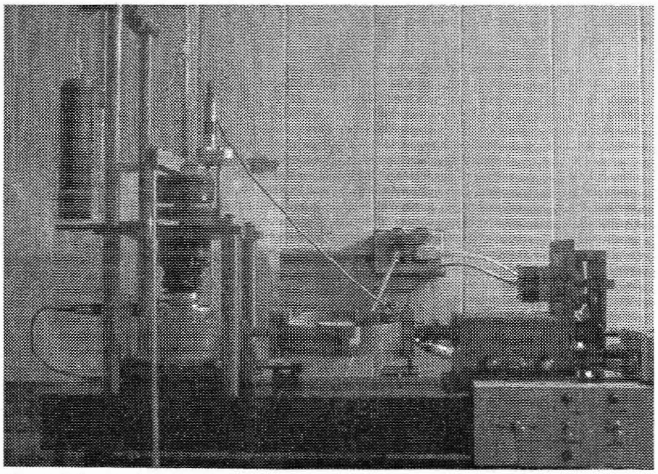

Fig. 1 Direct simple shear apparatus.

The normal force applied was 4.9 N, which corresponds to a stress of 470 Pa, and was kept constant during all experiments. During the tests horizontal and vertical displacements, and the applied horizontal (shear) force were measured and recorded. Due to hard-/software limitations the maximum possible scan frequency was only 10 Hz, which proved to be insufficient for the most rapid displacement rates (strain rates between 10^{-3} and 10^{-2} s^{-1}), so the number of measurements is generally too small to establish a reliable stress-strain curve.

The shear strength (failure or peak stress) is defined as the maximum stress, the peak, on the stress-strain curve. The initial slope of the stress-strain curve is called stiffness, and represents initial resistance to shear deformation. Stiffness as given below is the slope of the secant intersecting the stress-strain curve at 80% of the peak stress.

Strain rates, calculated from the time-displacement (or strain) curve, are typically not constant during the tests, since horizontal displacement (and accordingly strain) does not increase linearly with time. The strain rates given in the following sections are mean values calculated from the deformation at failure, the time to failure and the sample thickness.

RESULTS

Effect of strain rate

Typical stress strain-curves for three different strain rates are shown in Fig. 2. Curve (a) shows the response of the stressed snow sample for a strain rate of $6.1 = 10^{-5}$ s^{-1}; test duration was 80 min. The curve shows typical strain softening behaviour with a ductile type of failure characterized by large deformation and high toughness or energy absorption capability as evidenced by the area under the stress-strain curve. Curve (b) is typical for the tests performed with strain rates of about 10^{-4} s^{-1} and is believed

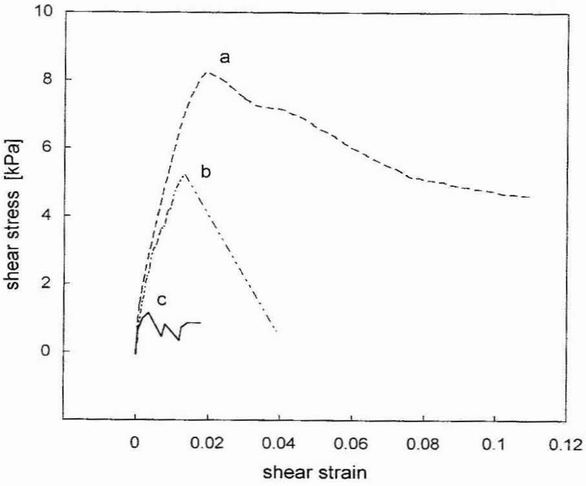

Fig. 2 Example of stress-strain curves for three different strain rates, (a): 6.1×10^{-5} s^{-1}, (b): 2.7×10^{-4} s^{-1}, (c): 2.3×10^{-3} s^{-1}; test temperature: -15°C.

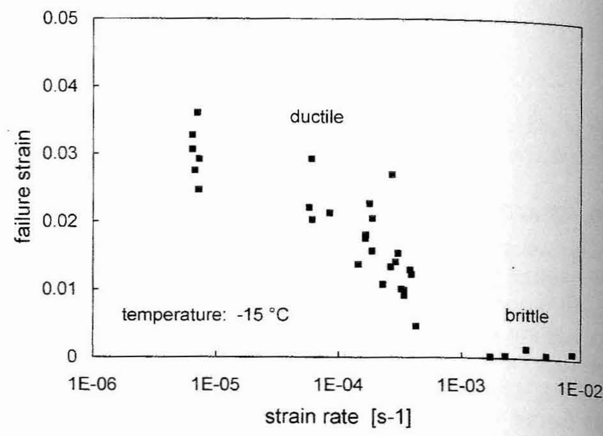

Fig. 3 Failure strain vs. strain rate; test temperature: -15 °C.

to be typical for the intermediate range between the purely ductile and brittle behaviour. The curve shows that ductile failures, causing microstructural damage, are going on, but the sample finally fails catastrophically after a certain amount of deformation. The test duration is typically about 20 s. Curve (c) shows the result of a fast test (strain rate: 2.3×10^{-4} s^{-1}). The type of failure is brittle; the sample breaks after very little deformation within fractions of seconds and exhibits minimal toughness.

The strain to failure decreases with increasing strain rate in the ductile range and seems to be independent of testing rate in the brittle range (Fig. 3). The ductile-brittle transition is at about 5×10^{-4} s^{-1}. Typical values for the failure strain are 1 to 3 % in the ductile range, and 0.05 to 0.1% in the brittle range.

Temperature effect

The temperature effect (Fig. 4) indicates substantially increasing stiffness and slightly increasing strength for decreasing temperature. The change in critical strain is not typical, since the analysis of all data suggests that the failure strain is not temperature dependent. Preliminary analysis (N = 46) shows that the stiffness increases about 60% when the temperature decreases from -5 to -15 °C. The shear strength increases about 20% when the temperature decreases from -5 to -15 °C. Although the correlation is significant (N = 46, R = 0.62, p = 0.015), the increase in strength is of the same order of magnitude as the scatter in the strength data due to the nonuniformity of the samples (S.E. 23%).

DISCUSSION

Generally, the results may be only valid for the snow type and the test equipment used. However, the typical behavioral trends for snow, known from other laboratory test experiments (e.g. Narita, 1980; Fukuzawa and Narita, 1993), were observed: in particular the rate dependence, the type of mechanical behaviour and the ductile-brittle transition, over test durations from tenths of a second to several hours. Stress-strain curves in the brittle range are similar to the ones in-situ measured by Föhn and Camponovo (1996).

The tests give some idea of the effect of temperature on some important mechanical properties. The preliminary results show a strong increase in snow stiffness and a slight, but significant, increase in snow strength with decreasing test temperature. The larger stiffness at colder temperatures suggests smaller deformations, and consequently the release probability decreases which is consistent with explanations of slab avalanche formation reported in detail by McClung (1996) and summarized by McClung and Schweizer (1996).

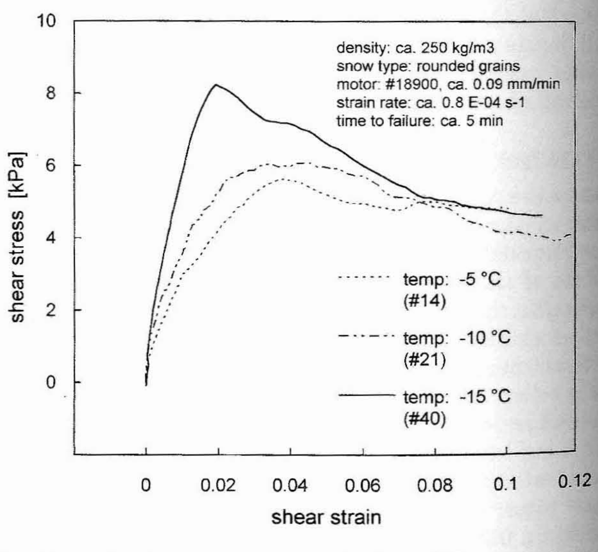

Fig. 4 Example of stress-strain curves for three different test temperatures: -5, -10, and -15 °C. Snow stiffness in these examples is about 200, 300 and 600 MPa, for -5, -10, and -15 °C, respectively.

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