An Experimental Study on the Mechanical Behavior of a Depth Hoar Layer under Shear Stress

—— preliminary report ——

Takuya FUKUZAWA and Hideki NARITA

Institute of Low Temperature Science
Hokkaido University, Sapporo, 060, Japan

ABSTRACT

Simple shear experiments were carried out to understand the mechanical behavior of a depth hoar layer at various shear strain rates of 10^{-5} s^{-1} to 10^{-3} s^{-1} at temperature of −6 °C. Ductile deformation took place in the layer at the shear strain rate lower than 8 x 10^{-5} s^{-1} and typical brittle fracture took place at the shear strain rate higher than 2 x 10^{-4} s^{-1}. The critical shear strain rate for the ductile–brittle transition was considered to be between these values. Shear strength increased with increasing shear strain rate within the ductile deformation region and took the peak value at the critical shear strain rate for the ductile–brittle transition. Experimental result indicated that a natural slab avalanche does not occur in the absence of super–weak zone in the weak layer dealt in this study.

INTRODUCTION

Field observations after released dry slab avalanches indicate the situation that a thin weak layer (sliding layer) underlies harder snow slab. The weak layer often consists of characteristic particles which are depth hoar crystals, surface hoar crystals, plate–like precipitation crystals without rime deposited horizontally or graupels. Even if it seems in site observation that a slab has slided on another slab below, thin section studies quite often indicate that there is a very thin weak layer between two layers.

A slab avalanche is the phenomenon that the low strain rate in the sliding layer transits to high strain rate, generating the shear fracture. To clarify the avalanche initiation mechanism, therefore, it is important to understand the mechanical properties of the weak layer under shear stress with various shear strain rates. This paper gives the procedure for shear experiments of depth hoar layers and also gives the preliminary result of the shear strength depending on strain rate, concerning with the failure mode.

EXPERIMENTAL PROCEDURE

Snow specimen

The snow specimen for the series of experiment is shown in figure 1, in the dimensions of 15 x 10 x 2.5 cm in width, height and thickness, respectively. It was prepared by cutting the sample block of three layer structure, middle layer of depth hoar crystals in class 5a (Colbeck et al., 1990) whose density was 170 to 190 kg/m^3 and thickness was about 2 cm, top and bottom layers of fine grains in class 3a whose density was 360 to 390 kg/m^3. This sample block was produced artificially in following way. At first, two layer structure snow that low density snow with use of an ice slicer overlies high density layer, was subjected to high temperature gradient of 250 K/m for 90 hours at the average temperature in the upper layer of −6 °C. This results in the quick growth of depth hoar crystals in the upper layer. Secondly, crushed fine grains were precipitated on the layer of depth hoar crystals using the ice slicer to have sample block of three layer structure. This sample block was left at −6.0 °C for 35 to 40 days in order to make easy to handle it.

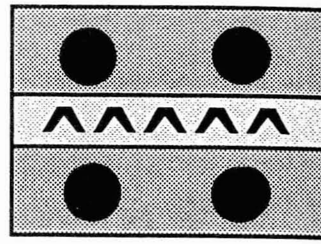

Fig.1. Snow specimen for shear experiment. Symbols follow Colbeck and 7 others (1990).

Method of simple shear experiment

Simple shear experiment of snow specimen described above was carried out at various strain rates of 8×10^{-6} to 2×10^{-3} s^{-1} at temperature of −6 °C.
The instrument used for the simple shear experiment is shown in figure 2. The specimen was fixed to aluminum bars with freezing method and was monitored video camera. One of the bars (2−2) was mounted on the instrument and another bar (2−1) was displaced at a constant speed in the direction of arrow in order to have simple shear deformation in the snow specimen. By shifting the gear of a decelerator (4) the displacement speed was adjustable. The strain was calculated from the distortion of each grid which was marked on the specimen at every 2 cm interval. The shear force was continuously recorded. The temperature was maintained at −6.0 °C within 0.5 °C.

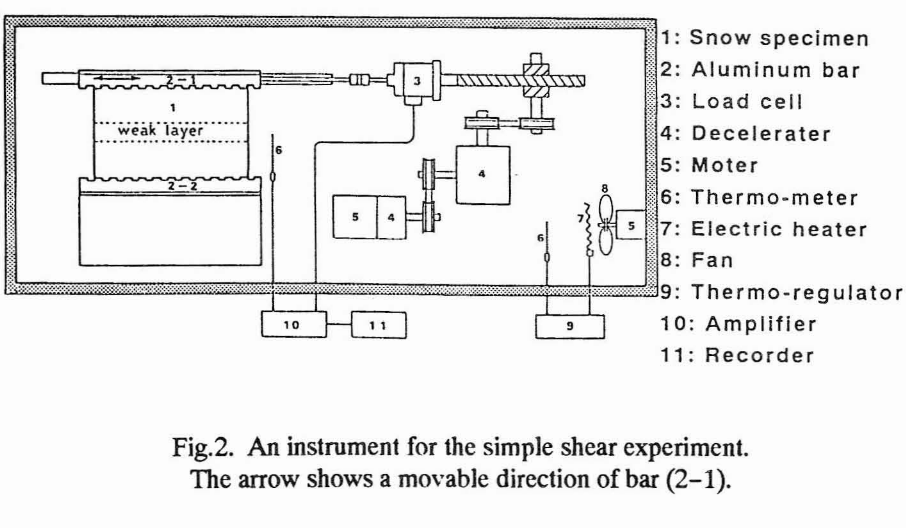

Fig.2. An instrument for the simple shear experiment.
The arrow shows a movable direction of bar (2−1).

RESULTS and DISCUSSION

The deformation and the failure took place preferentially in the depth hoar layer compared with other layers. The shear strain rate in the depth hoar layer was one order grater than those in other layers and it was one to two orders grater than the vertical strain rate in the depth hoar layer. This indicates that the depth hoar layer was under fairly simple shear stress.

The typical shear stress – strain curves are shown in figure 3. When depth hoar layer behaved in brittle manner at high strain rate, the shear stress increased linearly with increasing strain and decreased suddenly with the rupture. On the other hand, at low strain rate, depth hoar layer behaved in ductile manner. The shear stress increased gradually beyond the yield stress and small cracks began to appear in the depth hoar layer revealing the strain hardening. The shear strain and the shear stress where visual small cracks appear are defined here as *the fracture strain* and *the fracture stress*. After the shear stress took peak (*hardening limit*) stress, it began to decrease gradually, enlarging the crack size and increasing its population.

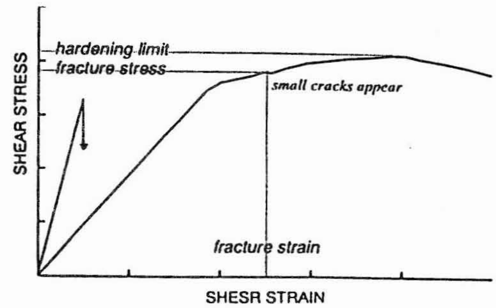

Fig.3. Typical stress–strain curves.

Figure 4 shows typical ductile deformation pattern. Compared with initial specimen (fig. 4a), several small cracks are recognized in figure 4(b) at the fracture strain. In figures 4(c) and 4(d) at hardening limit, enlargement of cracks and increasing of their population are observed. Small cracks did not appear homogeneously and, relatively speaking, larger crack tended to enlarged. These are attributed to the stress concentration.

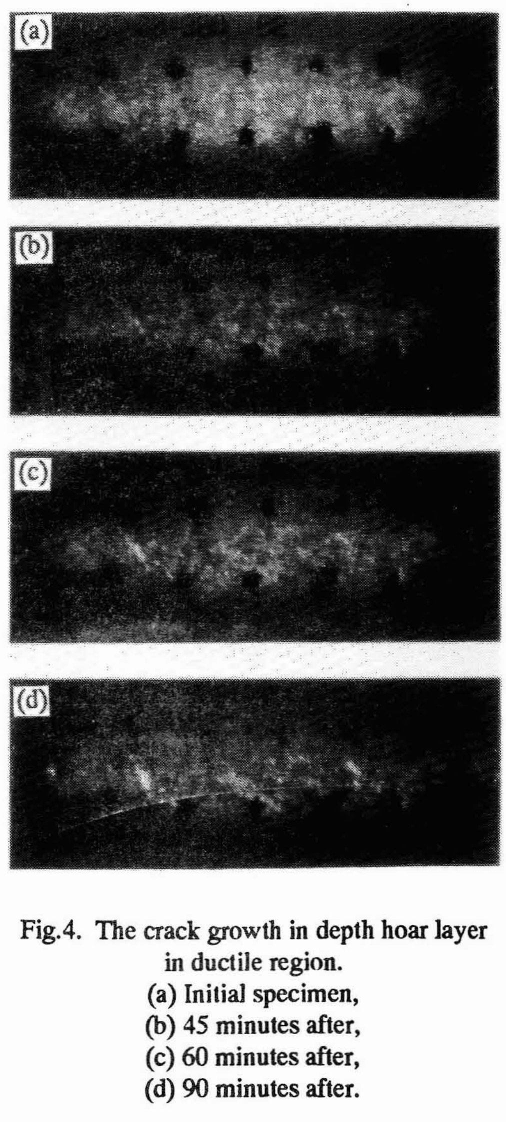

Fig.4. The crack growth in depth hoar layer in ductile region.
(a) Initial specimen,
(b) 45 minutes after,
(c) 60 minutes after,
(d) 90 minutes after.

The ductile deformation and the brittle fracture zones were grouped in figure 5. At low shear strain rate less than 8×10^{-5} s^{-1} ductile deformation takes place as shown in figure 4. On the other hand, brittle fracture takes place at high shear strain rate more than 2×10^{-4} s^{-1}. Between these two shear strain rates, stress – strain curve showed intermediate pattern which has small peak stress with higher hardening limit stress. Although this region might corresponds to the region of "cycles of brittle fracture" reported by montmollen (1982), cycles of brittle fracture were not observed in this experiment. From this result it is considered that the critical strain rate of ductile – brittle transition is between 8×10^{-5} and 2×10^{-4} s^{-1} (hatched area in figure 5).

The dependency of the shear strength and the fracture strain on the shear strain rate are also shown in figure 5. The fracture strain (symbolized in open square) decreases with increasing strain rate in ductile region and it takes constant value of 0.025 % at higher strain rate than the critical strain rate. Solid circle and dash indicate the fracture stress and the hardening limit stress, respectively. The fracture stress slightly increases with increasing strain rate in ductile region and decreases in transitional zone and slightly decreases in brittle region. The hardening limit stress increases with strain rate in ductile region and takes maximum values around critical strain rate. In brittle region any strain hardening does not occur but the softening takes place after the failure. The values of peak shear stress i.e. the shear strength are in the same order with the peak stress obtained by McClung(1977). If the concept of stress concentration is not accepted, these strengths correspond to the shear stress due to 5 to 13 m of wind packed snow assuming the inclination of 45° and the density of 200 kg/m^3.

The maximum shear strength appears at the critical strain rate in figure 5. If the concentrated stress which applied to the end of "a super–weak zone" (Bader and Salm, 1990) exceeds this maximum strength, the local shear strain rate will become higher. This results in the brittle fracture at the end of a super–weak zone promoting a natural slab avalanche release. When higher strain rate than the critical one is forced, e.g. by a skier, brittle fracture takes place with lower shear stress.

The shear strength and the critical strain rate of the layer of small rounded particles in class 3a with the density of 260 to 290 kg/m^3 were, respectively, 6 x 10^4 Pa and 6.5 x 10^{-4} s^{-1} (Narita et al., in press). They largely depend on the stage of metamorphism of snow crystals in a weak layer. Therefore, extensive experiments are necessary to understand sufficiently the mechanical property of weak layers, coupling with the concept of the super–weak zone and stress concentration.

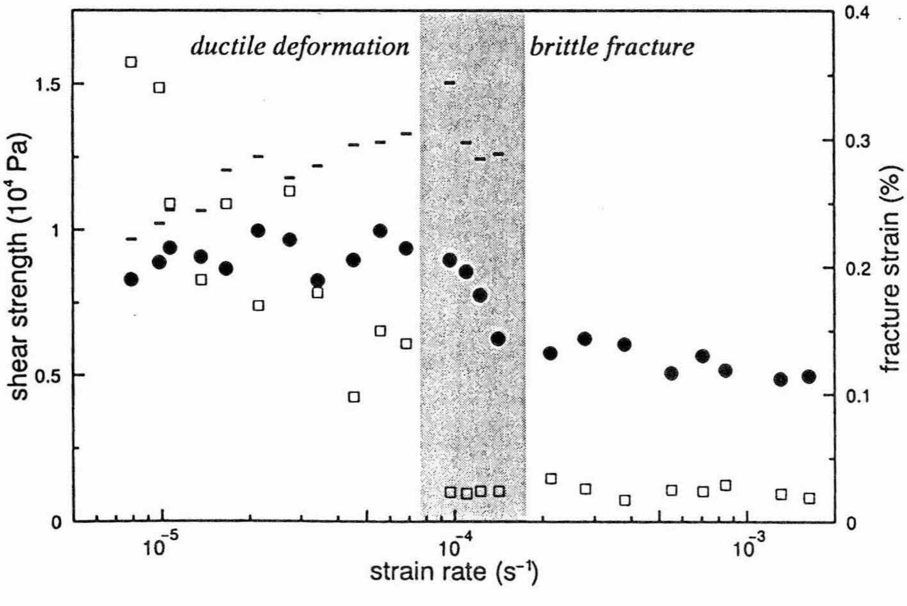

Fig.5. Strain–rate dependency of fracture strain (□), fracture stress (●) and hardening limit stress (–).

CONCLUSION

Simple shear experiments of a depth hoar layer showed that the ductile deformation with strain hardening took place at lower strain rate than the critical strain rate of approximate 1 x 10^{-4} and the brittle fracture took place at higher strain rate. The maximum shear strength appeared at the critical strain rate of ductile - brittle transition. It was considered that a natural slab avalanche is promoted when the local shear stress at the end of a super-weak zone becomes grater than the maximum strength. Extensive experiments on the mechanical behavior of various weak layers are expected because of dependency of the shear strength and the critical strain rate on the stage of metamorphism.

Acknowledgement

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