DEVELOPMENT OF SURFACE HOAR PRODUCTION APPARATUSES USING A CIRCUIT WIND TUNNEL

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ABSTRACT: The surface hoar layer is known to be one of the most typical types of weak layers in dry slab avalanches. To investigate the features of snow cover, including the surface hoar layer, we developed apparatuses that make surface hoars artificially. Two growth systems were developed using circuit wind tunnels. The first apparatus supplied wind using a small circuit wind tunnel. A few millimeters of snow were placed on the cooling panel (0.12 m^2) to form the fundamental snow layer. A surface hoar was then grown on the snow surface using the temperature difference between the high water vapor air pressure and the cooled snow surface. The shapes of the artificially grown surface hoar crystals were plate, sector, dendrite, needle, column and cup. The average size of the large crystals was 14.5 mm. The circuit wind tunnel of the second apparatus was large. We set nine cooling panels and made a surface hoar on the fundamental snow cover. It was possible to make the snow surface of a surface hoar with an area of 1.08 m^2 with one experiment using this system. Three surface temperatures could be selected in a single experiment because the panels were cooled with coolant controlled by three different thermostatic baths. These systems are useful for investigating the features of snow and the surface hoar layer efficiently.

KEYWORDS: surface hoar, avalanche, weak layer, wind tunnel

1. INTRODUCTION

The surface hoar layer is known to be one of the most typical types of weak layers in dry slab avalanches. Schweizer and Jamieson (2000) investigated the weak layer of the skier-triggered avalanches in Switzerland and Canada. They reported that half of the weak layer consisted of a surface hoar. On the other hand, it is rare for a surface hoar to grow large enough causing slab avalanche in Japan, although surface hoars with crystal sizes smaller than 1 mm are often observed. Ozeki et al. (2018) reported the characteristics of a weak layer that caused major avalanche accidents from 2007 to 2017 in Hokkaido. Two-thirds of the weak layers consisted of faceted crystals and depth hoars. However, they did not find the weak layer of a surface hoar during this period. Accordingly, to investigate the features of snow cover, including the surface hoar layer, we developed apparatuses that make surface hoars artificially.

Surface hoar crystals form by the transfer of water vapor from the atmosphere to the snow surface. To grow surface hoar crystals, snow surface cooling, light wind, and high water vapor pressure are necessary conditions. Hachikubo and Akitaya (1997) indicated the ideal weather conditions for surface hoar growth: radiative cooling greater than 60 W/m^2, wind speed about 2-3 m/s, and relative humidity greater than 90 %. Slaugter et al. (2011) indicated that surface hoar growth depended on relative humidity, snow surface temperature, the temperature gradient between atmosphere and snow surface, wind speed, and downward longwave radiation. Surface cooling and high water vapor pressure cause a supersaturated condition at the snow surface. Additionally, the temperature gradient between atmosphere and snow surface forms a water vapor gradient, and wind promotes the transfer of water vapor.

In this study, we produced a surface hoar artificially, and investigated the shapes of the artificially grown surface hoar crystals and the size distribution.

2. METHODS

We developed surface hoar growth systems using a circuit wind tunnel for transfer of water vapor. To produce advection of high water vapor pressure, we referred to the Nakaya (1954) apparatus that was used to grow snow crystals artificially. A double-pipe cylinder was used to make vertical free convection, and a water supply was placed at the bottom of the cylinder. We set the water supply in the

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middle of the circuit wind tunnel. Water was kept at a preset temperature, which was set between 0 and 20 ºC, using an electric heater.

Cooling of the snow surface was important for maintaining suitable weather conditions for crystal growth. Stanton et al. (2012) mimicked the longwave energy loss at the snow surface using a cold ceiling (–50 ºC) on the climate chamber. On the other hand, we used a cooling panel under the fundamental snow layer instead of radiative cooling, consisting of a cooling pipe and an aluminum plate, with an area of 0.12 m^2 (0.3 m width × 0.4 m length). Ethyl alcohol, which was cooled by a thermostatic bath, was circulated into the cooling pipe during the measurements, and the panel was kept at a preset temperature.

2.1 Apparatus 1

Two growth systems were developed using circuit wind tunnels. The first apparatus supplied wind using a small circuit wind tunnel. A schematic view of the apparatus 1 used in this study is shown in Figure 1. The working section of the wind tunnel was 0.8 m, and both the height and width were 0.3 m.

A few millimeters of snow were placed on the cooling panel to form the fundamental snow layer. The air temperature in the cold room was –5 ºC, and the snow surface was cooled by the cooling panel to a preset temperature (>–35 ºC). Relative humidity at the center of the wind tunnel was greater than 90 %. The surface hoar was then grown on the snow surface using the temperature difference between the high water vapor air pressure and the cooled snow surface. The hoar growing period was about 20 hours.

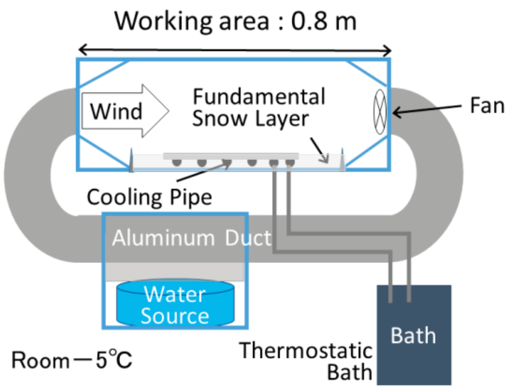

Figure 1 A schematic view of apparatus 1.

2.2 Apparatus 2

The circuit wind tunnel of the second apparatus was large (working section: 14 m). A schematic view of the apparatus 2 used in this study is shown in Figure 2a. We set nine cooling panels (or six cooling panels) and made a surface hoar on the fundamental snow cover (Figure 2b). It was possible to make the surface hoar with an area of 1.08 m^2 (or 0.72 m^2) with one experiment using this system. Three surface temperatures could be selected in a single experiment because the panels were cooled with coolant controlled by three different thermostatic baths. The snow surface was cooled by the cooling panel at preset temperatures (–35 ºC, –25 ºC). The air temperature in the cold room was –5 ºC, and the relative humidity at the center of the wind tunnel was about 90 %. The hoar growing period was about 16 hours.

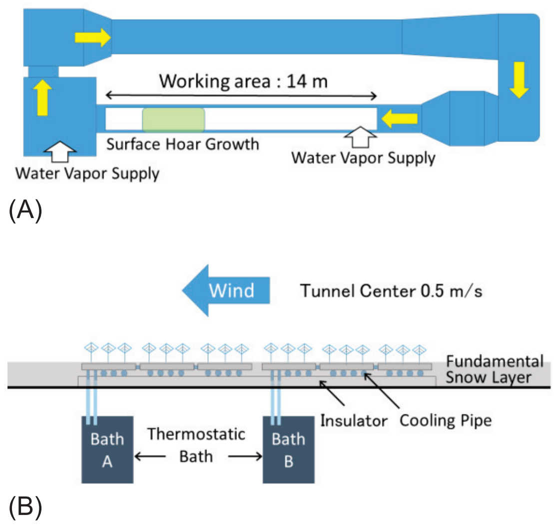

Figure 2 A schematic view of apparatus 2.
(A) Wind tunnel circuit, (B) Cooling plate area.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Crystal shape

The shapes of the artificially grown surface hoar crystals were plate, sector, dendrite, needle, column and cup. Plates and sectors were well observed crystals in this experiment (Figure 3), and are surface hoar crystals that often observed in nature.

Plates were observed to vary widely from a relatively high surface temperature to low surface temperature. Sectors were often found in the low surface temperature region, and were observed well where the surface temperature was about –30 ºC in this experiment, with central axis in the crystal, and growth like a fan. Plates exhibited similar shape as a fan. That is, the growth axis of the sector was offset by 30 degrees from the growth axis of the plate. Some of the large plates grew with multiple plates joined together (Figure 4).

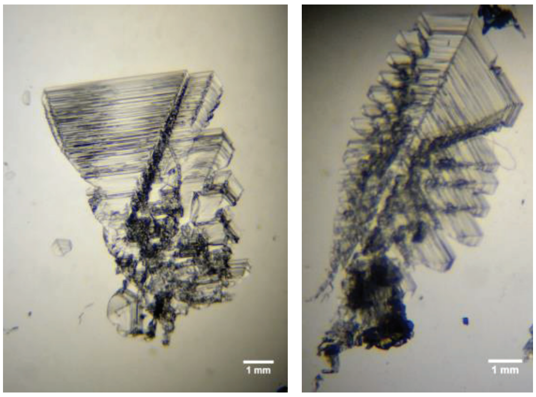

Figure 3 Artificial surface hoar crystals. Plate (left) and sector (right).

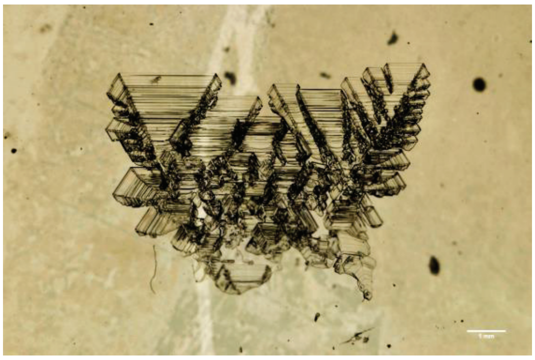

Figure 4 A large crystal consist of plates.

Both dendrites and needles were crystals that were produced under weak winds and high relative humidity conditions. The basic shape of the dendrite was the same as the sector; i.e., there was a central axis. However, dendrites had branches, and the shape of the branch was isomorphic to the central axis of the sector (Figure 5).

There were two kinds of needles. One was a crystal grown on the c-axis, and a column was also seen. The other one was a crystal, which contained only the central axis of the sector, and the fan spreading was poor (Figure 6). The latter was observed well in this experiment.

In this study, we used cooling panels instead of radiative cooling. To continue crystal growth, it is necessary to release the latent heat generated at the growth point. Radiative cooling plays its part in nature. However, the latent heat must be dissipated by thermal conduction through the surface hoar crystals in this experiment. It was feared that the effect of this cooling difference might reduce the growth speed of the crystal. However, it has become possible to grow large crystals exceeding 20 mm within 1 day by achieving a relative humidity of less than or greater than 100%. The average size of the large crystals was 14.5 mm. In addition, the shapes of the artificially grown surface hoar crystals were rich in variety, such as sector, plate, dendrite, and needle, which were similar to the shape in nature. Therefore, the method using the cooling plate is useful for artificially generating the surface hoar in the cold laboratory. By changing the relative humidity, it has become possible to adjust the growth from small crystals smaller than 2 mm to large crystals larger than 20 mm.

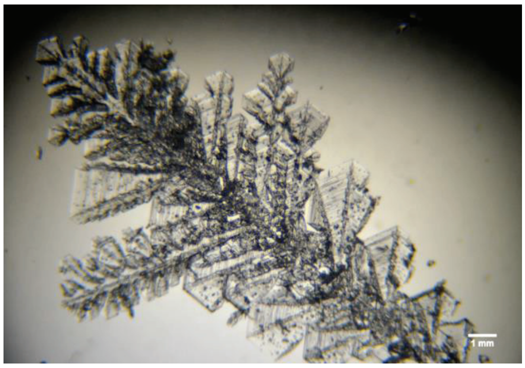

Figure 5 Dendritic type artificial surface hoar.

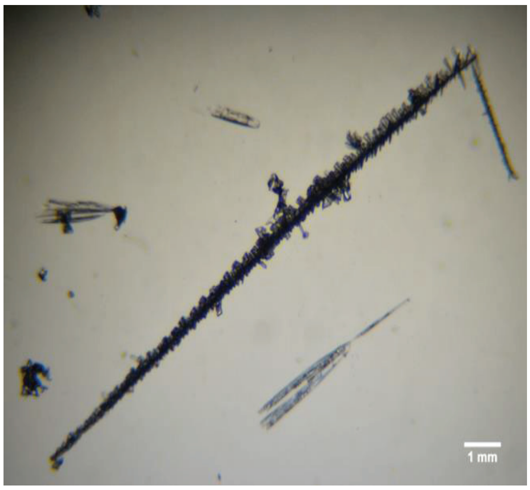

Figure 6 Needle type artificial surface hoar.

3.2 *Effect of wind speed*

Figure 7 shows the relationship between the crystal shape and the wind speed. First, vertical wind speed profiles in the wind tunnel were measured with a hot wire anemometer. Then, the wind speed of each experiment was measured at 10 cm above the snow surface, and extrapolated to 1 m wind speed using exponential curve fitting.

The plate type was generated at relatively high wind speed regions, about 1 m/s or more. The suitable wind speed for the sector type was lower than the wind for the plate, lower than 1 m/s. Both the dendritic and needle types were generated in the lowest wind speed regions, lower than 0.2 m/s. The cup shape was rare to generate. These were generated in calmer weather than dendrite and needle.

In this experiment, both dendrite and needle growth took place under the same conditions: plate temperature of –35 °C, room temperature of –5 °C, and wind speed of 0.1 m/s at 10 cm above the snow surface. However, there was a difference in the temperature of the water supply, which was 20 °C for the dendritic type and 10 °C for the needle type. In both experiments, the relative humidity was approximately 100%. However, considering the difference in the supply temperature of water, the supply of water (vapor and part as small water droplets) for the dendritic type might be more than the supply for the needle type.

4. CONCLUSIONS

In this study, the growth condition of the surface hoar was experimentally analyzed using an artificial surface hoar. We succeeded in growing a large surface hoar artificially by increasing the supply of water vapor. It was suggested that the crystal shape depended on snow surface temperature and wind condition. Both dendrite and needle shapes required extremely breezy conditions.

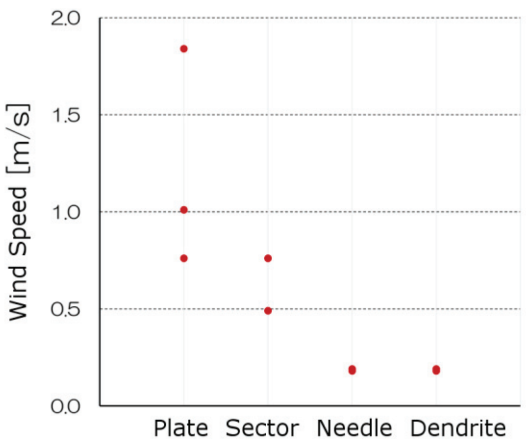

Figure 7 Dependence of crystal shape on wind speed.

These systems are useful for investigating the features of the surface hoar layer efficiently. In future work, we will investigate the difference in the shear strength of the weak layer, depending on the size and shape of the surface hoar using artificial surface hoar crystals.

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