STUDY ON SNOW TYPE QUANTIFICATION BY USING SPECIFIC SURFACE AREA AND INTRINSIC PERMEABILITY

Hayato Arakawa [1)2)], Kaoru Izumi [3)], Katsuhisa, Kawashima [3)], Toshiyuki Kawamura [4)]

(1) YAGAI-KAGAKU Co.,Ltd., Sapporo, Japan
(2) Graduate School of Science and Technology, Niigata University, Niigata, Japan
(3) Research Center for Natural Hazards and Disaster Recovery, Niigata University, Niigata, Japan
(4) Institute of Low Temperature Science, Hokkaido University, Sapporo, Japan

ABSTRACT: The release mechanism of snow avalanche depends on the mechanical property of snow, which is closely related to snow microstructure. The results of previous observations show that snow microstructure can be described qualitatively with snow types. However, the qualitative determination of the snow types may tend to become subjective. Therefore, quantitative classification of the snow is necessary. Measurements of the specific surface area per unit volume (SSA) and the intrinsic permeability (k_0), which are closely related to snow microstructure, were performed on the naturally deposited snow in Hokkaido, Japan. The parameter SSA was measured with stereological method, where section planes of snow samples were prepared, imaged and analyzed. The value of k_0 was measured in situ using the air permeameter with a double cylinder and was calculated to be assumed as laminar flow to follow Darcy's law. The results showed that the relationship between SSA and k_0 could clearly distinguish the snow types and estimate the metamorphic processes which occur in the snow cover.

KEYWORDS: snow type, permeability, specific surface area

1. INTRODUCTION

"The International Classification for Seasonal Snow on the Ground (Colbeck et al., 1990)" is now well accepted by most snow scientists and practitioners around the world (Fierz et al., 2008). The classification describes snow type by "words" based on "the shape" of snow particle and does not define snow type quantitatively. If a quantitative classification of the snow is established, a determination of the snow types may become objective. For example, in order to determine snow type, Lehning et al. (2002) introduced dendricity and sphericity as the index parameters into the their snow model. They are calculated from the value and the duration of temperature gradient in the snow layer. We think that geometric properties of them is not clear. Since snow scientists and practitioners determine snow type from the observation of "the shape" of snow particles, it is convenient that snow types are determined by parameters reflected the geometric character.

In this study, we propose a method of snow types quantification by using specific surface area and intrinsic permeability reflecting snow microstructure.

2 METHODS

2.1 Combination of SSA and permeability

A specific surface area (SSA) is surface area of grains, which constitute porous medium. Two kinds of the SSA are defined. One is a SSA per unit volume (SSAV ; $m^2\ m^{-3}$), and the other is a SSA per unit mass (SSAM ; $m^2\ kg^{-1}$). SSAM is obtained by dividing SSAV by snow density as follows;

$$SSAM = \frac{SSAV}{\rho}. \qquad (1)$$

The value of SSAV shows only area size, while the value of SSAM indicates snow microstructure. The increment of the SSAM expresses two geometric characters; (1) the shape of the particle becomes more complex like dendrite or skeleton crystal, or (2) the size of the particle become smaller and the number of the

* *Corresponding author address:* Hayato Arakawa, YAGAI-KAGAKU Co.Ltd., 12-2-39, Naebo-cho, Higashi, Sapporo, Hokkaido, 065-0043, Japan;
tel: +81-11-751-5152; fax: +81-11-748-3618;
email: h.arakawa@yagai.co.jp

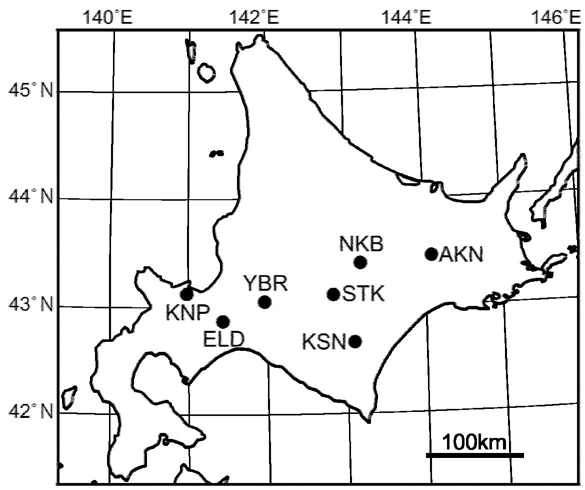

Figure 1: Study sites of permeability measurement and snow sampling for section planes.

particle per unit volume increases. The decrement of the SSAM expresses otherwise.

The intrinsic permeability (or permeability) is a parameter reflecting features of pore space (porosity), which are porosity, individual pore sizes and curvature. The higher the value, the faster the fluid can pass.

We think that combination of the SSAM and the permeability is useful for a determination of snow type, since the characteristics of grains and pores vary one snow type to another.

2.1 Study sites

Permeability measurement and snow sampling were carried out at seven sites ,where are Lake Eniwa dam site (ELD), Akan Lake side (AKN), Nukabira (NKB), Kamisatsunai (KSN), Shintoku (STK), Yubari (YBR) and Kenashi Pass (KNP), in Hokkaido, Japan, during the winter of 2007-2008 (Figure 1).

Observations were done once a week at ELD and once a month at AKN, while the others just once in the season. Various kinds of naturally deposited snow were measured and sampled. Especially, compacted snow was dominant in KNP and YBR, while in the other sites depth hoar and faceted particle were principally verified. All snow types observed were dry.

2.2 Intrinsic permeability

Permeability, k_0, is a proportional constant relating with the pressure gradient to the laminar flow rate through a porous medium via Darcy's law:

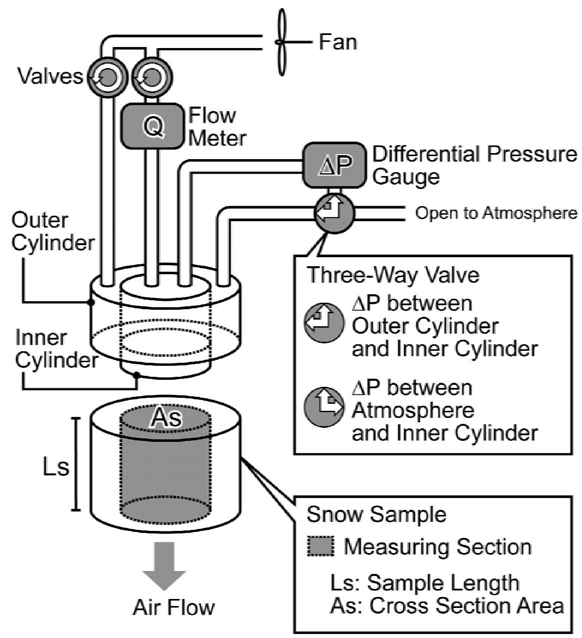

Figure 2: Schematic of the air permeameter with a double cylinder.

$$\frac{Q}{A_s} = \frac{k_0}{\mu}\frac{\Delta P}{L_s}, \qquad (2)$$

where Q is the volumetric discharge ($m^3\ s^{-1}$), A_s is the cross area (m^2), μ is the dynamic viscosity of fluid ($kg\ m^{-1}\ s^{-1}$), ΔP is the differential pressure (Pa), L_s is the length of the sample. In order to measure the intrinsic permeability, the double-cylinder design is required because Darcy's law assumes parallel, laminar flow (Shimizu, 1970). A schematic illustration of the measuring device is shown in Figure 2. The air permeameter was reduced to one differential pressure gauge and added to one three-way valve. It became a lighter and more economical device. The three-way valve can switch between two kinds of differential pressure; (1) ΔP between the inner cylinder and the outer cylinder, and (2) ΔP between the inner cylinder and the atmosphere.

2.3 Specific surface area

Specific surface area (SSA) was measured with stereological method (Narita, 1969), where section planes of snow samples were prepared, imaged and analyzed.

The technique for preparing section planes of snow dyed with Sudan Black B ($C_{29}H_{24}N_6$), which is oil-soluble stain, are similar to that by Hachikubo et al.(2000). The pore space of snow sample is filled with supercooled Dimethyl phthalate ($C_6H_4(COOCH_3)_2$). The thin section is microtomed. The filler is dyed with Sudan Black B. Perla and Dozier (1984) proposed to obtain optimum contrast using incident reflected light when taking pictures. However, we used transmitted light. It reduced shine and/or shade of surface of section plane. Surface of section plane become darker in the pore space, and more brightly and more whitely in the grains. Then, the more high-contrast photographs of section plane can be taken. The photographs are loaded onto the computer, denoised and then converted to the binary images.

The binary images are used for analyzed SSA per unit volume (SSAV). Figure 3 shows the stereological method to calculate the SSAV. When parallel test lines were drawn at even intervals on the image, SSAV is expressed by

$$SSAV = \frac{2N}{L}, \qquad (3)$$

where N is the total number of intersections of the test lines and the boundaries of snow particle, and L is the total real distance of the test lines. Let the real distance of the test line be l (m) and the number of the test line be m (lines), $L = m\, l$ (m). In this paper, for examining the snow type classification , we used SSAM that was calculated by using Equation (1); SSAV was obtained by Equation (3) and snow density was measured in situ.

3. RESULTS AND DISCUSSIONS

3.1 Density and parameters reflecting structure

Figure 4 shows correlations between snow density and (a) SSAM and (b) k_0 for various snow types. When the multiple snow types were observed in one layer, the multiple symbols are plotted on the same point in Figure 4. Both parameters reflecting microstrucre have a decreasing tendency with an increase in snow density, but it can be seen that the data vary widely for the same and/or the different snow types. That is to say, it is considered that both parameters can not defined uniquely using only snow density.

3.2 Correlation of SSAM and permeability

Figure 5 is a correlation between SSAM

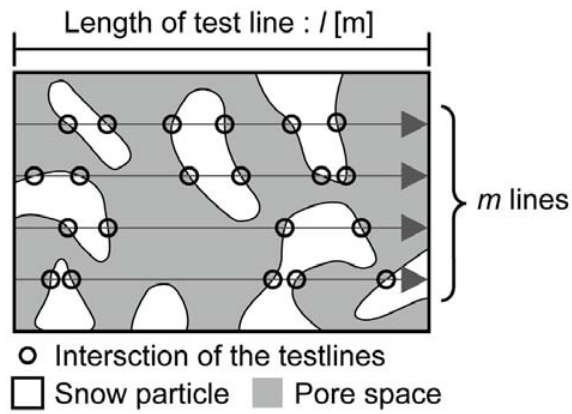

Figure 3: Stereological method for specific surface area per unit volume.

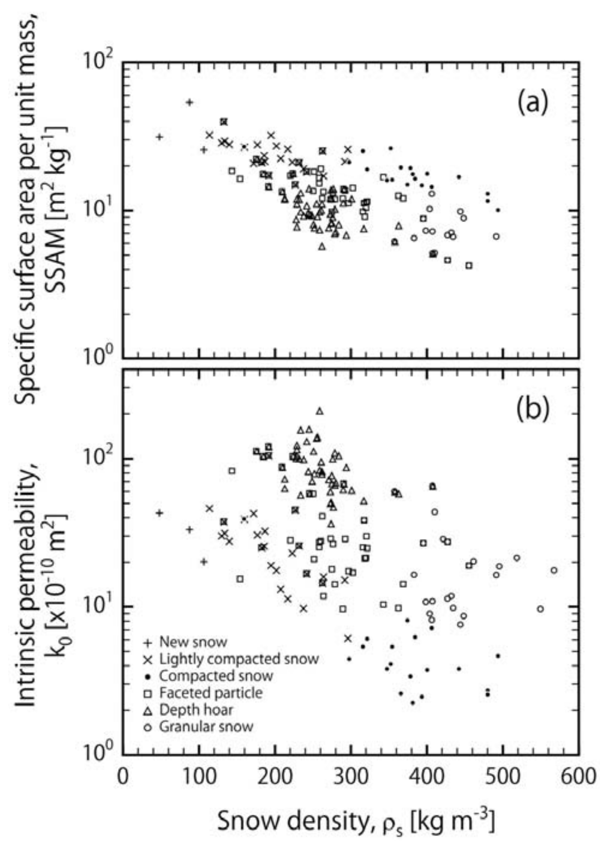

Figure 4: Correlations between snow density and (a) specific surface area per unit mass and (b) intrinsic permeability for various snow types.

and intrinsic permeability for the different of snow types. Regions of the equi-temperature metamorphism (R_e), the temperature gradient metamorphism (R_g) and the melt-refreezing metamorphism (R_m) can be divided by solid lines. Further, the regions of R_e and R_g can be divided into the sub-regions of R_{e1} (New snow and lightly compacted snow), R_{e2} (compacted snow), R_{g1} (depth hoar), R_{g2} (faceted particle) and R_{g3} (mixed layer of depth hoar and faceted particle) by three dash lines.

3.3 Metamorphism of snow and change of SSAM and permeability

Table 1 shows change of snow density, SSAM, permeability and snow type. We could confirm two kinds of metamorphism for total six cases.

Table 1(a) shows the process of the temperature gradient metamorphism confirmed by tracing certain two layers of A3 and A4. A3 shows the faceted particle growth from lightly compacted snow and A4 shows change of depth hoar itself. In

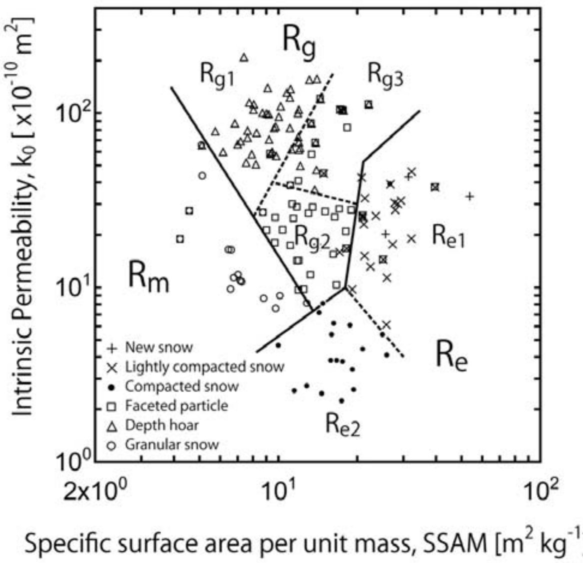

Figure 5: Correlation between SSAM and k_0 for the different of snow types.

Table 1: Change of density, SSAM and permeability by temperature gradient metamorphism and melt-refreezing metamorphism. Snow Type: LC, lightly compacted snow, FP, faceted particle, DH, depth hoar and GP, granular particle.

(a) Temperature gradient metamorphism

Site	Layer No.	Date	Density kg m^{-3}	SSAM m^2 kg^{-1}	k_0 x10^{-10} m^2	Snow Type
AKN	A3	29 Jan 2008	187	21.5	32.4	LC
		21 Feb 2008	227	15.0	44.9	LC and FP
		10 Mar 2008	251	13.5	57.7	FP
AKN	A4	29 Jan 2008	277	12.1	49.7	DH
		21 Feb 2008	277	9.5	59.9	DH
		10 Mar 2008	256	9.1	139.3	DH

(b) Melt-refreezing metamorphism

Site	Layer No.	Date	Density kg m^{-3}	SSAM m^2 kg^{-1}	k_0 x10^{-10} m^2	Snow Type
ELD	E3	09 Mar 2008	363	7.9	57.9	FP
		16 Mar 2008	358	6.1	57..8	FP and GP
ELD	E4	09 Mar 2008	321	11.3	29.9	DH
		16 Mar 2008	428	4.1	27.3	GP (and DH)
ELD	E7	09 Mar 2008	321	11.3	29.9	FP
		16 Mar 2008	396	8.8	26.7	FP and GR
ELD	E8	09 Mar 2008	261	19.0	27.7	FP
		16 Mar 2008	456	4.2	18.8	GR

the two cases, the value of SSAM decreased and the value of permeability increased, i.e. upward and leftward shift as shown in Figure 6. This means that the grain size and the pore size became larger. The result of the shift suggests that the snow particle grew under the temperature gradient metamorphism.

Table 1(b) shows melt-refreezing metamorphism confirmed by tracing certain four layers during the early snowmelt season from 9 March to 16 March. Permeability measurement and snow sampling were done for refreezing granular snow. In all cases, the value of SSAM decreased and the value of permeability changed little, i.e. leftward shift as shown in Figure 6. This means that the grain size and became larger. The result of the shift implies the snow particles grew under the melt-refreezing metamorphism.

3.4 *Process of equi-temperature metamorphism*

There is a physical process that we could not confirm, e.g. the equi-temperature metamorphism. In the process of the equi-temperature metamorphism, the downward and leftward shift will be assumed as shown by R_{e1} and R_{e2} in Figure 5 or Figure 6. We think that the process of the equi-temperature metamorphism involves the densification process. In the process of the equi-temperature metamorphism without the densification process, since the shape of the particle becomes rounded, the value of SSAM will diminish and then only leftward shift in the scatter plot may be indicated, which looks like the shift of the process of the melt-refreezing metamorphism. since snow density will became enlarge in the densification process, permeability and SSAM will get smaller and downward shift in the scatter plot may be indicated. Accordingly, in the process of the equi-temperature metamorphism with the densification process, downward and leftward shift in the scatter plot may be indicated and be distinguished from the melt-refreezing metamorphism. However, the examination of this processes is an issue to be resolved in the future.

4.CONCLUSIONS

We presented a method of snow type quantification by using SSAM and permeability by this and could clearly distinguish the snow types. Besides, we cloud show to correlate change of SSAM and permeability with two processes of the temperature gradient metamorphism and the melt-refreezing metamorphism. The shifts accompanied by metamorphism in the scatter plot show as follows; (1) the temperature gradient metamorphism, upward and leftward shift, (2) the melt-refreezing metamorphism, leftward shift. The equi-temperature metamorphism with the densification is believed to show downward and leftward shift in the scatter plot, because the shape

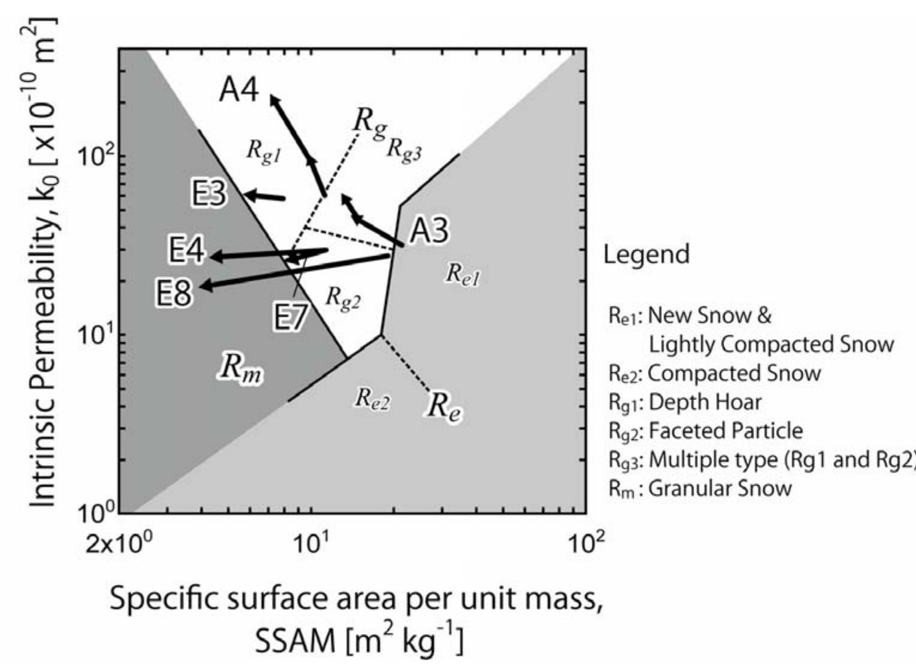

Figure 6: Change of SSAM and permeability accompanied by metamorphism of snow.

of the grain will become rounded and snow density will increase. In future, it is necessary to investigate change of SSAM and permeability accompanied by the equi-temperature metamorphism, and then to analyze the relationship between the method of snow type quantification and microstructure of snow.

ACKNOWLEDGEMENTS

We are grateful to K. Iinuma of YAGAI-KAGAKU Co.Ltd. for his support of a field assistance at Akan Lake side. This study was supported partly by the Grant for Joint Research Program of the Institute of Low Temperature Science, Hokkaido University.

REFERENCES

Colbeck, S.C., Akitaya, E., Armstrong, R., Gubler, H., Lafeuille, J., Lied, K., McClung, D., Morris, E., 1990. The international classification of seasonal snow on the ground. Int. Comm. on Snow and Ice, Int. Assoc. of Sci. Hydrol., Wallingford, U. K., 23 pp.

Fierz, C., Armstrong, R., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K. and Sokratov, S. 2008 The 2008 International Classification of Seasonal Snow on the Ground. Geophysical Research Abstracts, Vol. 10, EGU2008-A-10525. http://www.cosis.net/abstracts/EGU2008/10525/EGU2008-A-10525.pdf (accessed 14/Jul/2008)

Hachikubo, A., Arakawa, H, Nishida, K. Fukuzawa, T and Akitaya, E. 2000 Section Planes of snow specimens visualized with Sudan black B. Polar Meteo. Glaci., No.14, 103-109.

Lehning, M. and Bartlet, P. Brown, B. Fierz, C. and Satyawali, P., 2002. A physical SNOWPACK model for the Swiss avalanche warning Part II. Snow microstructure. Cold Reg. Sci. Technol. 35(3). 147-167.

Narita, H. 1969 Measurement of the specific surface of the deposited snow I. Low Temp. Sci. A(27). 77-86.

Perla, R. and Dozier, J. 1984 Observation of snow structure http://www.avalanche.org/~moonstone/snowpack/observations of snow structure.htm (accessed 14/Jul/2008).

Shimizu, H. 1970. Air permeability of deposited snow. Contr. Inst. Low Temp. Sci., A22, 1-32.