STUDY ON PREVENTION OF SNOW AND ICE ACCRETION TO ROAD SIGNS AND OTHER FACILITIES

Koji Fumoto*, Hideaki Yamagishi* and Fumihiro Hara**

*Kushiro National College of Technology.
Department of Mechanical Engineering
West 2-32-1, Otanoshike, Kushiro, Hokkaido
TEL +81-154-57-7299/FAX +81-154-57-5360
E-mail address: fumoto@mech.kushro-ct.ac.jp

**Hokkaido Development Engineering Center.
#11, South-1, East-2, Chuoku, Sapporo, Hokkaido.
TEL +81-11-271-3028/FAX +81-11-271-5115
E-mail address: hara@decnet.or.jp

1. Abstract

In cold regions, it is well known that snow and ice accretion to road accessories causes serious damage. In particular, information necessary for traffic safety does not reach road users when snow or ice adheres to road signs. For this reason, the prevention of accretion and the removal of accreted snow and ice are significant for ensuring safe road traffic in winter. In recent years, various methods for controlling snow and ice on road signs have been suggested. These methods chiefly depend on shifting the stagnation points of airflow from the standpoint of fluid mechanics, or on application of ice-accretion retardant materials made of water-repellent silicon or fluorine resin. However, no methods have been completely successful in controlling snow and ice. Additionally, there are many problems with water-repellent materials, including cost and durability, and various studies are being conducted to solve them.

Toward proposing a new control method that is inexpensive to implement and maintain, the authors have tested road signs outdoors. This paper suggests the following control methods:

(1) Covering the surface of road signs with materials (e.g., silicone rubber sheets) that are permeable and low in thermal conductivity; and

(2) Changing the surface properties of road signs.

These methods are expected to have the following effects in controlling snow and ice:

In (1) reduce the adhesive force of snow and ice by selecting covering materials from the standpoint of thermal engineering.

In (2), snow adhesion is controlled by focusing on a method of forming a very thin liquid film on the surface, and by using hydrophilic materials whose effects are opposite those of water-repellent materials (that is, TiO_2 photocatalyst coatings).

2. Introduction

For the winter traffic in cold, snowy regions, snow and ice accretion to road accessories is a major cause of traffic disturbance. When snow and ice adhere to these accessories to a great extent, road users are prevented from receiving information that is necessary to understand the current road conditions toward anticipating upcoming situations. During a snowstorm, snow-covered road accessories blend with the surroundings to bring about the whiteout phenomenon, by which the important role of road accessories in providing visual guidance is diminished. This situation results in traffic congestion and accidents in winter; thus, measures for controlling snow and ice accretion are urgently needed.

Regarding snow and ice control for road signs and other facilities, efforts have focused on changing the shapes, positions and properties of the icing surface. For example, there is a method of tilting road signs downward to shift the stagnation points of airflow, whereby the locations of snow accretion are controlled from the standpoint of fluid mechanics. Based on the changes in surface properties, studies are active on materials that are free from snow accretion as a result of water-repellent fluorine resin coatings. However, materials made of highly polymerized resin are susceptible to surface deterioration by UV radiation and acid rain, and their weatherproof performance is reduced due to the chlorides in de-icing agents. The surface of such road signs is not very durable against flaws, and it promotes adhesion of dust and carbides from car exhaust. Past reports indicate that these materials are not suitable for practical control of snow and ice because they are very expensive.

Based on an understanding of these problems and conditions in the field, this paper proposes new road signs with hydrophilic surface coating, and it shows the basic data that were collected in outdoor exposure tests done to clarify the snow accretion control performance. Surface hydrophilicity is achieved by coating with TiO_2 photocatalyst, which helps in maintaining hydrophilicity when UV radiation in sunlight or fluorescent light is applied. The aim is to form a liquid film by hydrophilicity, in order to reduce the adhesive force of snowflakes on the surface of road signs, so that snow and ice will slide down off the surface.

3. Examination method

3-1. Examination object series

The conditions of the samples used in the examination and the experiment are shown in Table 1 and Figure 1, respectively. The sample is an all-purpose aluminum road sign (for indicating speed limit) that is round, 600 mm in diameter and 2 mm thick. For comparison with existing road signs, the samples include one without any coating application (Table 1-iii.) The test parameters are the droplet contact angle (θ), the presence/absence of surface covering, and the attachment angle (ϕ .) The surface is coated with titanium dioxide (TiO_2), which achieves photocatalysis when the contact angle is changed. The coating was done in the following procedure: After applying a first coat of commercial primer to the surface, it is dried and sprayed with a solution of TiO_2. The surface of road sign was treated in the same way in the tests that were done by covering the surface with a transparent polycarbonate plate of 5 mm thickness or with a transparent vinyl sheet of 1 mm thickness.

Table1. Examination conditions

	Model	Cover	Average of contact angle [θ]	Attachment angle [ϕ]	Note
i	NNF1	Non-cover	24.0°	+5°	
ii	NMH2		49.7°	0°	
iii	NSB3		80.3°	−5°	
iv	SNF4	Sheet	61.0°	0°	Sheet thickness 5mm
v	SMB5		65.2°	−5°	
vi	SSF6		38.2°	+5°	
vii	BNB7	Plate	81.0°	−5°	Plate thickness 5mm
viii	BMF8		69.1°	+5°	
ix	BSH9		34.1°	0°	

As shown in Figure 1, owing to the space-wise restrictions of the sample setup, signs are turned at an angle of 90 degrees counterclockwise from the ordinary upright position and attached to the horizontal pole, except for those that are attached upright($\phi = 0°$).

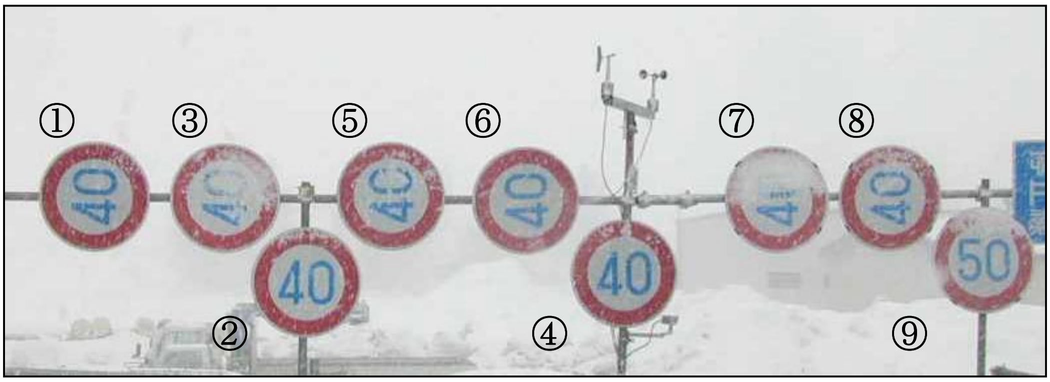


Fig1. Experimental situation

3-2. Surface roughness and droplet contact angle

It has been reported that the adhesive force of snowflakes is greatly influenced by the surface roughness. Most studies in the past depended on a control method that weakens bonding with snowflakes, relying on surface hydrophobicity. As mentioned above, the hydrophobic surface is neither greatly weatherproof nor durable. It also has many problems including that snow and ice accretion is induced by microscopic concavities and convexities created by dry patches (or water patches) of residual impurities left after droplets have evaporated from the water-repellent surface. In contrast, because the hydrophilicity focused on in this examination facilitates the formation of a water film on the surface, the surface becomes extremely flat and smooth. Figure 2 shows various contact angles of droplets that are applied to the surface of the samples used in the examination. Sample I shows a droplet put on an existing road sign. In Sample III, a droplet is put on the surface coated with TiO_2 photocatalyst, to which ultraviolet rays have been applied in advance. A comparison between the two clearly shows that the surface of III is more hydrophilic. Although the contact angle of a single droplet was measured in this examination, it should be noted that droplets on actual road signs merge to form a water film. In the past, it was usual to report measurements of the freezing force or the adhesive force acting between a hydrophobic surface and ice pieces and/or snowflakes. In this study, however, the freezing force acting on the hydrophilic surface was not measured because it is assumed that ice and snow would slide off before freezing.

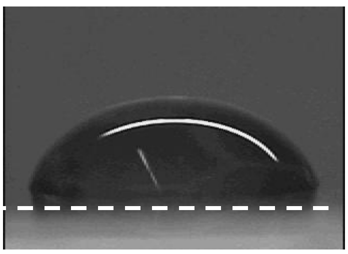
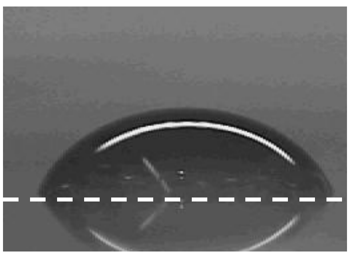
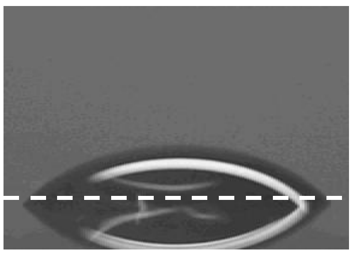
I ③[NSB3], θ =82.0°	II ④[SNF4], θ =63.4°	III ⑨[BSH9], θ =33.7°
		

Fig2. Contact angle of water droplet

3-3. Optical catalyst and TiO_2 photocatalyst

The photocatalytic effects of TiO_2 used in this study were discovered in 1995, and since then they have been studied for practical use in various basic sciences and for other applications. The effects of TiO_2 photocatalyst are briefly explained as follows. Figure 3 shows the hydrophilic and other effects of a TiO_2 film formed on an object, when the object is exposed to the UV radiation in sunlight and in fluorescent light. It is known that application of UV radiation causes generation of hydroxyl radicals and oxide ions on the surface of the film, which leads to conditions of very strong oxidization and hydrophilicity. Other effects include superior weatherproof performance, self-purification and NOx absorption. The high added value of TiO_2 photocatalyst is also proven by the lasting stability of surface properties even when chemicals (e.g., de-icing agents) adhere to the surface. However, there seem to be no reports on the application of TiO_2 photocatalyst in snow and ice control.

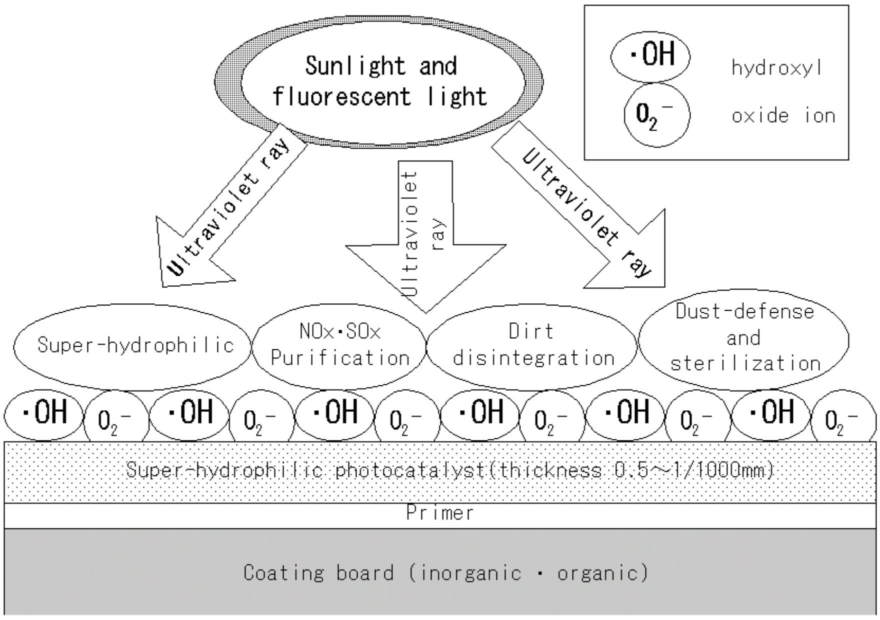


Fig3. Sketch of the optical catalyst effect

4. Results and consideration

4-1. Situation of field study

Observation was done on samples left outdoors from February 20 to March 24, 2001. The samples were placed at a height of about 4 m, to prevent influences of air turbulence caused by surrounding buildings. Snow adhesion image data were collected by digital camera at regular intervals from the moment when snow began to adhere to road signs. Weather data were collected continuously for 24 hours (air temperature, wind direction, wind velocity, snowfall). In some periods, images were collected by around-the-clock videotaping. Figure 4 shows the frequency distribution of wind direction at the sample site during the examination period. As shown in the figure, the northwesterlies and southeasterlies are predominant, and the road signs are exposed to wind that blows perpendicularly to the surface because the signs are set facing northwest.

Figure 5 shows the daily average temperature and the daily average wind velocity during the examination period. The temperature and the wind velocity measured during the times of snowfall, which were observed by a pulse snowfall-measuring device, are expressed as lines. The average temperature in this period is higher than in

Sample site: Kita-Okadama, Higashi-ku, Sapporo, Hokkaido
Sample orientation: northwest (42.5 degrees westward from due north)
Measurement site for air temperature and wind: near the samples
Measurement frequency: 10 minute intervals
Average wind velocity during the test period: 2.9 m/s
Average temperature during the test period: - 1.2 ℃

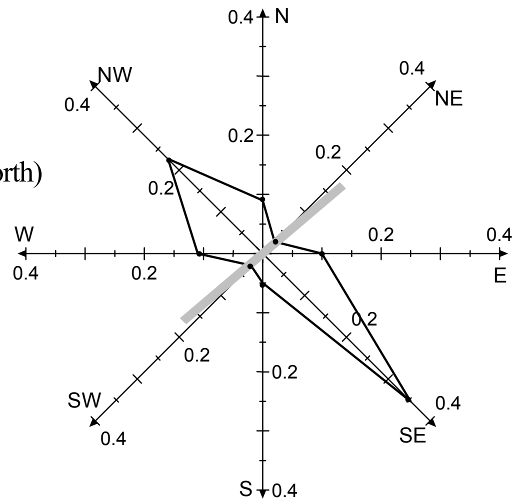


Fig4. Wind distribution of examination term

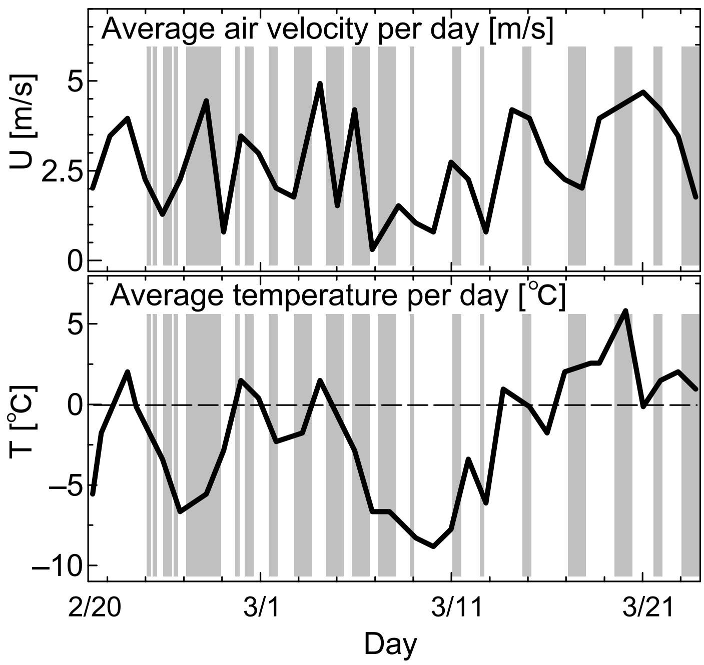


Fig5. Temperature, air velocity, and snowfall of an examination term

the coldest season, and the average wind velocity varies predominantly in the low-velocity range below 4 m/s. Based on these results, it is presumed that the mechanism of snow adhesion during the examination period related to what is generally classified as "wet snow." This is snow where the surface tension of minute water droplets in snowflakes causes adhesion with an object, and such snow is found in the Hokuriku region and, in early spring, in Hokkaido. No concurrent tests were possible with regard to snow adhesion when the wind velocity is great during a snowstorm, or when the temperature is low and snow is less wet. (As for the latter, it is reported that kinetic energy of snowflakes is converted to thermal energy when they collide with a surface, and that snow partly melts to form a liquid film that adheres to the surface.)

4-2. Experimental evaluation method

The properties of snow and ice adhesion were evaluated as follows. Although it was impossible to examine every parameter in detail because exposure tests were done under natural conditions, the conditions of snow and ice accretion were understood by filmed images and according to the properties of the road signs (that is, the attachment angle, the surface treatment or lack of treatment, and the presence/absence of surface covering). Based on the coverage area and the conditions of snow adhesion, evaluation was performed by classifying visual recognition of road signs into three grades. The snow adhesion coverage was calculated as a percentage, by processing of the snow adhesion image data.

Snow adhesion coverage (%) = surface area with adhering snow / total surface area of road sign x 100
Evaluation based on visual recognition of sign: 1 = no snow adhesion (easy to recognize), 2 = 50 % snow adhesion (hard to recognize), and 3 = 100 % snow adhesion (impossible to recognize)

4-2-1. Relation between droplet contact angle and snow adhesion

Figure 6 shows an example of snow adhesion conditions observed in the tests. The parameters are the presence/absence of surface coating (that is, the changes in the droplet contact angle (θ) on the surface) and the attachment angle (ϕ) of a road sign. From the top of the vertical axis in this figure, the attachment angles of road signs are (a) forward-inclined (ϕ = - 5°), (b) perpendicular (ϕ = 0°), and (c) backward-inclined (ϕ = +5°), and the horizontal axis shows the snow adhesion coverage (%). The results are shown for both a polycarbonate plate (hereinafter called "plate") and a silicon vinyl sheet (hereinafter called "sheet"), which share similar qualities as materials for surface covering. Figure 6 (a) shows that the snow adhesion coverage becomes smaller in area as the contact angle becomes smaller or as the hydrophilic effect grows. The result in Figure 6 (b) contrasts with that in (a), and this is probably due to some influences of the metal fixtures on the plate and also to the insufficient treatment of the plate edges. Nevertheless, it is clear that the snow adhesion coverage area in Figure 6 (b), when the contact angle is large, is only about 40 % of that in Figure 6 (c). It had been expected that coverage with snow would be controlled for the backward-inclined sign of (c), but snow adhesion was actually accelerated.

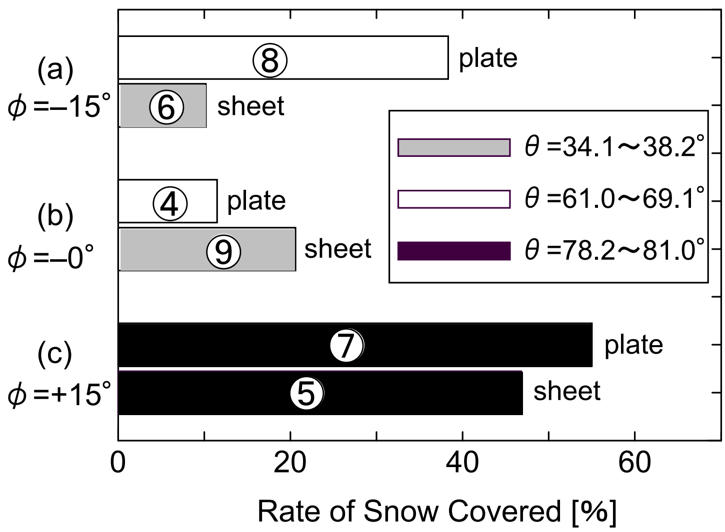


Fig6. Rate of area by the difference in the contact angle of droplet

No.7

No.6

fig7. Snowy photograph in an examination

Figure 7 shows the road sign at the largest (No. 7) and the smallest (No. 6) snow adhesion coverage from Figure 6. Whereas snow uniformly covers the upper half of the sign in No. 7, snow adheres sparsely to some upper parts of the sign in No. 6. Although it is not easy to elucidate the mechanisms of these different types of snow adhesion, the above results indicate sufficient effects of hydrophilicity in preventing snow adhesion.

4-2-2. Relation between surface cover and snow adhesion

With regard to freezing of droplets and water films, it has been reported that surface application of materials with low thermal conductivity and small thermal diffusion results in decreased absorption of the latent heat of coagulation and, consequently, in adhesive strength smaller than that on metallic-surfaced materials. In this study, from the standpoint of thermal properties, the surface of road sign was covered with a plate or a sheet, and then was rendered hydrophilic before examination of the effects of controlling snow adhesion. From the top of the vertical axis in Figure 8, road signs in (a) are forward-inclined (ϕ = - 5°) with a small droplet contact angle, those in (b) are perpendicular (ϕ = 0°) with a medium contact angle, and those in (c) are backward-inclined (ϕ = +5°) with a large contact angle. In (a), the snow adhesion coverage rate on the sign covered with a sheet is less than a half of that on the aluminum surface without a cover, when the droplet contact angles are small for both. When road signs are installed perpendicular with a medium contact angle in (b), the difference between signs with and without a cover is reduced. In (c), however, the rate of coverage generally increases because the signs are backward-inclined and the droplet contact angle is large. At the same time, it is shown that the snow adhesion coverage rate becomes smaller as the heat-resistant properties become larger, or when the samples are covered with a plate or a sheet (No. 7 and No. 5). Based on these results, the effects in controlling snow adhesion seem to be promoted when hydrophilicity is generated on the surface cover or on the body of a road sign that is made of materials that mitigate snow adhesion. This mechanism of snow adhesion control results from water originating in adhering snowflakes being supercooled and sliding down the surface due to hydrophilicity.

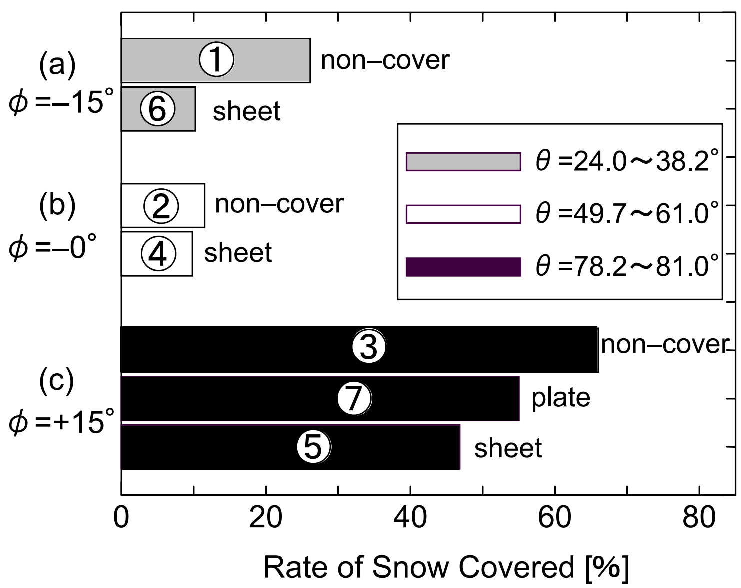


Fig8. Rate of area by the difference in a cover

4-2-3. Relationship between sign attachment angle and snow adhesion

Besides snow and ice adhesion to the surface of a road sign, snow coverage on the top, or snow accretion to the upper part also causes poor visual recognition. Snow usually accumulates on the top when the temperature is relatively high and the wind velocity is small. Under such conditions, snow that falls perpendicularly to the ground accretes to road signs and to edges of other road accessories, and the accretion keeps growing. Toward solving this problem, this study included tests on road signs that are angled to face the direction opposite that of conventional ones. In other words, road signs face upward (No. 3, No. 5 and No. 7) for the purpose of enhancing the efficiency of UV incidence on the surface, increasing the photocatalytic effects on the surface, and preventing snow from accreting to the back of the sign. However, as Figures 6 and 8 show clearly, it was impossible to obtain desired results within the limits of this study because when road signs were inclined upward, the photocatalytic and hydrophilic effects that had been expected to increase on the surface were not enough to control snow adhesion but rather caused snow accretion. In contrast, the following effects were confirmed in the tests with backward-inclined signs. Figure 9 shows sliding of snowflakes on the surface when sufficient time has elapsed after snow adhered to the entire surface of a backward-inclined road sign. The vertical axis indicates the evaluation values based on visual recognition of signs (1 - 3) as explained above, and the horizontal axis shows the time elapsed after the moment when sign No. 5 became recognizable due to slide of snow layers on the surface. In the figure, there is a lag of more than 10 minutes between when sign No. 5 (small droplet contact angle) was evaluated at 1 after all snow had slid down the surface and when snow completely slid down sign No. 3 (large droplet contact angle). It is clear that early sliding of snow layers is promoted by generating surface hydrophilicity.

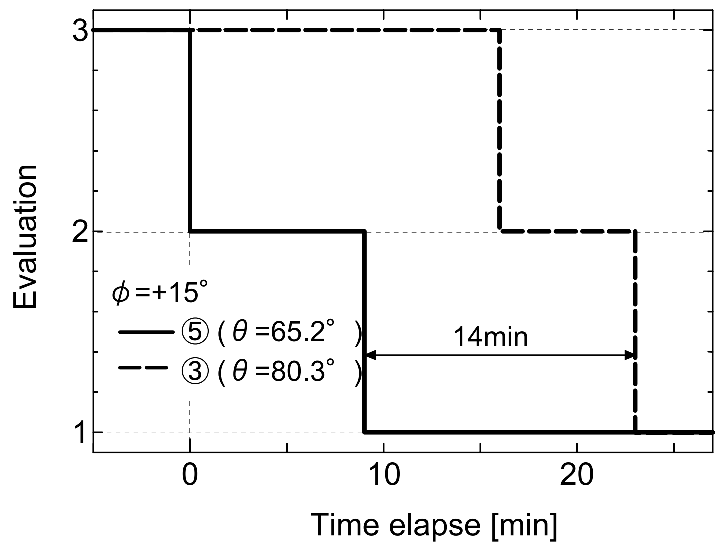


Fig9. Piece slipping down of snow by the difference in a contact angle

5. Conclusion

Based on the outdoor tests done on road signs in order to control snow and ice accretion, the authors of this study concluded the following:

(1) The hydrophilic effects of TiO_2 photocatalyst help to control adhesion of snow and ice on the surface of road signs, to some extent.

(2) By applying materials with low thermal conductivity and small thermal diffusion to the surface, the adhesive strength is reduced to induce sliding down of snow. Generating hydrophilicity on the surface enhances the effect of controlling snow adhesion.

(3) When a road sign is tilted upward for the purpose of reducing snow coverage, desired results cannot be achieved because the adhesive force is greater than the sliding force produced by hydrophilicity. However, the early sliding of snow adhered to and accumulated on the surface is induced by generating hydrophilicity.

In light of the results of this study, the authors will continue experimental examinations. Additionally, the minimum quantity of heat for preventing snow and ice adhesion (as the authors have proposed) will be supplied to a part of a road sign (or to the most effective part of a sign) and hydrophilicity will be generated on the surface, for the purpose of studying functional road signs. In closing, we would like to express deep gratitude to Iwao Satou and Tatsuya Noda of Soritoncom Co., Ltd., who helped by kindly allowing us to use their experiment station and facilities.