Protective Coverings for Ice and Snow

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Abstract

Summer deterioration of snow and ice surfaces due to high solar radiation and near melting temperatures hampers the year-round use of natural ice islands and smooth sea-ice areas in the Arctic Ocean, and permanent snow and ice areas in the Antarctic. Use of snow or chipped ice on ice surfaces in the Antarctic has generally provided sufficient protection to prevent deterioration and ablation, but the warmer environment of the arctic summer often precludes use of these natural materials.

Sawdust has been used successfully in the California Sierras for protecting compacted-snow areas during periods of alternating above-and below-freezing temperatures and high solar radiation, but its scarcity and shipping bulk preclude its use in polar areas. Polyurethane foam has proven even more successful than sawdust as a protective covering in laboratory tests during alternating above-and below-freezing temperatures and simulated solar radiation.

I. Introduction

The use of pack ice and ice islands as bases for scientific observations has been hampered in some polar areas because of extensive summer melting of the ice surface. In areas with high solar radiation and temperatures above freezing part of the day, the ice surface becomes rough and soft, buildings become elevated on pedestals of protected ice because of ablation of the surrounding ice, and compacted snow becomes soft and mushy, surfaces are impassable to vehicular traffic under these conditions. In other areas, summer melting is of little concern, but use of compacted-snow or ice surfaces for wheeled vehicles during near-thaw temperatures and high solar radiation is restricted because of decreased strength and resistance to wear of the surface.

The effect of above-freezing temperatures on the stability of ice and snow is well know, but the influence of solar radiation is less well understood. Lyons and Leavitt (1961, p. 22) observed that the albedo of the surface was significant in modifying the topography of the Ward Hunt Ice Shelf off Ellesmere Island, but they were doubtful that it was the major modifying agent. However, on the perennially frozen freshwater lake, Anguissaq, in Greenland, Barnes (1960, p. 117) found that solar radiation was the major source of energy for ablation of the ice. Melting occurred at crystal boundaries with open channels developing between crystals in the upper 10 cm of ice; this resulted in nearly total loss of ice strength in the top 45 cm (Barnes, 1960, p. 73). The detrimental effect of solar radiation on the strength of ice was also demonstrated on Lake Peters, Alaska, by Barnes (1959, p. 106). A white tarpaulin, which shielded the ice from solar radiation but not from convection or conduction of heat, was placed over a test area on the lake in early May. In July, a beam was broken in this area which was the same thickness as the surrounding ice, about 120 cm; this ice, which was clearer than the unprotected ice and showed little evidence of internal deterioration, had about the same strength as it had in early May, while the unprotected ice had decreased to one-tenth of its earlier strength.

Any ice or snow area carrying traffic will also be subject to deterioration from tracked silt, oil spots, and gasoline spillage. While traffic-caused damage can be mechanically repaired under favorable conditions, nature-caused damage can only be repaired by favorable weather conditions. Consequently, surface protection is needed to prevent damage by adverse weather, that is, intense daily solar radiation coupled with prolonged air temperatures above $-4°C$. Such damage can occur during the summer season in polar regions and during the winter season at lower latitudes.

The influence of solar radiation and temperature on an ice or snow surface is strongly dependent on reflectance, opacity, emmisivity, and insulation characteristics of

Fig. 1. Compacted-snow parking lot protected with sawdust at Squaw Valley, California

the surface or a protective covering (Kingery, 1959, p. 120). This paper summarizes the properties of the materials used by the U. S. Navy as coverings for snow and ice surfaces to protect them from deterioration and ablation due to high solar radiation and near-thawing air temperatures.

II. Protective Coverings

Sawdust. The first material used by the U. S. Navy for the protection of ice and snow surfaces was sawdust, which was used on the compacted-snow parking lots and access road (Fig. 1) at the Olympic Winter Games, Squaw Valley, California, in February 1960.

Tests by Moser and Gifford (1962) in Squaw Valley showed that unprotected compacted-snow would support vehicle traffic on warm, sunny days only during the morning; by noon, the top 10 to 15 cm of snow became soft and mushy. After several days of continuous above-freezing temperatures, the snow was impassable to traffic even in the early morning; however, one night of below-freezing temperatures always restored its traffic-bearing capability. In an effort to obtain all day traffic-bearing snow at Squaw Valley, experiments were conducted to determine whether sawdust would prevent

Fig. 2. Ice lens formed beneath sawdust due to melt water percolation and refreezing

deterioration. It was found that a 1/2-cm-thick dusting not only prevented afternoon deterioration, but also provided good traction and enhanced safe vehicle operation on the snow. Also, it caused the formation of about 8 cm of ice just below the surface, thus providing the compacted snow with a hard, tough wearing surface. This ice apparently formed from melt water which drained into the snow and refroze (Fig. 2).

When first sawdusted, the surface of the area was about 15 cm below that of the adjacent unprotected natural uncompacted-snow, but a few weeks later, its surface was about 15 cm above the natural snow. This was attributed to ablation of the unprotected natural snow surface.

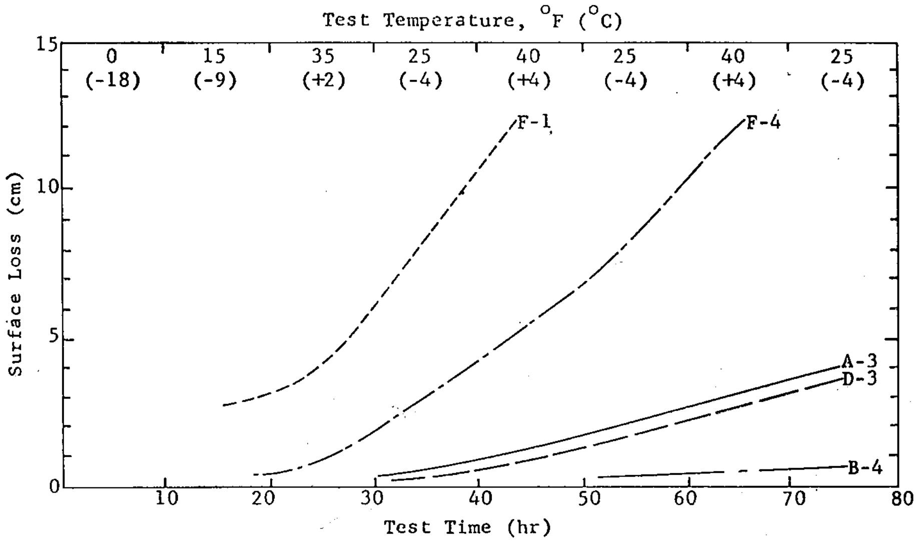
Sawdust has a thermal conductivity of 1.4×10^{-4} g·cal·sec^{-1}·cm^{-2}·°C^{-1}·cm^{-1} when dry; this increases with an increase in moisture content. Laboratory tests with sawdust (Goodyear Aerospace Corp., 1964, pp. 82–84) on an ice surface showed that the temperature of the sawdust due to solar radiation absorption was 28% less when it was wet than when it was dry, probably because of evaporation of water from the sawdust surface. However, 11% of the incident radiation penetrated the sawdust by diffusion when it was wet, but only 5% penetrated it when dry. By readily absorbing water, sawdust can maintain an area dry which otherwise would have puddles, which increase

Fig. 3. Ice plot protected by aqueous foam; surrounding ice, which has melted about 1 foot, was originally level with the protected ice surface

solar radiation absorption and deterioration. The success of sawdust in protecting the snow surface is attributed to its ability to absorb water, the lower temperature when wet, and the low penetration of solar radiation by diffusion.

Aqueous foams. Sawdust, however, is scarce and has a high shipping bulk; therefore, aqueous foams in which water and air are the main ingredients, and which can be prepared at the site, were considered as a protective covering. A protein-base aqueous foam with stabilizer was investigated by Onondaga Associates, Inc., under contract with the U. S. Air Force and the U. S. Navy (Grove and others, 1963). In laboratory tests, this foam protected an ice surface during periods of melt, was easily generated from stabilized foam liquids and, once cured and dried, appeared to last indefinitely. Field tests at Port Hueneme, California, and at Point Barrow, Alaska, however, proved aqueous foam to be inadequate for continued protection of ice and snow surfaces against summer deterioration (Fig. 3). The foam was difficult to generate, would not cure under normal polar climatic conditions, and so had a short field life, was easily damaged by traffic, and offered only a slight weight savings over sawdust (Stehle, 1964).

Urethane foam. Urethane foams were tested by the Navy as a material to protect ice and snow surfaces since they are excellent insulators, having a thermal conductivity of only 0.51×10^{-4} g·cal·sec^{-1}·cm^{-2}·°C^{-1}·cm^{-1} (Goodyear Aerospace Corp., 1964, p. 18). Rigid, white granular urethane foam, 2-1/2 cm thick, proved in laboratory tests to be an excellent protective covering. The 122 by 122 cm ice plots, 12-1/2 cm deep, were subjec-



Plot No.	Cover	Thickness (cm)
A-3	Natural rigid granules	1.0
B-4	Natural rigid granules	2.5
D-3	White rigid granules	1.0
F-1	Unprotected ice	none
F-4	Sawdust	0.63

Fig. 4. Surface loss from ice test plots with different protective coverings (after Goodyear Aerospace Corp., 1964, p. 77)

ted to alternating periods of 5 hours with and 5 hours without 0.8 Langleys/min simulated solar radiation at temperatures varying between −18 and +4°C. The plot of surface loss versus time (Fig. 4) shows that the ice protected by this white foam lost less than 1 cm after 75 hours, while the exposed plot was completely melted after 45 hours. Even when melting and puddling did occur, the foam floated on the water, preventing absorption of solar radiation by water, which has a much higher absorptivity than ice.

Of the granules tested, the finer granules (less than 1/4 cm diameter) transmitted 2.4 times less solar radiation than did coarser granules (less than 1/2 cm but greater than 1/4 cm diameter). A white coloring due to the addition of 10% titanium dioxide pigment materially increased the reflectivity of the foam. Although gray granules (from the addition of 0.5% graphite flakes) had an increased absorptivity and so were more effective in blocking transmission of the solar radiation, they also had a higher temperature than the white or natural foam under the radiation because of absorption of the radia-

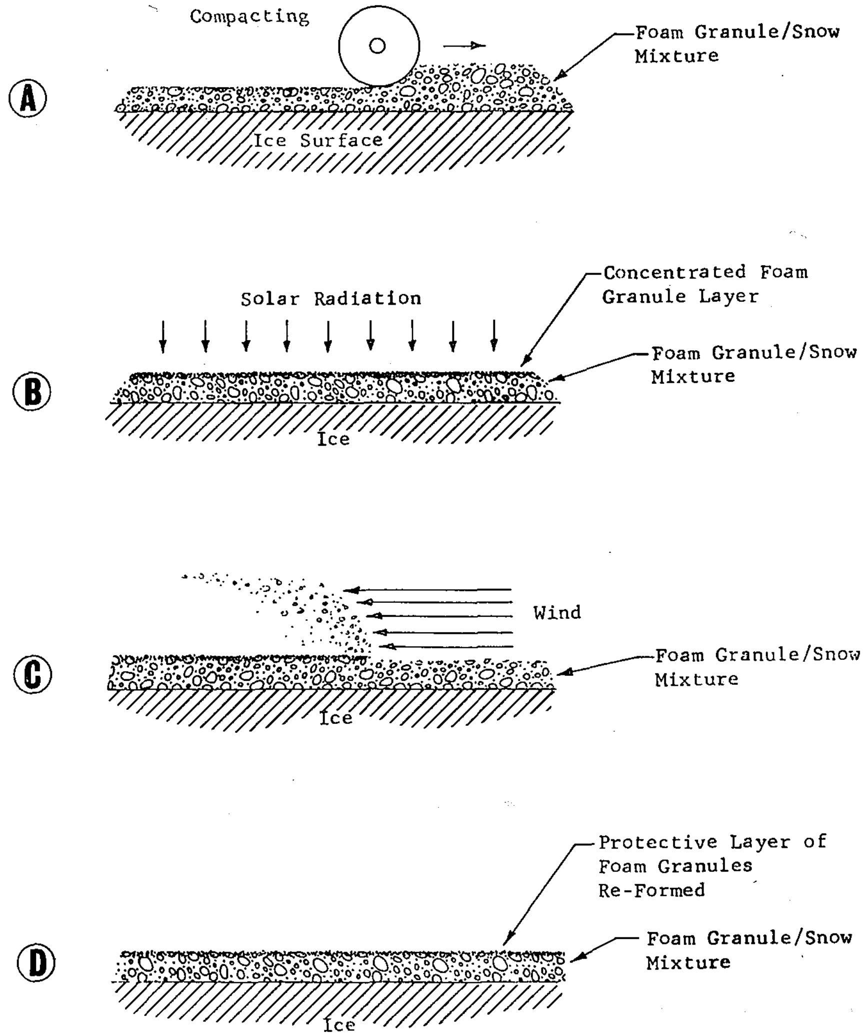


Fig. 5. Foam granule/snow regenerating blanket

tion, instead of reflection. The white, rigid urethane foam granules were concluded to be about 5 times more effective than sawdust. However, the granules alone are pushed aside by trafficking, and have no resistance to wind.

A 50–50 mixture of snow or chipped ice and rigid white urethane foam granules compacted on the surface is one suggested method of stabilizing surface protection with foam, particularly in an area where solar radiation is more important than higher temperatures (Goodyear Aerospace Corp., 1965). The snow or chipped ice would permit the mixture to be packed into a durable layer capable of withstanding traffic loads and high winds (Fig. 5). The foam would provide insulation to the ice or compacted-snow surface beneath. Under the effects of near-freezing temperatures and high solar radiation, rather than deteriorating the surface, the snow in the mixture would melt and release the foam particles. Because of their buoyancy, these particles would migrate to the surfce, forming an efficient protective blanket which would insulate the snow from further melting, and would reflect and block solar radiation. Should the foam be displaced or removed, this process would be repeated. The insulating value of this cover increases as the percent of foam granules increases; the trafficability, however, increases as the percent of ice or snow increases.

For areas where the influence of solar radiation and air temperatures are more severe, a matrix other than snow, or a cover, would be needed to provide resistance to wind and traffic. All attempts to find a satisfactory bonding agent matrix for the foam have been unsuccessful because the foam does not wet easily, and resins do not cure well at below freezing temperatures or in moist conditions. Open mesh, film materials

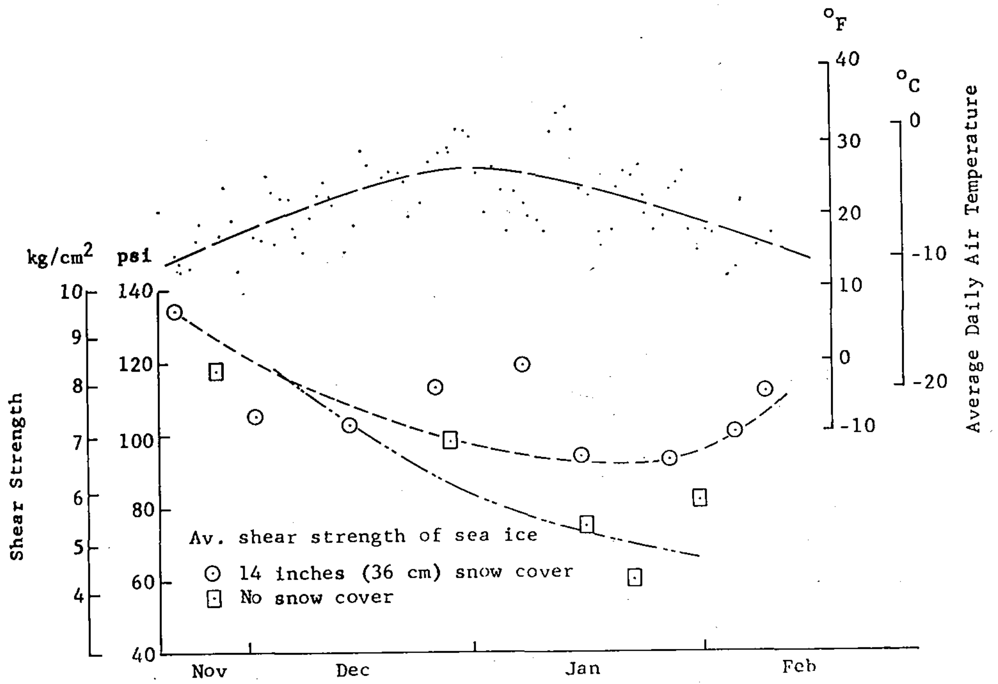


Fig. 6. Average shear strength of sea ice with and without snow cover (after Paige and Lee, 1966, p. 20)

and sprayed-on coatings were also unsuccessful because of poor trafficability or the difficult curing conditions. One cover, however, a fiberglass mat combined with flexible resin laid over the granules, appeared very successful in laboratory tests by Goodyear Aerospace Corporation (1965). Field tests of this cover on soil showed that it would perform well, but problems were encountered with quality control since resin-poor areas were weak and failed. To date, none of the urethane foam protective covers has been field tested.

Snow and chipped ice. Of the natural materials, fresh snow is the best insulator, with a thermal conductivity of $0.48\times10^{-4}\,g\cdot cal\cdot sec^{-1}\cdot cm^{-2}\cdot{}^{\circ}C^{-1}\cdot cm^{-1}$ (Mantis, 1951, p. 55), a good reflector of solar radiation with an albedo as high as 0.9 (Mantis, 1951, p. 64) and a good emitter of low-temperature radiation (Kingery, 1959, p. 120). Fresh snow, however, which may have a density less than $0.1\,g/cm^3$, is too soft to support traffic, and cannot be maintained because it is unstable; it quickly sublimates and packs into a more dense mass of up to $0.45\,g/cm^3$.

Old snow and chipped ice have nearly as good thermal properties and have proven themselves to be good protective coverings. Measurements by Mantis (1951, p. 68) showed that the transmission of incident solar radiation through uniform fine-grained older compact snow with an average density of $0.45\,g/cm^{-3}$ decreases from 22.3% with a 1 cm thickness of snow to 0% with an 18 cm thickness. Shear strength measurements in the Antarctic by Paige and Lee (1966) have shown that sea ice protected by 35 cm of older compact snow is generally stronger than ice exposed to solar radiation even at below-freezing air temperatures (Fig. 6).

A chipped ice and snow mixture has been used periodically by the Naval Support Forces in the Antarctic to protect the surface of the sea ice runway at McMurdo Sound. For example, with the progression of the 1963–64 summer season, the frequency and number of meltwater ponds on the Deep Freeze 63–65 Williams Field ice runway increased and, by late December, threatened the shutdown of the runway. With a pulvimixer, a 10 cm deep cut was made in the ice with an overlapping pattern (Fig. 7); the material produced was the consistency of coarse snow with a few ice chips. The surface was then rolled with a snow-compacting roller. Although this was done in early January 1963, during the height of the high temperature-high solar radiation season, this treatment improved the surface immediately, and no further problems were encountered.

The following year, 1964–65, the ice runway surface was chipped with a pulvimixer early in October before warm temperatures and high solar radiation presented any problems. Within 2 weeks, the chipped ice surface was consolidated so that little maintenance was required other than roughening slick spots and cleaning discolored areas. Because oil or fuel leaks and silt or other dark material tracked onto the surface darken the ice and increase the solar radiation absorption, the discolored ice was removed from the runway and replaced with a clean layer of chipped ice or snow. During the lull in aircraft traffic, from mid-December to mid-January, the ice runway was cleared of all discolored ice and repulvimixed because the October pulvimixed layer had become less effective. This was the first season the runway had not been closed because of surface deterioration.

Laboratory tests to determine the qualitative effects of solar radiation varying from

Fig. 7. Pulvimixed ice surface on left and untouched ice on far right at McMurdo Station, Antarctica sea ice runway

0.2 to 1.2 Langleys/min at below-freezing temperatures on snow over ice or on snow alone were conducted in 1.2 by 1.2 m pans 12-1/2 cm deep. At high solar radiation, any snow which melted drained into the underlying snow, the depth of penetration of the meltwater depending on the permeability and temperature of the snow. If the meltwater reached an impermeable layer, such as the bottom of the pan, or the ice layer, it refroze, forming an opaque bubbly ice layer. At lower solar radiation, little snow melted but surface loss due to sublimation and moderate deterioration did occur.

Summary

Although sawdust proved to be more than an insulator by absorbing water and so reducing puddling, it is difficult to obtain in large quantities and has a high shipping bulk. Other equally good insulating materials with lower shipping bulk and which are more readily available must be considered instead. Field tests of the aqueous foam showed that it was difficult to generate, offered only a slight weight savings over sawdust, and was inadequate for protection of the ice under normal polar climatic conditions.

The urethane foam provided a good insulating blanket, allowed little penetration of

solar radiation, and because of its buoyancy, could float on water in extreme cases of deterioration, reducing solar radiation absorption by the water. Because the granules, which formed a more effective protective covering than sheet foam, had no resistance to wind or traffic, several methods of stabilization were developed. These included a compacted mixture of snow or chipped ice and foam granules, and a fiberglass and resin mat covering the granules. To date, however, none of the urethane foam protective coverings and stabilizing methods has been field tested.

Snow and chipped ice have also proven to be good insulators, as well as being readily available. Except under prolonged above-freezing temperatures, or high solar radiation and near-or above-freezing temperatures part of the day, snow and chipped ice provide an easily applied adequate protective covering. When severe climatic conditions are prevalent, or in a situation where high heat-producing conditions are expected, such as a warm-up area for jet aircraft, the urethane foam protective covering would probably be superior.

Although snow and ice roads and runways continue to be used in the Antarctic, little systematic use of natural protective coverings has been made. The use of natural materials should be exploited and further studies should be made to gain quantitative knowledge on the protective properties of these natural materials and to determine the practical application of urethane foam in polar areas.

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