# UTILIZATION OF ICE AND SNOW FOR ARCTIC OPERATIONS*
# (PRELIMINARY REPORT)

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## Introduction

The purpose of the present investigation has been to determine the feasibility of using ice and snow as structural materials for arctic operations. Studies have included theoretical and analytical calculations, laboratory experiments under controlled conditions, and field investigations. Many of the data obtained have not as yet been analyzed in detail; this will be done, even without this final analysis, but conclusions can be reached as to the feasibility (but not development of optimum techniques) of various proposals.

Any widespread utility of ice and snow as structural materials requires (a) improved processing techniques, (b) improved properties, and (c) an extended life. Techniques currently being used are of marginal utility in all these regards as discussed previously (Kingery, 1959). In this feasibility study we have taken a broad approach to all these problems.

Snow comminution and compaction have been investigated at New Hampshire, at Watertown, Massachusetts in cooperation with the Watertown Arsenal, and at Eglin Air Force Base, Eglin, Florida. Sea-ice solidification has been investigated at Point Barrow, Alaska, and at Eglin Air Force Base. Effects of additives to improve properties have been investigated at Eglin Air Force Base. Methods of controlling ice deterioration have been studied on the Ellesmere Ice Shelf and at Eglin Air Force Base. All these investigations have reached a point where definite conclusions can be stated as to the feasibility of various approaches.

## Snow and Ice Comminution and Compaction

As shown by theoretical calculations and also by the improved strength and compactibility of wind-driven snow and Peters Snow-Miller snow, fine-particle material is one of the main requirements for successful snow compaction. A device that is suitable, at least in principle, for reducing a coarse snow or ice feed to a product having particle sizes in a range of a few microns has been built and tested. In this device a high-speed rotor with attached lugs creates extreme turbulence, giving impact grinding of fine particles; at the same time a mechanism is provided for breaking coarse ice lumps. Effects of operating temperature and rotor speed on the product particle size has been investigated.

Ice and snow were found to be comminuted more effectively as the temperature is lowered below the freezing point; in addition, high rotor speed is critical to achieve

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effective comminutions. At temperatures from +15°F to -40°F, rotor speeds of 10,500 rpm gave a product containing an appreciable fraction of material less than ten microns in diameter.

Compaction of this fine particle size material resulted in a density of 0.64 - 0.68 g/cc compared to 0.55 - 0.57 obtained for natural frost compacted under the same conditions; the strength of the fine-grain material was also greater than that of the natural frost. Measurements and analysis of the shrinkage of these materials indicate that another advantage of fine grinding is a greater speed of age hardening.

Various additives have been considered which might improve the compacted densities. Of these, small additions of methyl alcohol appeared most promising on the basis of theoretical analyses. Experimental results indicate that a one per cent addition of alcohol substantially increases the ultimate density (giving values of 0.70 - 0.77 gm/cc) and strength obtained. The best strength samples had an average strength of 320 psi, several times greater than normally obtained. However, this addition also slows down the age hardening process. Further studies are indicated.

We plan to construct an improved grinding apparatus that will allow for variable speed, increased capacity, simplified construction for operations at high speeds, and be suitable for field trials. In addition, our program includes further studies of materials suitable as additives in small amounts to improve compaction.

## Sea-Ice Solidification

In the freezing of sea water for structural applications, the principal objectives are (a) to maximize the overall solidification rate in order that structures can be built rapidly and economically, and (b) to generate a mechanically useful product, which implies that sound ice of low salt content should be formed. Both at Point Barrow, Alaska, and in studies at the Eglin Air Force Base, various solidification techniques were investigated to test the feasibility of attaining these objectives. Ice structures, salinity, and rates of formation have been studied in light of various overall heat transfer patterns in order to study rates of formation.

When natural ice forms, heat must flow from the liquid-solid interface through the ice to the cold ice-air surface. As the ice increases in thickness, the heat flow path becomes longer, and freezing becomes slow. In general, to obtain rapid solidification it is necessary to short-circuit this heat flow pattern and bring the water directly in contact with the ultimate cooling medium, the air. The simplest procedure for this has been flooding layers of sea water in dikes and allowing the complete layer to freeze. This results in undesirable brine segregation and no desalination. By proper sequencing, brine segregation effects may be minimized and rapid solidification obtained; in order to obtain rapid solidification without brine segregation, sequential freezing with brine separation was investigated, using a cold layer of base ice as a regenerative heat sink. A layer of sea water when brought in contact with an ice surface at a temperature of about -20°F forms a solid layer. From this layer the supernatant water can be removed by means of a rubber squeegee or heavy roller. With a typical cycle of four minutes freezing, sixteen minutes allowed for the ice to cool, one-eighth inch of ice is produced per cycle having a salinity of 1.2% from sea water of 3.5% initial salinity, using squeegees. The use of rollers to remove supernatant liquid was found to be more effective, increasing the freezing rate by about 60%.

Preliminary measurements, however, indicate that partially solidified sea water can be spread and rolled or otherwise compacted on a cold ice surface, where solidification becomes complete. In this way, a major part of the heat transfer and brine separation can be effected separately from the preparation of the final ice surface. Consequently, deposition rates are independent of the local rate of freezing and can be greatly increased. Preliminary studies at the Eglin Air Force Base indicate that this will be a practical technique for forming ice rapidly without the thermal barrier that has existed in previous methods. At the same time, low salinities are obtained. Where low salinities are not required, growth rates in excess of three-quarters of an inch per hour can be maintained by thin layer flooding without desalination. Using one-quarter inch layers, rapid freezing is obtained; the fine grain structure without gross segregations gives rise to good low-temperature properties and high strengths.

We plan to make additional field studies aimed at developing optimum techniques for separately carrying out the heat exchange, partial solidification, and desalination--and subsequently depositing the ice to form a surface in the area where desired. In this way, it seems entirely feasible to build up rapidly thick layers which will have high strength and low salinity, starting with sea water or possibly with old sea ice. Further studies will be related to methods for rapid solidification and to methods of desalination suitable for arctic conditions.

## Additives To Improve Ice Properties

The major previous attempt at using additives td improve ice properties was the development of ice-sawdust "pykrete" by the British during World War II (Perutz, 1948). The addition of 14% wood pulp increased the average modulus of rupture of ice from 22.5 to about 65 $kg/cm^2$ at $-15^{o}C$.

For strengthening of ice it is desirable to obtain a high-strength, high-modulus material that will form a strong bond to the ice. For this purpose we have tested both the breaking strength and creep of ice containing fiberglass additions. Substantial improvements were obtained in both cases; but since dispersion of the fiberglass was not uniform, results are not of high precision. As far as creep resistance is concerned, the addition of 2.5% fiberglass improves this by a factor of 5. Addition of about 9% fiberglass increases the creep resistance by a factor of about 30 to 35 with a load of 300 psi. The effect on breaking strength is more complex, since the nature of the fracture changes. Samples tested without fiberglass failed with typical brittle fracture. Samples containing fiberglass formed cracks in the ice starting at applied stresses of about 150 $kg/cm^2$ (compared to fracture at 30 $kg/cm^2$ for the straight ice), but the sample remained able to maintain a considerable load even after the cracking of the ice matrix.

Another type of additive tested consisted of fiberglass strands used as a strengthening agent in compacted snow. During the compaction process stresses apparently were built up which prevented the satisfactory adherence of ice and fiberglass. Consequently, these results were not successful.

Fiberglass was also investigated as an additive during the formation of sea-ice solidification, both with rolled ice and with freely frozen ice. In both cases the strength levels were increased substantially by the addition of fiberglass as a reinforcement.

The optimum strengths obtained with fiberglass were an increase of a factor of 10 over the strength values of ice alone. This kind of increase has important implications with regard to processing techniques and use of ice in that substantially thinner ice layers can be used (where properly reinforced) with a subsequent saving in the processing expense and time requirements. Additional effort should be extended to develop optimum techniques, including the particular type of fiberglass which is most effective, the amounts which are useful, and methods of incorporating it which give best results.

## Ablation Control

An analysis of available data for solar radiation, ice and air temperatures for the 1953 season on ice island T-3 shows that only a small fraction of the incident radiant energy is consumed by melting ice and snow. The major portion is either re-radiated or goes into raising the temperature of the ice sheet. Consequently, small changes in the reflectance, emissivity, and insulation characteristics of the surface can have a large effect on the amount of ice that melts.

The effectiveness of various surface treatments has been considered and experimental measurements carried out on the Ellesmere Ice Shelf and at Eglin Air Force Base. These results show that, in agreement with calculations, a number of surfaces are better reflectors than ice or wet snow surfaces. In addition, many are more effective than snow as insulating layers on the surfaces. Few, if any, have the combined effectiveness of fresh snow which is an excellent thermal insulator, excellent reflector for solar radiation, and good emitter for low-temperature radiation. (Aged snow is neither a good insulator nor a particularly good reflector.) Consequently, a composite coating is required which must also have suitable mechanical properties.

Calculations and experimental observations indicate that summer melting can be substantially reduced at sites such as ice island T-3, and similar areas. In order to be effective, surface layers should be installed in winter before the ice begins to warm. Sites are being prepared for such studies at Ellesmere and at Point Barrow.

## Summary and Conclusions

In this investigation we have obtained sufficient experience and accumulated enough experimental data to reach definite conclusions as to the feasibility of various proposed methods of utilizing ice and snow as structural materials for arctic operations. Specific conclusions are:

1. Devices can be designed for more effective snow comminution that will give better properties to compacted structures. Additives in small amounts can also be developed to give higher densities and improved compaction properties.

2. In the solidification of sea water, controlled methods of rapid deposition appear feasible with lower salinities and higher strengths than are available in

natural ice. Appropriate process controls will give rise to better materials.

3. Additives to improve ice properties can be used which will substantially increase the strength and decrease the amount of material that must be processed.

4. Insulation, surface coatings, and possibly some refrigeration techniques probably can be developed which will substantially reduce, and in some cases eliminate, ice ablation and allow construction of more permanent structures.

In general, development of optimum techniques and practical methods for applying these findings and field trials of their utility are clearly indicated and should be vigorously pursued.

Kingery, W. D. (1959) Utilization of ice and snow in arctic operations, in Proceedings of the First Annual Arctic Planning Session, J. H. Hartshorn, ed. GRD Research Note No. 15, AFCRC-TN-59-256, ASTIA Doc. No. AD-212265, p. 43.

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