

ADHESION OF FRAZIL ICE TO UNDERWATER STRUCTURES

by

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ABSTRACT

The adhesion of frazil ice to different surfaces was studied in the laboratory under varying conditions. Field tests were made by submerging pipes, coated in a non-ice-nucleating grease, in frazil-producing rapids. The results of these experiments are discussed and the usefulness of protective coatings in preventing the adhesion of frazil ice to underwater structures is assessed.

Frazil is a term used to describe ice formed in supercooled water in swift-flowing streams or rapids. In the early stages of formation the ice particles are thin, circular discoids about 1/8 in. in diameter. As growth proceeds, however, dendrites grow out from the edge of the flat discs. Under favourable cooling conditions, these ice fragments form and group into large spongy masses sometimes termed "slush ice." Slush ice, floating from the area where it was formed, can, under severe conditions, completely block hydro-electric or water supply intakes.

Water supply intakes or pumps installed in the zone where ice crystals are actively produced (sometimes called the active zone) will have ice form and grow on them, which can result in blockage or partial blockage. Coating such underwater structures with a material that will inhibit or prevent ice formation, has been suggested as a means of controlling ice formed under these circumstances. Such coatings probably would not be of value for blockage caused by large amounts of slush ice.

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Piotrovich (1956) was one of the first to suggest that underwater structures be coated with a material such as plastic, to reduce the strength of adhesion of ice. Michel (1963) conducted several experiments in an outdoor flume and concluded that frazil will not cling to certain materials, the most important being amorphous plastic. As far as is known, however, special materials or coatings have never been used for preventing the adhesion of frazil on an operational basis. Because of lack of information, experiments were initiated to assess the usefulness of such protective coatings. The purpose of this paper is to report on the results of these experiments.

FACTORS THAT AFFECT THE ADHESION OF ICE IN SUPERCOOLED WATER

Several factors affect the rate at which ice will adhere to and grow on underwater structures in supercooled water. Chalmers (1961) and others have shown that the rate of ice growth is much greater if it grows on a metallic substrate which acts as a heat sink for removal of latent heat. Other factors, such as the degree of turbulence of the supercooled water, amount of supercooling, or shape of the underwater structure, can affect the rate at which latent heat is removed. Surface characteristics of the substrate will affect the structure and adhesion of ice as shown in papers by Kumai and Itagaki (1954) and Knight (1962). Impurities in the water, such as salt, can also affect the characteristics of the ice that is formed.

Of these variables, thermal factors are possibly the most significant. Priestley (1959) discusses the "conductive capacity" of a medium and points out that it is proportional to $pc\sqrt{k}$, where k is the thermal diffusivity of the medium, p is the density and c is the specific heat. The values he listed for water are as follows:

	<u>$pc\sqrt{k}$</u>
Still Water	0.039
Stirred Water:	
(a) Great stability	0.32
(b) Moderate stability	7.0
(c) Homogeneous, strong current	17.0

Values for some other materials are:

	<u>pc/√k</u>
Aluminum	1.6
Copper	0.8
Steel	0.3
Glass	0.04
Ice	0.05
Rubber	0.02)
Wood	0.01) - varies
Plastic	0.015)

If pc/\sqrt{k} is a measure of the ability of a material to conduct heat away from its surface, then the latent heat released by ice formed in supercooled water would be conducted away about 50 to 100 times faster by aluminum and copper than by rubber, wood, or plastic. Heat would be conducted away by homogeneous, strong currents about 10 times faster than by aluminum. Under slow mixing conditions, however, heat would be conducted away faster by a metal substrate, and the rate of ice growth would be greater on a metal surface than in supercooled water.

From the foregoing it is evident that the thermal properties of a material, its ability to accept or absorb heat, should have a significant influence not only on the rate at which ice might form on its surface, but also, possibly, on the ability of an adhesive bond to be formed between ice carried by the flowing water and the solid.

EXPERIMENTS

Frazil ice was produced in a cylindrical, thin-walled, plastic container about 8 in. in diameter and 10 in. high. The water in the vessel was cooled below the freezing point by placing the vessel inside an anti-freeze bath, the temperature of which could be controlled. The water in the plastic container was kept mixed by a mechanical stirrer, the speed of which could be controlled. The rate of cooling of the water was varied by changing the temperature of the anti-freeze and the rate of mixing. Thermocouples were installed in the water bath, and the water temperature was recorded on a Leeds and Northrup recorder. At a desired amount of supercooling the water was seeded with a small particle of ice resulting in frazil formation in the container.

Three vertical 1/2-in. diameter posts were completely submerged in the water bath, equidistant from the centre of the plastic vessel. One post was made of steel, the second of plastic and the third of steel,

coated with plastic. Thermocouples were embedded in the centre of the posts, and the temperatures recorded. The adhesion of ice to the posts was observed visually.

Figure 1 shows a typical change of water temperature with time. Almost immediately after nucleation, minute ice particles were visible in a flashlight beam directed into the water, and the temperature of the water increased because of released heat of fusion. Shortly after the frazil was visible, a thin layer of spiral sheet ice could be seen growing on the steel bar. Sheet ice was not observed in any of the experiments on either the plastic bar or plastic-coated steel bar, but this might have been due to the difficulty of observing clear ice on this material.

Figure 2 shows frazil ice accumulated on the metal stirrer at the end of a run. For the experiments the stirrer was coated with a non-ice nucleating grease to prevent frazil ice adhering to it.

Figures 3a and 3b show typical cooling curves for the centre of the steel post, the plastic-coated steel post and the plastic post. For all tests there was a decided difference between the temperature at the centre of the steel bar and the temperature at the centre of the plastic-coated steel. For supercooling of 0.1°C . or less, frazil would collect on the steel bar but not on the plastic bar or plastic-coated steel bar. If the amount of supercooling was increased, frazil could be observed clinging to the plastic bar and plastic-coated steel bar, but the amount that collected was much less than the amount that collected on the steel bar.

Figures 4a and 4b show the cooling curves obtained for supercooling of between 0.20 to 0.30°C . Trials with greater supercooling were made, but the rapid growth of frazil hampered visual observation of the ice accumulation. In these runs the spiral sheet ice formation was clearly visible on the steel bar but not on the other bars. For some of these cooling runs, however, ice crystals could be observed forming on the inside surface of the plastic vessel where the rate of cooling would be greatest. Sometimes when this happened, frazil ice would not form but, instead, a layer of surface ice would grow on the inside of the plastic container.

In further experiments in a cold room where frazil ice was produced by cooling the surface of the water at a slow rate, the temperature at the centre of the plastic bar did not approach 0°C . until after the water temperature had returned to 0°C . at the end of a cooling run. Under these conditions frazil ice would not cling to the lower part of the steel bar, but only to the upper part where cooling was the greatest.

The minimum rate of cooling in these experiments was about 1.2°C./hr. which is more representative of the cooling rate reported by Michel in his outdoor flume (1-4°C./hr.). The minimum rate of cooling associated with frazil production in a river is reported to be .01°C./hr. (Granbois, 1953).

In assessing these results, the difference between the way frazil is produced in a laboratory and the way it is produced in the rapids of a river must be emphasized. In the laboratory, frazil production is not a continuous process as a cooling run lasts only for the few minutes required for a small volume of water to supercool a few hundredths of a degree and then warm up to 0°C. In a river, frazil will be produced or "manufactured" continuously for several hours or even days under prolonged, severe, cooling conditions. Submerged objects subjected to several hours of cooling would be at a temperature close to that of the surrounding supercooled water. Under these conditions, the thermal properties of the material might not significantly affect the rate of accumulation of ice on the surface.

TEST OF NON-ICE-NUCLEATING GREASE

A non-ice-nucleating surface coating which would keep its effectiveness after prolonged exposure to supercooled water would be of value in preventing frazil ice adhering to the surface of underwater structures. Some preliminary experiments were conducted to test the effectiveness of non-ice-nucleating grease under laboratory and field conditions.

Silicon grease (a special non-ice-nucleating grease) was tested by applying it to a steel bar. Several experimental cooling tests were made at various amounts of supercooling. The adhesion of ice to the coated bar was checked by visual observation. In every test no ice was observed on the silicon-coated steel post and frazil did not accumulate on it. Coating the metal stirrer with the silicon grease also prevented frazil from clinging to it.

The usefulness of the silicon grease was checked under field conditions by coating three 1-in. diameter metal pipes with the grease and submerging the pipes in shallow, frazil-producing rapids. For a period of three weeks in the winter of 1964-65, frazil was produced in the rapids, forming heavy accumulations on uncoated steel wires and pipes. Frazil did not form or accumulate on the pipes coated with the grease. No tests were made on long-term effects of this grease, i.e., whether the grease would inhibit the adhesion of frazil after prolonged exposure.

CONCLUSIONS

The laboratory experiments demonstrated that the thermal properties of materials affect the ability of frazil ice to adhere to them. Under laboratory conditions and supercooling of 0.1°C ., frazil will adhere to steel but not to plastic or plastic-coated steel. For supercooling $.2-.3^{\circ}\text{C}$., frazil will adhere to plastic and plastic-coated steel but in lesser amounts than to untreated steel.

A silicon grease was tested and found to inhibit the adhesion of frazil to metallic objects during frazil production. This grease was effective, as well, in preventing the accumulation of frazil on 1-in. diameter steel pipes under field conditions.

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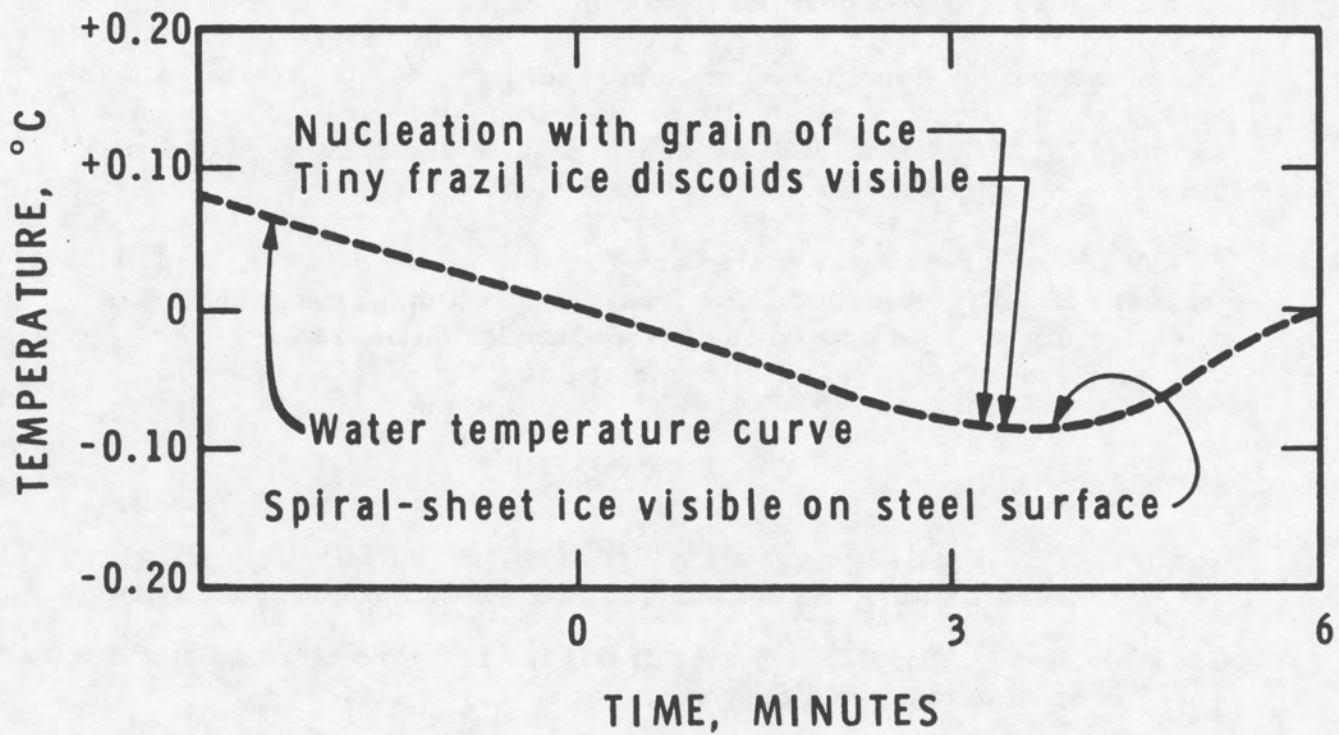


FIGURE 1
TYPICAL COOLING CURVE - FRAZIL ICE RUN

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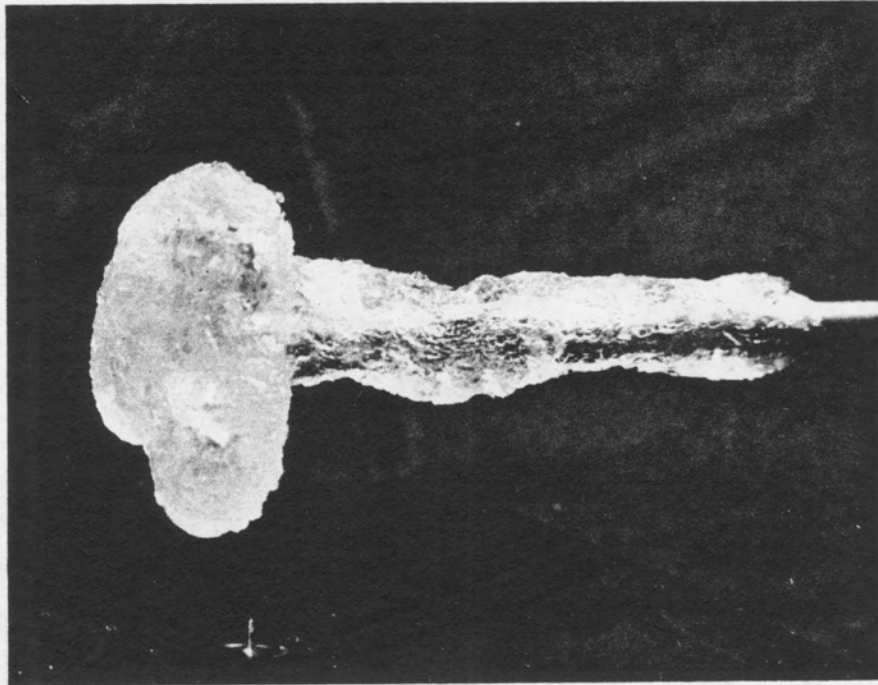


Figure 2 Frazil ice accumulation on stirrer used in experiments.

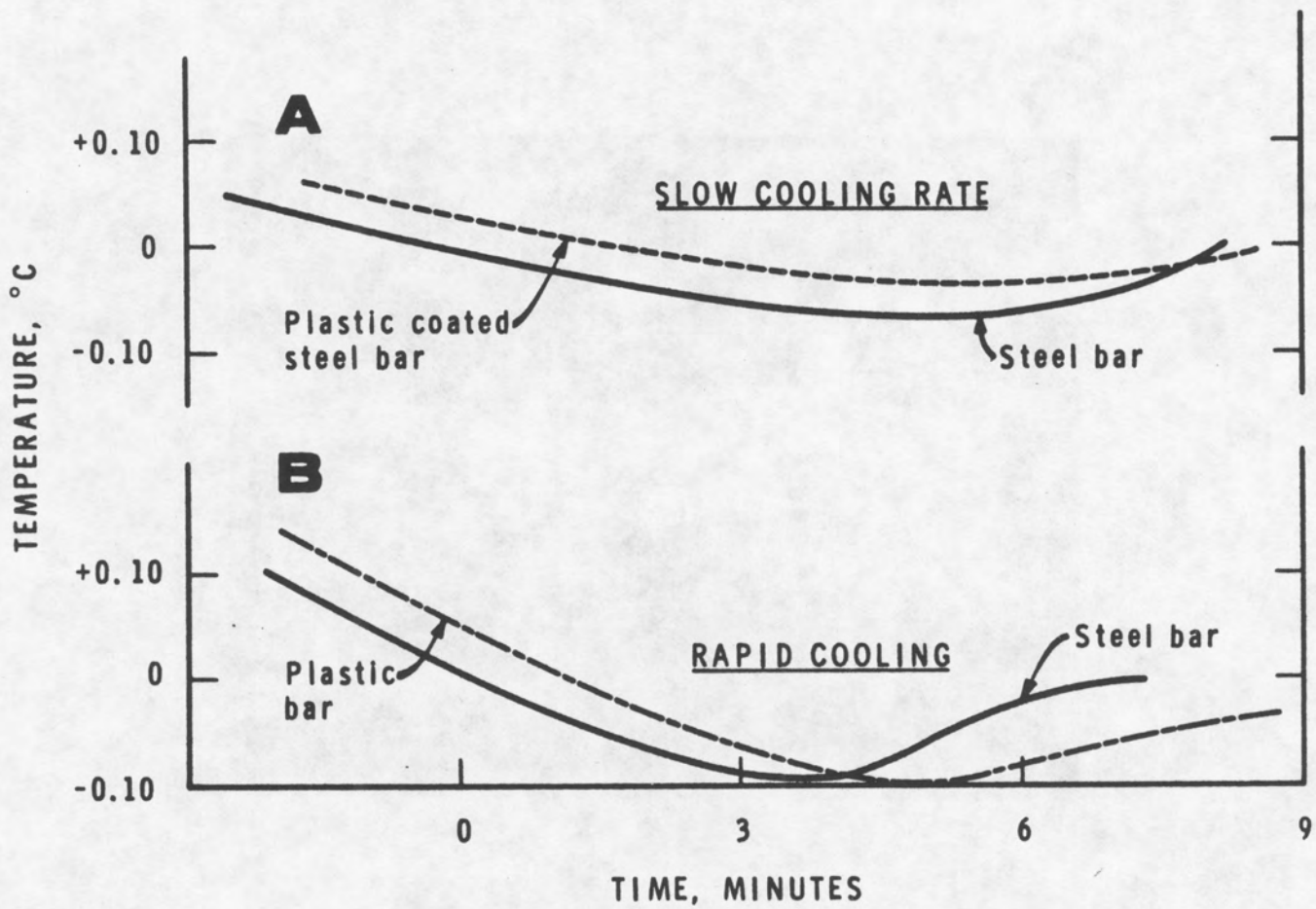


FIGURE 3

FIGURE 3
 COOLING CURVES FOR PLASTIC, PLASTIC-COATED STEEL, AND STEEL BARS

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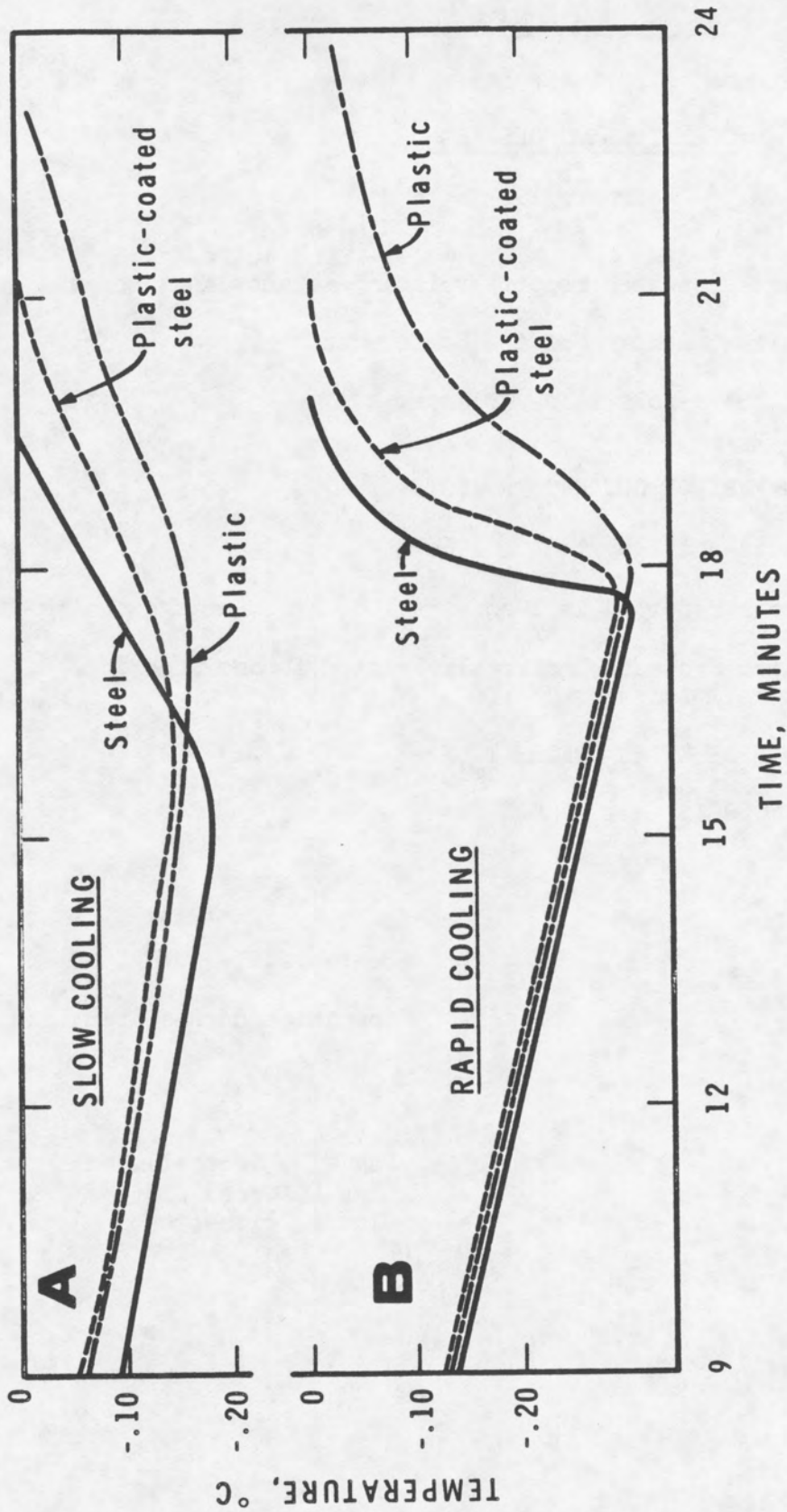


FIGURE 4
 COMPARISON OF STEEL, PLASTIC-COATED STEEL, AND PLASTIC BARS
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