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EXPERIMENTAL STUDY OF FRICTIONAL COEFFICIENT BETWEEN MODEL ICE AND A MODEL SHIP

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ABSTRACT
The importance of frictional resistance has increased for ice-going vessels navigating in the Arctic Ocean because the extent of the sea ice is decreasing more rapidly than predicted. Frictional resistance mainly depends on the frictional coefficient between the ship's hull and the sea ice. It also relies on factors such as the roughness of surface of the hull, the ship's speed, sea ice conditions, floe size, lubrication conditions, and air and sea ice temperatures.

In this paper, we studied frictional coefficients between a model ship and model ice to predict frictional resistance at the model test stage. We used various materials with ethylene glycol/aliphatic detergent (EG/AD) model ice to measure the frictional coefficient, and analyzed the results with those of previous studies. In addition, we verified test methods for the frictional coefficient in the test model. Finally, we evaluated the ability of paint containing different amount of matting powder to control the frictional coefficient between the test sample and the model ice.

INTRODUCTION
The number of ships sailing the Arctic Ocean is gradually increasing, particularly since two German ships, Beluga Fraternity and Beluga Foresight, completed the first commercial journeys across the Northern Sea Route (NSR) linking Busan to Rotterdam in 2009 (Brigham, 2010). In addition, recent research has found that the extent of the sea ice in the Arctic Ocean is decreasing more rapidly than predicted due to global warming and unseasonal weather (Meier et al., 2006). At present, the government of the Russian Federation is drawing up plans to enlarge the economic efficiency of the NSR. Eventually, the NSR will be used more frequently, except during harsh winter seasons, as icebreakers will be strategically placed to guide fleets of ice-class vessels through a safe route at each zone.

The resistance and propulsive performances in broken ice channels, safe operation with the help of a fleet of ice-class vessels, and equipment able to deal with the harsh conditions are more important for commercial ships sailing the NSR than ice-breaking capabilities or maneuverability. The most important factor associated with resistance and propulsion in broken ice channels is the frictional resistance between the ship's hull and the broken ices. Therefore, several devices to decrease frictional resistance such as air-bubbles and water-jet systems have been developed and applied to the bow and mid-ship of ice-class vessels (Lecourt and Major, 1978). Furthermore, some paint companies are developing several paints aimed at reducing the friction of ice-class vessels, thereby making the vessels simultaneously strong, smooth, and capable of dealing with ice impacts and interactions (HYDREX, 2011).

In this paper, we first review some advanced research related to the frictional resistance of ice-class vessels. We then measure the frictional coefficient between EG/AD model ice and various materials and compare the results with those of other studies. Moreover, we evaluate a painting method for a model ship for an ice-class vessel; the method involves the addition of small amounts of matting powder to control the surface roughness. This study is intended to contribute to the development of painting techniques for model ships in the Korea Institute of Ocean Science and Technology (KIOST) ice model basin. We expect the findings of this study to improve the accuracy of tests of model ships for ice-class vessels.

ADVANCED RESEARCH

In the late 1930s, Bowden et al. (1939, 1940) published several papers associated with tribology, focusing especially the lubrication effect of pressure melting and frictional heat on ice and snow. Since the 1950s, numerous ice trials and ice model tests have been undertaken to estimate a ship's performance in ice-covered waters (Milano, 1975). The prediction of the ice-breaking capability of a vessel has long constituted an important domain of research. In the 1970s, there was a renewal of interest in the resistance component related to the friction of ice in some ice model basins. Enkvist (1972) measured the frictional coefficient between metal plates and model ice, and showed that the frictional coefficient at metal plates over ice decreases as the normal load increases. The frictional coefficient at ice over metal plates, on the other hand, is constant above a specific normal pressure (1.3 kPa). Ryvlin (1973) concluded that the frictional coefficient decreases at a load of 10 kPa or less through a field test in freshwater ice. In 1975, Vuorio reported that the frictional coefficient of ice over a hull sample increases as the speed increases, whereas the frictional coefficient at a hull sample over ice remains constant at a change of speed. Furthermore, Vuorio stated that the roughness of a sample hull would greatly affect the frictional coefficient, but is not absolute. For example, a sample of Inerta160 paint had a lower frictional coefficient than an aluminium sample, even though the roughness of the sample of the Inerta160 paint (1.6μm Ra) was much higher than that of the aluminium sample (0.3 μm). Augstein et al. (1984) conducted various ice-breaking trials with the Polarstern off the Labrador coast. In particular, they attached three 1 m^2 load cells in the fore-body below the water line. They measured the normal load, as well as the tangent load, in two directions. They found that the frictional coefficient decreases with an increase in normal load and that the velocity seems to have no significant effect on the frictional coefficient. In addition, they showed the average frictional coefficient in various kinds of ice conditions (Table 1).

Table 1. Frictional coefficient between sea ice and ship's hull (fore-body).

Ice Condition	Frictional Coefficient	
	Middle Pocket Mean Value	Rear Pocket Mean Value
Total Voyage	0.15	0.13
Level Ice	0.13	0.11
Ice Floes	0.18	0.14
Ridges	0.16	0.09
Mush Ice	0.13	0.12
Ramming	0.09	0.07

The 16th International Towing Tank Conference (ITTC) ice committee analyzed three model test results carried out in three different ice model basins (Arctec U.S., Hamburgische Schiffban Versuchsanstalt (HSVA) GmbH and Wartsila) with liquefied natural gas (LNG) carrier models and suggested that differences between the three results were caused by their different frictional coefficients (1981). The 18th ITTC ice committee (1987) also introduced painting methods for a model ship at the HSVA and Wartsila Arctic Research Centre. Bell and Newbury (1991) developed a new painting method for a model ship using magnesium silicate (MgSi). Recently, the impact resistance and the anti-icing capability of coatings for ice-class vessels have been strengthened. Thus, new full-scale studies of the frictional coefficient between the new coating on the hull and the sea ice should be investigated in detail to estimate the ship's performance in the ice model basin accurately.

EXPERIMENTAL SETUP

Test samples

The test samples were classified into four groups according to Table 2. The first group was selected to verify the frictional coefficient of various materials. The second group consisted of a conventional paint applied to commercial ship at the KIOST towing tank, a Gelcoat solid that is sprayed in the air and coated as a solid type, and a Gelcoat liquid that is directly sprayed onto the surface of the sample and coated as a liquid type. The third group was composed of paint containing varous amounts of MgSi to evaluate the effect of the matting powder. As this was the first time to test the matting powder, 12 g, 24 g, and 36 g of MgSi were projected into the clear lacquer and diluent. Results of testing showed that the paint should contain only a small quantity of MgSi. The final tests, the fourth group, contained the amounts shown in Table 2.

Table 2. Classification of test sample.

Group	Sample materials
1	Coated steel, Uncoated steel, Glass, Wood, Rubber
2	Conventional paint, Gelcoat solid, Gelcoat liquid
3	MgSi 12 g, MgSi 24 g, MgSi 36 g
4	MgSi 1 g, MgSi 2 g, MgSi 3 g, MgSi 4 g, MgSi 5 g

EG/AD model ice

In this study, EG/AD model ice was used. The thickness of the model ice was more than 30 mm, and flexural strength of the model ice was greater than 40 kPa. A sample of the model ice was cut and moved to an ice friction measurement device. To verify the effect of the side of the model ice, we tested both sides: the top side comes into contact with the air, whereas the bottom side is immersed in the tank water.

Test procedures

First, we placed a test sample into the ice friction measurement device and checked the gradient of the device and the test sample. Second, we sprinkled the surface of the test sample with 50 ml of tank water and eliminated this step if the test condition was dry. The cut model ice was located into the tray, and a deadweight was loaded on the model ice. The test was then conducted using a digital control of a computer. Table 3 shows the test matrix carried out in this study.

Table 3. Test matrix.

Test sample	Speed (m/s)	Model ice	Normal load (N)	Lubrication
Group 1	0.1, 0.3	Top side	49.033, 98.067	Wet
Conventional paint	0.05, 0.1, 0.2, 0.3, 0.4	Top side	49.033, 98.067	Wet
Conventional paint	0.1, 0.2	Top side	0, 49.033, 98.067	Wet/Dry
Conventional paint	0.3	Top/Bottom side	0, 49.033, 98.067	Wet
Group 2	0.357	Top side	0, 49.033, 98.067	Wet
Group 3	0.2	Top side	49.033, 98.067	Wet
Group 4	0.2	Top side	49.033	Wet

Ice friction measurement device

We developed an ice friction measurement device to measure the frictional coefficient between the hull sample and the model ice, as shown in Fig. 1. This device measures the friction force of the test sample over the ice, as well as the force directly over the ice touching the flat part of the model ship. The tray that holds the sample of model ice is moved along a track by an electric motor. The speed of the tray can be precisely controlled by a computer. The normal load is provided by a dead-weight. The friction force is measured by a load cell, which is attached to the tray when a sample of the model ice moves on a test sample.

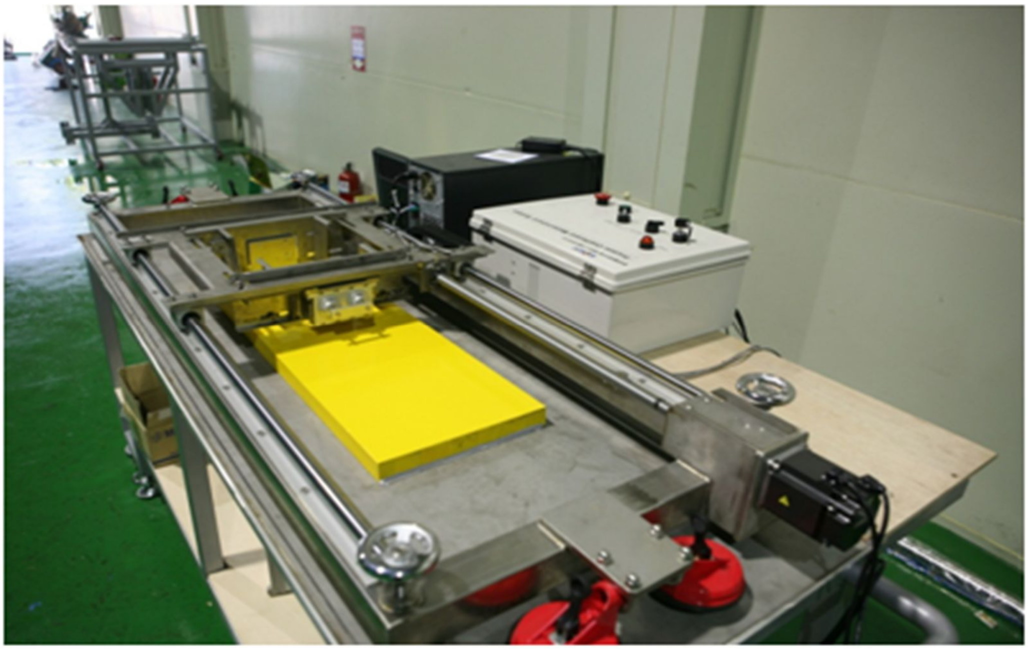


Figure 1. Ice friction measurement device.

TEST RESULTS

Various materials

Various materials were prepared, and their frictional coefficients with the model ice were tested. First, their friction forces were measured by a measurement device and were divided by the sum of a normal load and a model ice weight. Figure 2 shows the mean frictional coefficient between a range of materials and the model ice. The values did not change greatly with a change in the moving speed, except with wood materials (plywood). The value for glass was lowest whereas that of wood was highest. In addition, the value for coated steel was about 0.05, but the value for uncoated steel was under 0.02. The coating or treatment of the surface could exert a dominant effect on the frictional coefficient with the ice. We verified that the frictional coefficient between the coated steel and the model ice that is similar to the frictional coefficient between a coated ship's hull and sea ice.

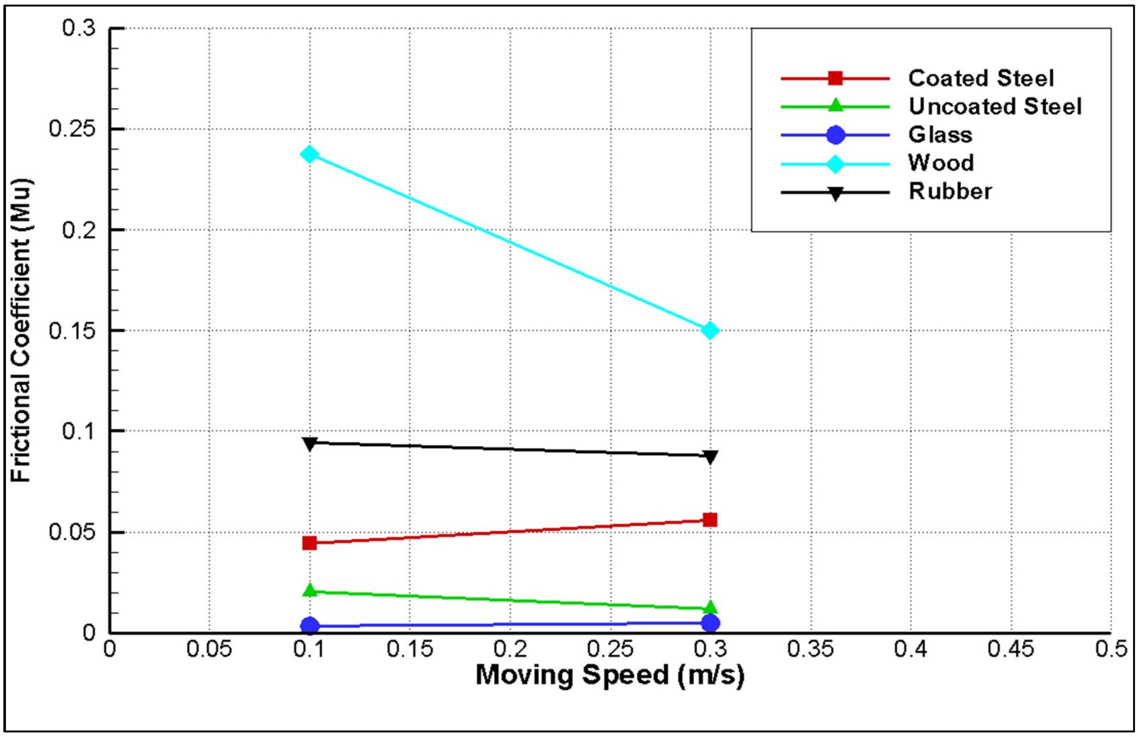


Figure 2. Frictional coefficients of various materials with EG/AD model ice.

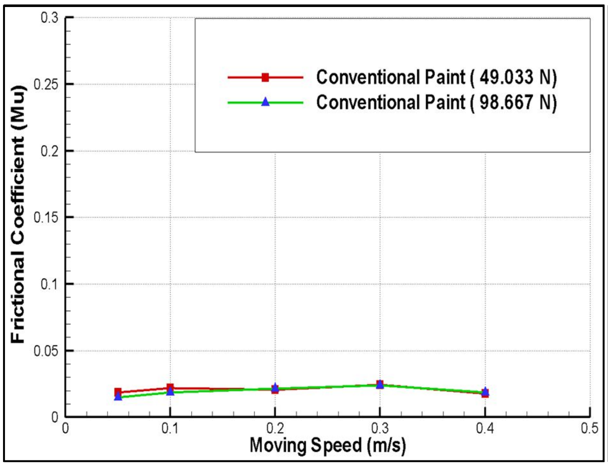
Change of test conditions

To validate the measurement method of the frictional coefficient in the KIOST ice model basin, some test conditions were changed, and the results were plotted, as shown in Figure 3. In Fig. 3(a), the frictional coefficient at a wide range of speeds is shown. It demonstrates that the moving speed exerted no effect at either 5 or 10 kgf of normal loads.

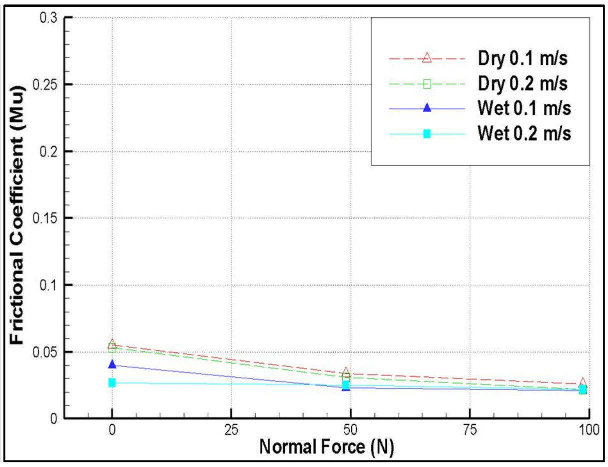
Figure 3(b) shows the results of the frictional coefficient under dry and wet friction conditions. The value under the dry friction condition is greater than that under the wet friction condition. The trend is similar to that reported in advanced research. As the wet friction condition is normally generated when an ice-class vessel sails in ice-covered water, we determined the frictional coefficient under this condition in this research.

In figure 3(c), the effect of both sides of the EG/AD model ice is indicated with the change of normal load. The test results showed that the difference between the top and the bottom side is not great. However, the top side of the model ice was used in this study to maintain the test condition.

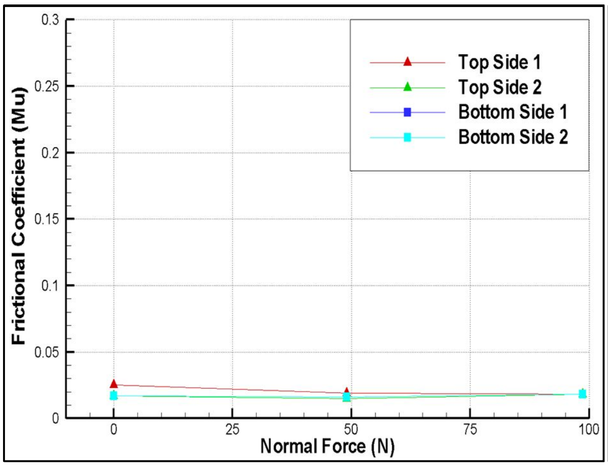
In figure 3(d), a conventional paint, a Gelcoat solid method, and a Gelcoat liquid method are compared. The frictional coefficient values with both Gelcoat methods were greater than the target value (0.05). The Gelcoat solid method had a frictional coefficient of 0.23, whereas the Gelcoat liquid method had a frictional coefficient of 0.16. The results show that paints with the same components can yield different values, demonstrating that the method of application is very important.



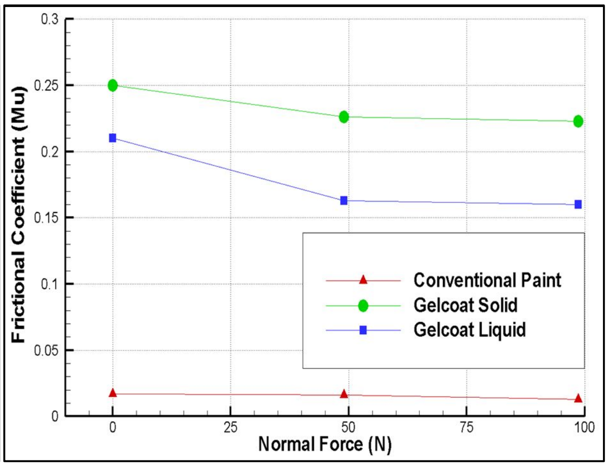
(a) change in the moving speed



(b) change in the normal load



(c) change in the side of the model ice



(d) change in the components of the test samples

Figure 3. Frictional coefficients according to the change in the test conditions.

New type of paint

The frictional coefficients of the test samples that were painted with the different amounts of the matting powder are plotted in Fig. 4. The frictional coefficient increased as the amount of the matting powder increased. There was no difference between the model ice exposed to heat for 10 and 16 h to reduce the flexural strength of the model ice. Consequently, we concluded that the frictional coefficient of a test sample or a model hull can be controlled by regulating the amount of matting powder and that this paint could be applied when manufacturing model ice-class vessels in the KIOST ice model basin.

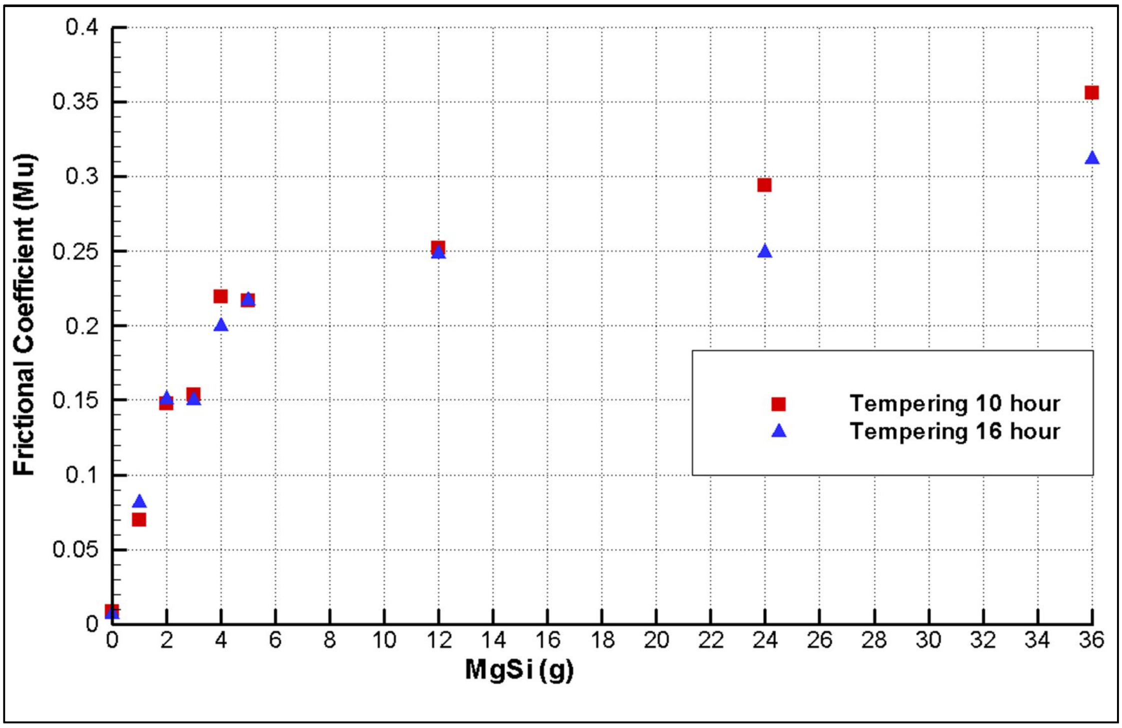


Figure 4. Frictional coefficient vs. amount of MgSi in the lacquer and diluent.

CONCLUSIONS

This study was conducted to develop an effective model paint for the hulls of ships in the KIOST ice model basin, as well as an efficient method of paint application. We evaluated the frictional coefficients of various materials with model ice, as well as measurement techniques of the friction coefficient. In particular, we found that Gelcoat paints yield surfaces that are too rough for application to model ice-class vessels. Finally, we verified a new painting method, which involves the addition of small amounts of MgSi to lacquer and diluent. With this method, the frictional coefficient between a test sample and model ice is controlled in the range of the target value.

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