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AN EXPERIMENTAL STUDY ON A NEW METHOD USED TO PREPARE GRANULAR EG/AD MODEL ICE

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ABSTRACT

This study proposes a new method of preparing granular ethylene glycol/aliphatic detergent (EG/AD) model ice that has both strength and uniform thickness. Various sheets of granular model ice prepared in ice tanks are surveyed and their preparation procedures are analyzed. We not only made a new granular model ice using the EG/AD solution but also measured its thickness, strength, and density. In addition, we found that the strength of the model ice could be controlled by varying the time and air temperature in the consolidation phase. Based on the results of this study, we verified that granular EG/AD model ice can be prepared more uniformly and effectively than columnar EG/AD model ice. This study is intended to contribute to reducing the time required for the ice model test and the operation of the ice model basin.

INTRODUCTION

The preparation of model ice is the most basic and sufficient procedure in ice model tests, and it is one of the most important factors in testing and assessing the performance of ice breaking ships and platforms in the Arctic region. Therefore, a model ice should be accurately prepared to replicate the real sea ice conditions in which icebreakers and platforms are operated. Moreover, because the prepared ice conditions are measured in detail, the accuracy of the model test is increased.

The many commercial ice facilities worldwide use their own methods to prepare model ice, which is classified into two groups: columnar model ice, which is a solid structure, and granular model ice, which is layered by spraying continuously with a solution. The results of advanced research showed that the two type of model ice have different physical properties, each having unique advantages and disadvantages (Wang and Lau, 2007).

The ice model basin at the Korea Research Institute of Ships and Ocean Engineering (KRISO) is used to conducted model tests with columnar EA/AD model ice, which was developed from ethylene glycol/aliphatic detergent/sugar (EG/AD/S) model ice (Timco, 1986) and is similar to the properties of EG/AD/S model ice (Cho et al., 2010). Columnar EG/AD model ice may show behavior similar to real ice when it contacts a ship or platform because sea ice and columnar model ice have similar structures. However, its lateral non-uniform thickness could increase because of the air bubbles in the initial spraying layer, which controls the density of the model ice. In addition, it needs much more time to prepare.

Moreover, granular model ice not only grows uniformly because the solution in the tank water is sprayed uniformly but also has uniform mechanical properties. This reduces the uncertainty of the model test because it produces results similar to computational fluid dynamics (CFD). Furthermore, ice sheets are efficient, and they are easy to prepare and control because they take less time to prepare, compared to columnar model ice. However, in model tests, granular model ice may not include the ice failure mechanism in icebreakers. The compressive strength of granular model ice is much less than that of columnar model ice and sea ice.

This paper reports an experiment designed to prepare granular EG/AD model ice in a cold room facility. We verified that a granular EG/AD model could be prepared and applied in the ice model basin. The results showed not only the characteristics, preparation procedure, and strength control method of granular EG/AD model ice but also its advantages in operating the ice model basin. In addition, we analyzed the detailed procedure and hazardous factors for preparing uniform granular EG/AD model ice. If both columnar model ice and granular model ice are used appropriately, the operational efficiency of the KRISO ice model basin will be improved.

ADVANCED RESEARCH

Enkvist and Makinen (1984) first proposed granular model ice (fine-grained [FG] saline ice) to compensate for the disadvantages of columnar model ice, which has two layers: a hard top layer and a soft columnar-grain main layer. The preparation of the FG model ice used 2% saline water in the tank solution, which was made by spraying saline water onto the ice to build up the ice layers. The FG model was produced in a seven-step process involving seeded initial layers, a sprayed main layer, consolidation, tempering, and so on. The grain size of the FG model ice was about 0.5 mm, and the E/σ_f ratios were generally between 1000 and 2000.

Urea-doped model ice was used when the Nippon Kokan (NKK) built an ice model basin in 1982, but it was found that this double-layered model ice caused serious problems, including the separation of the top layer and the main layer, large broken ice pieces, and considerable residual stress after bending failure. Subsequently, Narita et al. (1988) developed urea-doped granular ice and described its preparation in detail. They used a high concentration (25%) of urea tank water and a low concentration (5‰ to 13‰) of urea-sprayed water because the ice particles initially sprayed no longer grew toward the tank water. They reported that it took about nine hours or about 100 sprayings to produce an ice sheet that was 60 mm thick. Figure 1 shows different crack patterns in columnar and granular model ice, created by the same ship model.

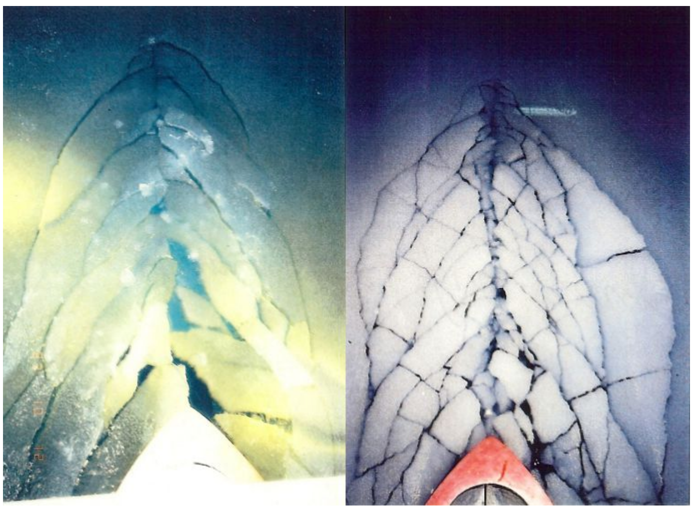


Fig. 1 Crack patterns created by the same ship model under the same value of flexural strength; left: columnar model ice, right: granular model ice (Narita et al., 1988)

In 1987, the Masa Yard Research Centre (MARC) introduced an improved version of finely grained model ice, FGX model ice (Nortala-Hoikkanen, 1990). FGX model ice uses different salinities in the spray water (0.1–1.6%) and the tank water (1.5%), whereas FG model ice uses 2% saline water. As shown in Fig. 2, the manufacturing process is divided into the following phases: 1) initial seeding; 2) spraying; 3) preserving; 4) hardening; 5) tempering. They reduced the preparation time by 30%, compared with the time required to prepare FG model ice. The E/σ_f ratios were four times higher than that of FG model ice. They also showed that because of its physical properties and preparation procedure, it has many advantages.

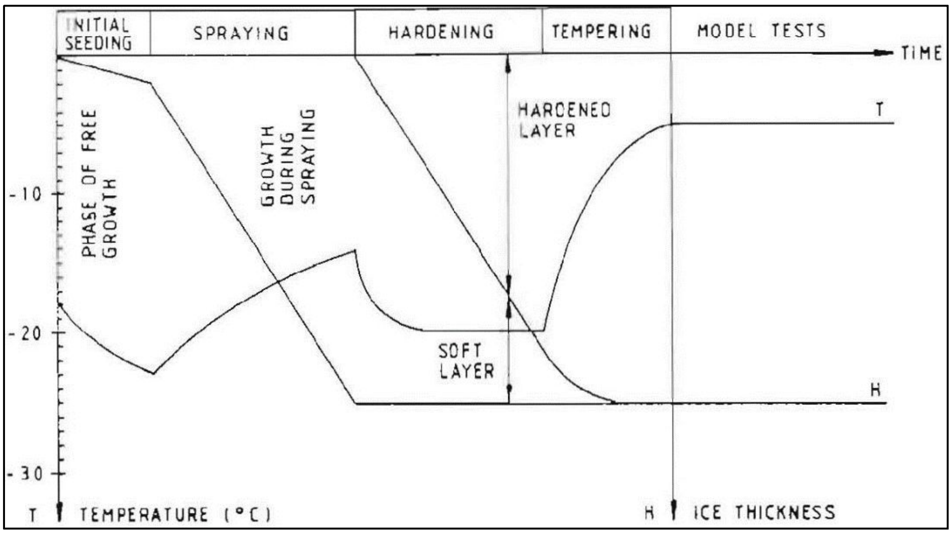


Fig. 2 Schematic diagram of the manufacturing method of FGX model ice (Nortala-Hoikkanen, 1990)

Jalonen and Ilves (1990) introduced granular ethanol (GE) model ice by using a 0.5% ethanol solution at the Helsinki University of Technology in Finland. Approximately five hours for spraying, six hours for preservation, and five hours for consolidation were required to produce a 30 mm thick layer of model ice. GE model ice is brittle, and it shows realistic bending failure characteristics without remnant forces.

Table 1 Major characterisitcs of four different kinds of granular model ice

Model ice	Tank water	Sprayed water	Build rate	Flexural strength (kPa)	E/σ_f	Compressive strength (kPa)	Density (Mg/m^3)
WARC -FG	Saline of 2%	Saline of 2%	70mm/ overnight	20~75	1000~ 2000	50~400	0.89
NKK -Urea	Urea of 2.5%	Urea of 0.5~1.3%	6.7 mm/h	15~45	200~ 310	10~45	0.92
MARC -FGX	Saline of 1.5%	Saline of 0.1~1.6%	30% faster than FG	15~90	700~ 8000	15~180	0.88~0.9 1
HUT -GE	Ethanol of 0.5%	Ethanol of 0.5%	6 mm/h	15~90	1000~ 2000	15~55	NR

EXPERIMENTAL SETUP

Cold room facilities

Granular EG/AD model ice was built in the KRISO cold room (5 mL x 4 mB x 2.5 mH), using a miniature acrylic tank (1.5 mL x 0.8 mB x 0.6 mD). Although the air temperature can be cooled to -55 ℃ in cold room, we prepared the model ice at around -20 ℃, based on the results of advanced research and experience with columnar EG/AD model ice. In addition, the miniature tank was covered by four polystyrene sheets 200 mm thick in order to block the wall effect, as shown in Fig. 3.

The tank water was the same as the solution in KRISO's ice model basin: a diluted aqueous solution of ethylene glycol and aliphatic detergent in approximate ratios of 0.39/0.036%. The aliphatic detergent was dissolved by hot water at about 50 ℃ because it is difficult to liquefy at normal temperature. In addition, the sprayed water was the same as the tank water.

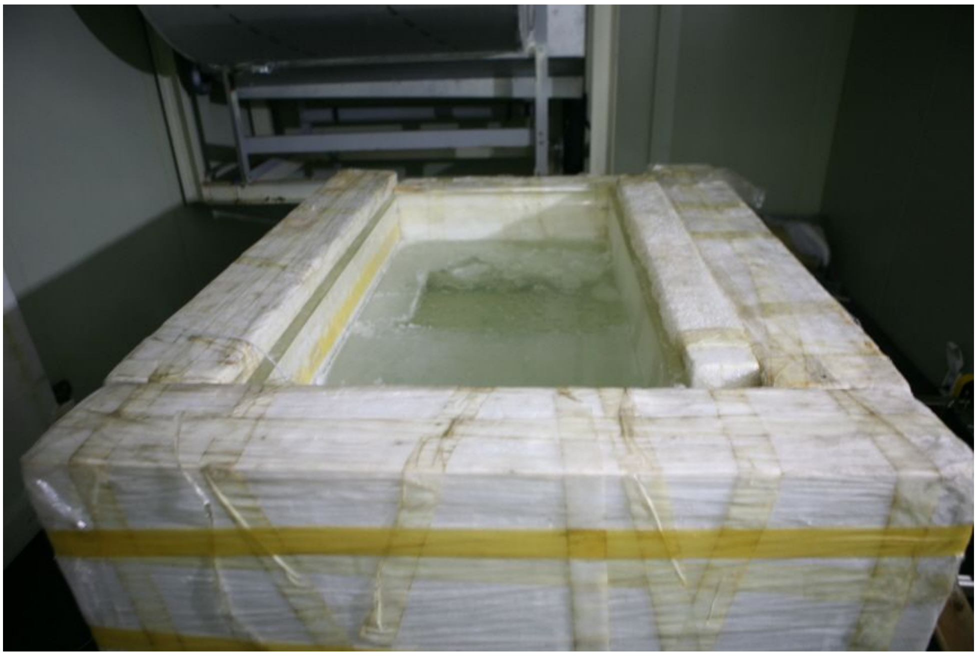
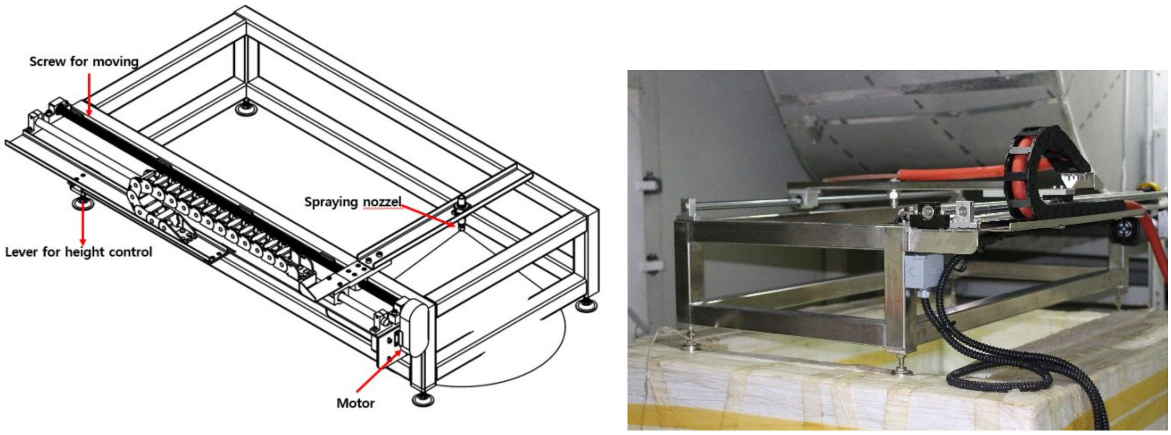


Fig. 3 Miniature acrylic tank of granular EG/AD model ice, covered by four polystyrene sheets 200 mm thick

Auto-spraying machine

An auto-spraying machine was built to spray the water particles evenly (Fig. 4). The machine consists of a spraying nozzle, a moving device in the direction of length, a pump, pipes, a tank for the sprayed water, and a control console. To ensure wide distribution, the angle of the spraying nozzle is 120°, and a micro filter is installed inside the pipes to eliminate foreign substances. The spraying nozzle can be moved at speeds of 0.01 ~ 0.1 m/s and is automatically controlled by the control console. The rates of flow and nozzle pressure were 0.2 l/min. and 0.3 MPa (approximately 3 kg/cm^2), respectively, to facilitate changes in the phases of spraying the sprayed water. A devise to height adjustment is also attached to the main frame, in order that the water is sprayed accurately and uniformly. The pipes and spraying nozzle are wrapped in a heating coil.



(a) Schematic of auto-spraying machine (b) Auto-spraying machine with the miniature tank

Fig. 4 Auto-spraying machine for granular EG/AD model ice

Test procedures

The procedure for the columnar EG/AD model ice at 40 mm thick was developed in the KRISO ice model basin, as shown in the top of Fig. 5 (Cho et al., 2010). It took about 18 hours to produce a 40 mm thick ice sheet, including the pre-cooling and seeding phases, and about 33 hours to prepare an ice sheet with a flexural strength of approximately 30 kPa, including the tempering phase. The reason is that the growth rate of columnar EG/AD model ice is about 2.5 mm/h at -20 ℃, and the initial flexural strength measures more than 250 kPa when the tempering phase starts.

First, the tank water must be cooled below 0 ℃ and the room temperature decreased to -20 ℃ in order to build granular EG/AD model ice. This is a fundamental condition for the surface of the water. The sprayed water in the storage tank is simultaneously cooled to 5 ℃ to change the sprayed water into ice particles and to prevent the spraying nozzle from freezing (pre-cooling phase).

Other ice model basins include an initial seeding phase. However, the droplets of the EG/AD solution safely fall onto the water surface as ice particles. Therefore, the procedure instantly enters the spraying phase without any change in room temperature. At this moment, the spraying nozzle is activated in a reciprocal motion at a constant speed of 0.05 m/s, and the room temperature is maintained at -20 ℃(spraying phase).

The auto-spraying machine and refrigerator are shut down when the ice sheet is close to the target thickness. Granular EG/AD model ice only needs about 30 minutes in the preservation phase, which was shown in experiments with columnar EG/AD model ice. GE model ice requires more than five hours to form ice particles (conservation phase).

The ice particles must combine as an elastic body through the consolidating phase, even though the granular EG/AD is still plastic after the conservation phase. We found the optimal environment condition in which flexural strength can be controlled by changing the time and room temperature during the consolidating phase: the maintenance time was more two hours and the room temperature was below -15 ℃.

Finally, the tempering phase starts to control the flexural strength of the model ice, as in columnar EG/AD model ice. The flexural strength of granular EA/AD model ice highly depends on the consolidating phase. We found that it reached the target within eight hours under the optimal condition. Therefore, the room temperature is heated to approximately 2 ℃ by the heater and maintained at that level. The procedure for the granular EG/AD model ice is plotted as shown in the bottom of Fig. 5.

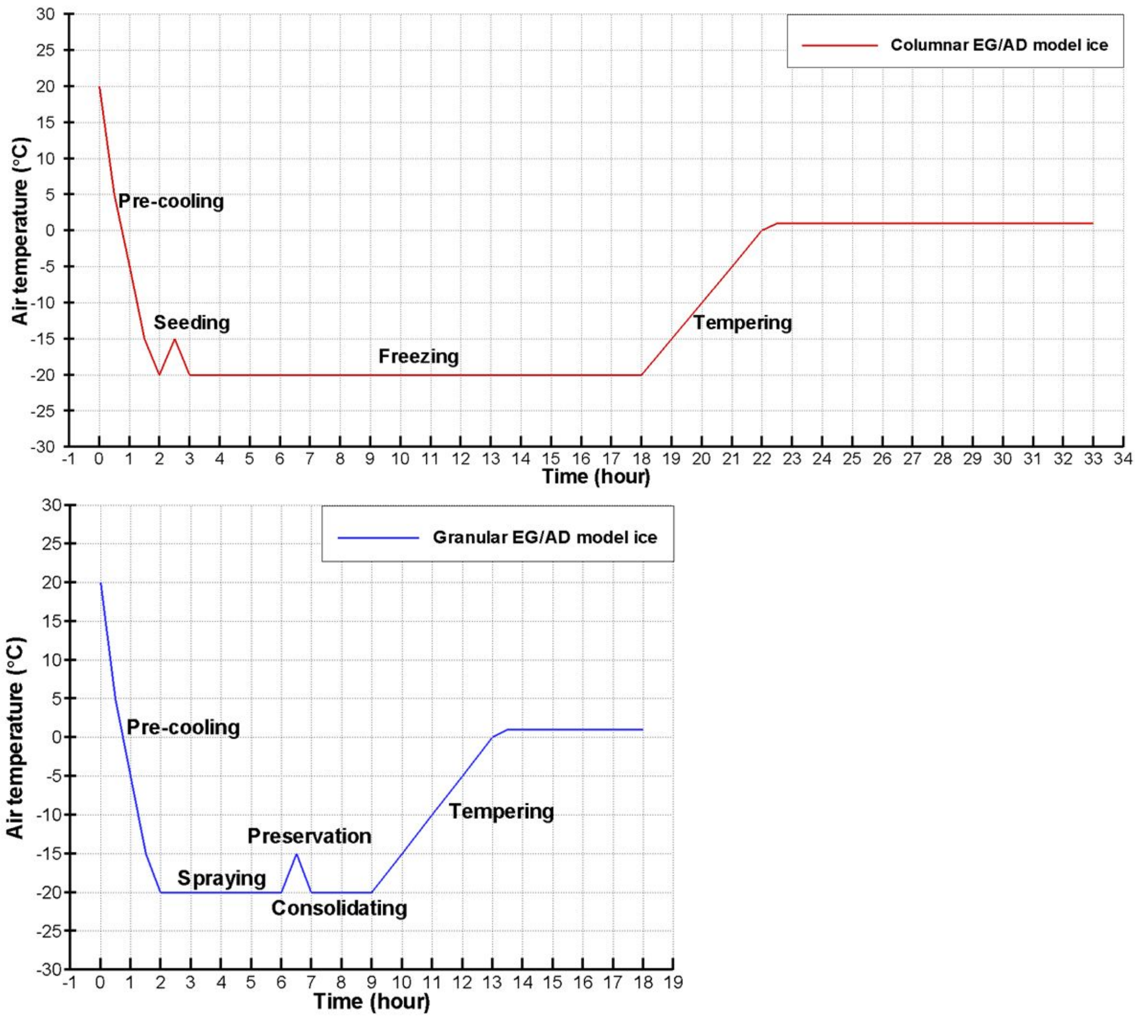


Fig. 5 Air temperature curves during the entire process of generating columnar and granular EG/AD model ice 40 mm thick

TEST RESULTS

In this study, seven sheets of granular EG/AD model ice were built, as listed in Table 2. The major experimental conditions and the results of the model ice's properties are also recorded in this table. We were unable to obtain a large number of specimens because of the size of the miniature tank in the cold room. Therefore, only the thickness and flexural strength of the model ice were measured for all ice sheets. Other properties of the model ice were measured, such as the order of the density of ice, ice particle structure, and compressive strength.

Table 2 Experimental conditions and measurements of the granular EG/AD model ice

Ice sheet no.	Target ice thick-ness (mm)	Consoli-dating tempera-ture (℃)	Consoli-dating time (h)	Control-lability of flexural strength	Flexural strength (kPa)	Density of ice (kg/m^3)	Compres-sive strength in horizontal (kPa)	Compres-sive strength in vertical (kPa)
1	30	-20	2	O	30.0	840	NR	NR
2	20	-10	1	X	Fail	NR	NR	NR
3	20	-10	2	△	33.1	874 ~ 890	NR	NR
4	30	-15	2	O	35.0	-	NR	NR
5	35	-15	2	O	32.2	-	NR	NR
6	35	-15	2	O	34.6	-	56.0	56.2
7	20	-15	2.3	O	163.0	-	81.4	-

The rate of building the thickness of the ice was about 11.5 mm/h. The growth rate of the thickness of columnar EG/AD model ice is usually less than 3.0 mm/h, so it takes less time to prepare an ice sheet. The variation in the ice thickness was about 10% because we used the spraying nozzle only at the middle. Uniform granular EG/AD model ice will be built by using many nozzles, as well as changing the spraying angle and the spraying pressure.

Figure 6 shows a cross section of 35 mm thick granular EG/AD model ice, in which the ice particles are piled. The initially sprayed particles at the bottom are slightly grown in columnar model ice, and the bottom of the ice is more densely populated than the top is because of the weight of the particles.

Fig. 6 Cross section of granular EG/AD model ice (about 35 mm)

The initial flexural strength of granular EG/AD model ice was lower (100–140 kPa) than that of the columnar model ice, which indicates that it was highly efficient in reducing the tempering time.

Figure 7 shows the measured flexural strength of the model ice in the tempering phase, which took about six to eight hours. The flexural strength was not well controlled when the consolidation time was not sufficiently maintained, as shown in the figure.

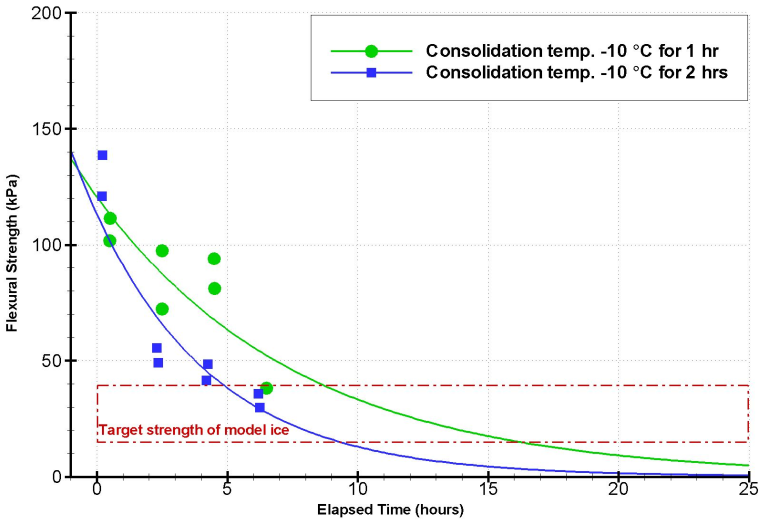


Fig. 7 Measured flexural strength of granular EG/AD model ice vs. tempering time (20 mm thick)

The compressive strength of granular EG/AD model ice measured lower (56–82 kPa) than that of the columnar model ice at the target flexural strength of the model ice. The compressive strength of columnar model ice is normally seven to ten times greater than the flexural strength of the columnar model ice. The failure modes along the horizontal and vertical planes were similar, whereas those of the columnar model ice were quite different. In addition, the specimen showed a size effect.

Granular model ice has good visibility. Its densities at the beginning and end of tempering were about 840 and 890 kg/m^3, respectively. When the columnar type was grown, some micro bubbles entered the ice sheets because of the visibility and density of the columnar model ice. However, we did not need a micro bubble distributor for the granular model ice.

Fig. 8 The granular EG/AD model ice with good visibility

CONCLUSIONS

In this study, we conducted a generation test in order to prepare uniform thickness and strength of granular EG/AD model ice. Various sheets of granular model ice were prepared and the procedures were analyzed. We prepared a new granular model ice using the EG/AD solution and measured its thickness, strength, and density. In addition, we found that the strength of the model ice could be controlled by varying the time and air temperature in the consolidation phase. Moreover, the density and visibility of the granular EG/AD model ice were satisfied without micro bubble systems. We verified that granular EG/AD model ice can be prepared more uniformly and effectively than columnar EG/AD model ice can. The results of this study are intended to contribute to reducing the time required for the ice model test and the operation of the ice model basin. In future research, we will prepare granular EG/AD model ice in the KRISO ice tank.

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