Field Observation of Sea Spray Icing on Lighthouses and Ice Adhesion Test of Superhydrophilic Pliable Sheet for Deicing

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***Abstract*— Heavy sea spray icing on lighthouses severely affects their maintenance in the northern harbors that face the Sea of Japan. We investigated the growth rate of sea spray icing by interval recording telephotographs and we then tested superhydrophilic pliable sheets that can wrap the small lighthouse. The field observation was conducted using two dummy lighthouses set up on the breakwater. The ice accretion on the dummy lighthouses was recorded by a monitoring system set up on a conventional lighthouse during the winter of 2007–2008. The distance between the dummy lighthouses and the camera was approximately 170 m. The growth rate of icing was defined as an increase of projected ice area per unit time. Ice accretion often occurred on the lighthouse. Weather condition and marine condition during sea spray icing was analyzed: the growth rate of cross section of icing monotonically increased with the product of air temperature and wind speed, i.e. the heat loss by convective heat flux. One of the dummy lighthouses was wrapped with a superhydrophilic sheet during the winter of 2008–2009. The tree-climbing technique was tested to suspend the pliable sheet. The sheet model was maintained successfully through one entire winter. Deicing was easy for the superhydrophilic sheet due to the low adhesion strength of saline ice and the exfoliation, although icing was observed on the top part of the lighthouse as crown snow.**

I. Introduction

THE northern part of Sea of Japan and sea around Kuril Islands are characterized by extreme sea spray icing in winter [1]. The ice accretion is a big problem for not only fishing vessel and trawler but also lighthouses on breakwater. Heavy sea spray icing on lighthouses severely affects their maintenance in the northern harbors that face the Sea of Japan and the Sea of Okhotsk. Small lighthouses on breakwater, which are on the increase by economic reason, are initially not equipped with countermeasures for spray icing.

Several recent studies have investigated the feature of sea spray ice and deicing for lighthouse. It is considered that the effect of low adfreeze materials or anti-icing coatings is insufficient for long periods in severe conditions on breakwater. [2] tested canvas clothes for anti-icing in a laboratory experiment. The cloths were coated with polypropylene, vinylidene fluoride, vinyl chloride, and silicone. However, these cloths were not practically used in the deicing of lighthouses. [3] performed laboratory experiments of saline ice adhesion on several chemical cloths. They obtained a preliminary result stating that deicing could be easily performed by vibrating the cloths. [4] researched the features of icing on chemical cloths and polymer films and the deicing condition were verified by cold experiments conducted in the laboratory and field.

We investigated the growth rate of sea spray icing on small lighthouse by interval recording telephotographs and we then tested superhydrophilic pliable sheets that can wrap the small lighthouse.

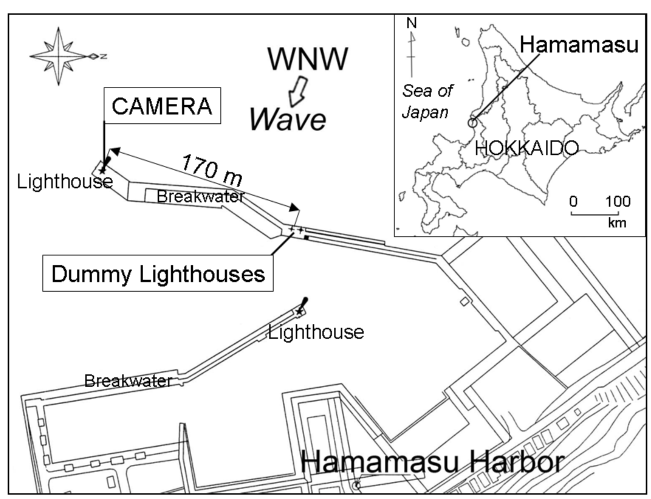


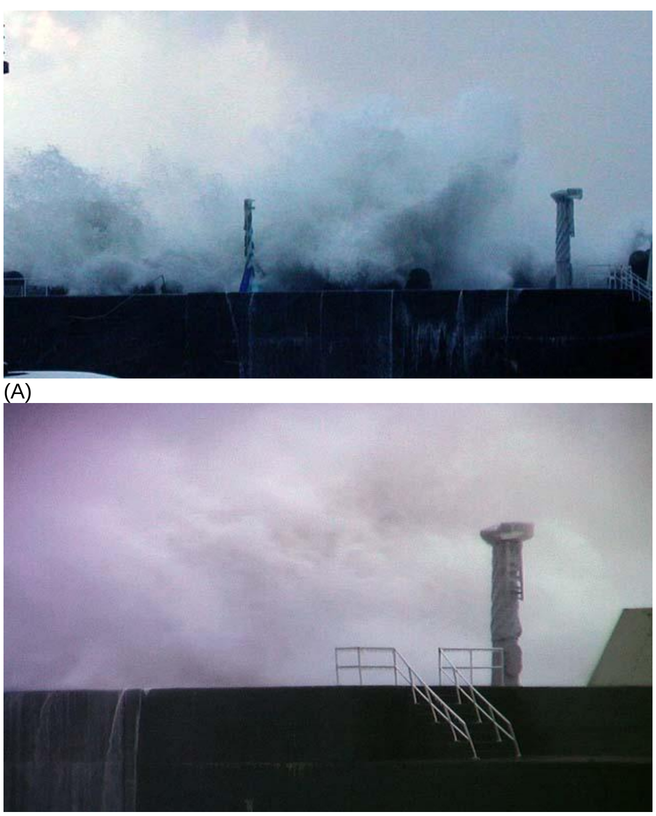
Fig. 1. Location of Hamamasu Observational Site.

II. Observations

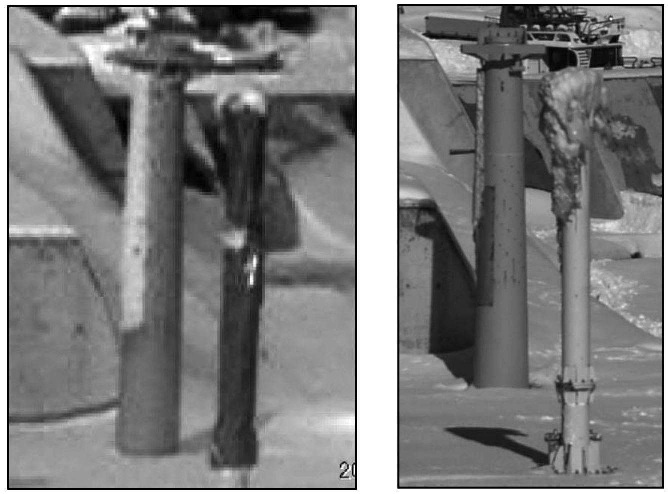
A. Observational Site and Instruments

The field observation was conducted at the Hamamasu harbor located on the west coast of Hokkaido. Fig. 1 shows the location of the observational site. Two dummy lighthouses were set up on the north breakwater extending from the north to the south: one was made of FRP and the other was made of steel coated with acrylic silicon resin. The height of both the dummy lighthouses was approximately 4 m. The breakwater has been made as intersect perpendicularly to primary wind direction of a seasonal wind in winter. High waves by northwesterly wind often generated heavy spray jet at the dummy lighthouses (Fig. 2A).

The ice accretion on the dummy lighthouses was recorded by a monitoring system set up on a lighthouse that was on the tip of the north breakwater. The height of the monitoring system was approximately 10 m, which was known as a solution to avoid the sea spray ice. The distance between the dummy lighthouses and the camera was 170 m. The monitoring system has been operated since 2004 winter [4]. We improved the quality of camera system in order to obtain ice accretion information by graphic data processing (Fig. 3). The recording data of 2007–2008 winter were used for the graphic analysis in this study. We used the surface meteorological data, hourly observations at Hamamasu, and sea surface temperature charts provided by Japan Meteorological Agency.



(B)
Fig. 2. Two dummy lighthouses set up on the north breakwater of Hamamasu harbor. (A) Spray jet generated by the breakwater, (B) Impinging of spray jet and green water.



(A) (B)
Fig. 3. The pictures by monitoring system. (A) Previous work (2004-2007), (B) Improved camera system (2007-2008).

B. Graphic Data Processing

Ice accretion information was obtained from graphic data set of the steel lighthouse. Fig. 4(A) shows ice accretion on the steel lighthouse on January 15, 2008. The photo was cropped to leave only the subjects that include ice and the lighthouse (Fig. 4(B)). Cross section area of the sea spray ice was obtained from the difference between the projected area of the sea spray ice and the projected area of steel lighthouse (Fig. 4(C)).

In 2007–2008 winter, the existence of ice accretion was confirmed January 10, 2008 by the graphic data. Fig. 5 indicates time series of the cross section of sea spray icing from January 10 to February 13, 2008. The graphic data from February 14 to 16 were missed because of stormy weather and whiteout of the photographs. The existence of ice was not confirmed after February 17. The remarkable ice accretion was observed from January 10 to 17.

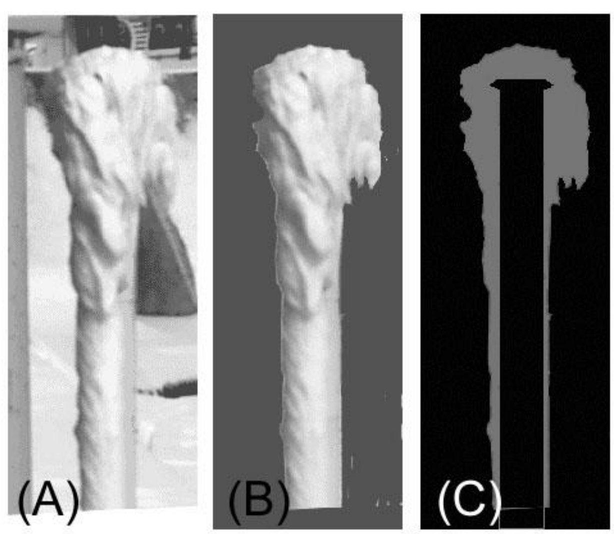


Fig. 4. Graphic data procedure. (A) An original picture, (B) Cropped picture leaving only the subjects, (C) Cross section area of the sea spray icing.

C. Weather Conditions

Weather conditions and marine conditions during sea spray icing on the lighthouse were considered. To address the icing on the breakwater, sea spray generation, spray delivery and heat transfer for ice accretion are important. A number of physical models were developed for marine icing [5]. As shown in [6], wet growth with brine flow might be principle in this case. The major heat flux for the accreting surface is as follows: the convective heat flux, Q_C; the evaporative heat flux, Q_E; the radiative heat flux, Q_R; and the sensible heat flux associated with both the directly impinging spray and the surface flow of unfrozen brine, Q_S [5]. In this study, we focused on the convective heat flux. The convective heat flux is given by

$$Q_C = h(T_F - T_A), \qquad (1)$$

where T_F is the freezing temperature of the brine, T_A is the air temperature and h is the local convective heat transfer coefficient. h is given by

$$h = \frac{Nuk_A}{L}, \qquad (2)$$

where k_A is the thermal conductivity of air, L is the characteristic length of the component and Nu is the Nusselt number. The Nusselt number is related to Reynolds number, which defined using the wind speed and the characteristic length of the component. The parameter $(T_F - T_{AVG}) \cdot W_S$ was used for comparing with growth rate of spray ice in this preliminary analysis. W_S is average wind speed and T_{AVG} is average air temperature. T_F = –1.9 $^{\circ}$C was used because the salinity of seawater was approximately 3 % during the observational period. The wind velocity might be related to sea spray generation and spray delivery as well as conductive heat transfer.

The growth rate of icing was defined as an increase of projected ice area per unit time. Fig. 6 indicates relations between the parameter $(T_F - T_{AVG}) \cdot W_S$ and the growth rate of cross section. The growth rate of icing monotonically increased with the parameter $(T_F - T_{AVG}) \cdot W_S$, i.e. the heat losses by convective heat flux.

III. Field Test

One of the dummy lighthouses was wrapped with a superhydrophilic sheet during the winter of 2008–2009. The pliable sheets were effective to control the growth of icing in previous study [4]. However, some problems that needed to be solved in order to put the pliable sheet model to practical use were encountered. A balance between pliability and durability was a matter to solve because pliability generally decreases with an increase in durability. The fixing method was a matter, too. The pasted film, surface coating and foundation cloth could not withstand the heavy spray jet and green water as shown in Fig. 2B through one entire winter, resulting in their breakage. To address these problems, we developed a new fixing method in this study. Fig. 7 shows the conventional method using stainless steel bands and cords. The upper and lower edges of the pliable sheet were firmly fixed by steel bands. On the other hand, tree-climbing technique was applied to the new fixing method. The pliable sheet was suspended by four static ropes and fixed by four Prusik cords to the bottom anchor (Fig. 8). The sheet model was maintained successfully through 2008-2009 winter.

The superhydrophilic surface worked favourably for sea spray icing because of the low adhesion strength of saline ice [4]. Deicing was easy for the superhydrophilic sheet due to the low adhesion strength and the exfoliation, although icing was observed on the top part of the lighthouse; ice accretion occurred in the form of crown snow and the icing gradually grew downward.

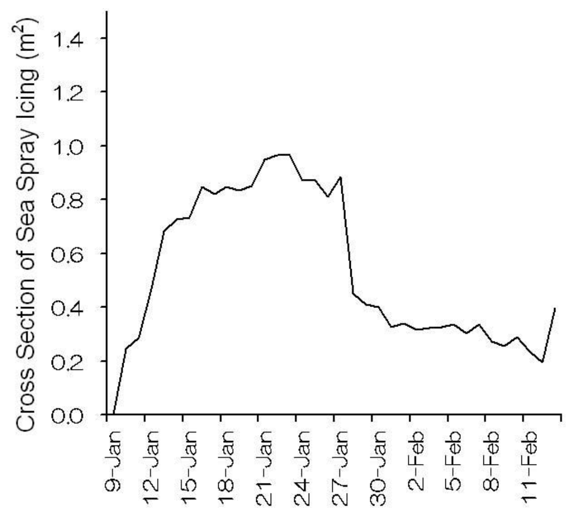


Fig. 5. Time series of the cross section area of icing.

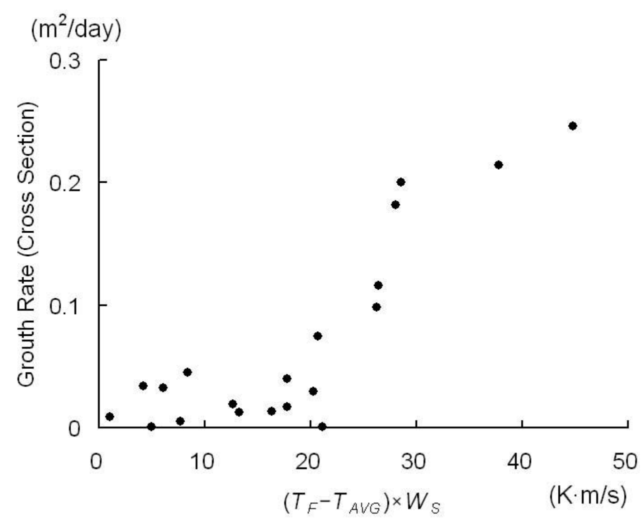


Fig. 6. Relation between the product of air temperature and wind speed and the growth rate of cross section.

Fig. 7. The conventional method.

Fig. 8. The tree-climbing technique for suspending the pliable sheet.

IV. Conclusions

The quality of monitoring system was improved to record the ice accretion on the dummy lighthouses. The resolution of the graphic data was enough to obtain the ice accretion information though the distance between the dummy lighthouses and the camera was 170 m.

The growth rate of icing, which defined as an increase of projected ice area per unit time, was obtained from graphic data analysis. The growth rate of icing monotonically increased with the parameter $(T_F - T_{AVG}) \cdot W_S$. This preliminary result suggested that the heat loss by convective heat flux is major heat transfer for the sea spray ice accretion.

One of the dummy lighthouses was wrapped with a superhydrophilic sheet during the winter of 2008–2009. The tree-climbing technique was tested to suspend the pliable sheet. The sheet model was maintained successfully through one entire winter, although icing was observed on the top part of the lighthouse.

Further improvement of camera system was conducted through 2008-2009 winter, and then ice accretion analysis is a subject for future work. Further tests of the fixing method are required for the practical use of the pliable sheet model for deicing.

V. Acknowledgment

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