



# Experimental study of precipitation icing on an architectural polycarbonate open mesh

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**Abstract**— Architectural polycarbonate open mesh (APOM) is a structure that is installed on the exterior of other structures for design and organization purposes and its aesthetic features. Consequently, it is susceptible to ice and snow accretion when installed in areas where ice and snow might occur. Large pieces of snow and ice falling from the APOM present hazards to pedestrians and vehicles. To understand the wet snow and ice accretion processes and to gain insight into the snow and ice falling mechanism from the APOM, a series of indoor and outdoor experiments for both freezing rain and wet snow were conducted. The indoor experiments were performed in the freezing room of an icing tunnel, while outdoor experiments were conducted at an outdoor icing station. Results showed that the ice accumulation rate was high at the beginning of the accumulation, then decreased with time. Conversely, wet snow accumulated with a slow rate at the beginning of the event, then the rate increased followed by a small decrease, and then remained constant. Shedding of ice and wet snow occurred due to solar radiation, increase of ambient temperature, and wind where ice and wet snow shed in different sizes. Findings from this study are important in understanding the mechanism of accumulation and shedding of ice and snow for open mesh structure and its effects on public safety.

**Keywords**— *ice, snow, accumulation, shedding, architectural polycarbonate open mesh*

## I. INTRODUCTION

Architectural polycarbonate open mesh (APOM) can be installed in open areas to create, divide, accent, and protect spaces inside and outside of structures. APOM is flexible and iridescent, thus it moves in the wind or air currents and creates dramatic kinetic highlights on a structure. Since it can be installed as a kinetic exterior aesthetic feature or cladding in locations where ice or snowstorms might occur, APOM is prone to ice and snow accumulation and shedding. For both ice and snow, the accretion depends on many variables that include wind speed, wind direction, precipitation amount, and the surface area.

Accretion of ice or snow on structures may cause overloading which may trigger collapse or loss of function, whereas shedding may result in public safety hazards due to the fall of the big pieces of ice or snow [1-3]. Since APOM is installed in areas near pedestrian and vehicles, the fall of these pieces of ice or clumps of wet snow can cause injuries to people passing below or damage vehicles. Moreover, it is possible in extreme circumstances that ice or wet snow could overload the mesh or its supports and cause its collapse, which can be a serious issue especially in pedestrian areas.

Therefore, it is important to understand how ice and wet snow will accrete on this type of structures and understand the difference between ice accretion and wet snow accretion, e.g.,

which one will be more severe, and how both shed from the APOM structure. In this study, indoor experiments were conducted at the University of Toledo (UT) icing tunnel and outdoor experiments were performed at the UT outdoor icing experiment station for both freezing rain and wet snow. Utilizing these facilities allowed the authors to conduct several different experiments with desired conditions.

## II. EXPERIMENTAL WORK

The UT icing tunnel was designed and built to conduct experiments with scenarios similar to the natural environment [4]. It consists of two main parts: a freezing room and a tunnel system. The walls of the freezing room are insulated to reduce heat transfer from the outside air to the icing tunnel system. The cooling unit can keep the temperature constant as low as  $-20^{\circ}\text{C}$ . A multi-speed fan was installed inside the tunnel system for adjusting the wind speed to the desired test conditions. The tunnel also includes a misting system. The misting system consists of mounted multi-nozzles to produce a fine mist, which is blown by air driven by the fan [4-7]. To conduct the experiments on a real size APOM, experiments were conducted in the freezing room due to its larger size compared to the test section. In addition, an outdoor icing experiment station was set up at UT's Scott Park Campus to better understand the nature of icing events, to conduct icing experiments regardless of the natural precipitation, and to minimize the risks for investigators [5-7].

Freezing rain experiments were conducted by spraying water from a nozzle onto the target object at a temperature below freezing. Wet snow experiments were conducted using an internal mixing snow gun that was designed and built at UT. Compressed air generated by a compressor was essential for the atomization of the water fed into the snow gun. Due to the size limitation in the icing tunnel, only freezing rain experiments were conducted at the icing tunnel. Both freezing rain and wet snow experiments were conducted at the outdoor station.

### A. Indoor experiment setup

The indoor experiments setup consisted of a piece of APOM ( $110\text{ cm} \times 61\text{ cm}$ ) hung from an aluminium rod which was inserted through the top row of links so that the APOM hung uniformly as shown in Fig. 1. The rod also worked as a support for the APOM. Two stands were used to hold another aluminium rod in which scales were used to measure the total weight of the APOM and the accumulated ice. To perform observation of the whole process, an IP camera was used to record the process and transfer it to a computer. As mentioned previously, ice accumulation was only tested indoor which was produced by spraying water on

the APOM specimen. Cold water was used for the spraying by leaving the water in a tank in the freezing room until the temperature reached to near freezing temperature. The water was pumped to the nozzle using a submerged water pump existed in the tank. The temperature of the air in the freezing room was set to  $-10^{\circ}\text{C}$  and the water temperature in the tank was  $2^{\circ}\text{C}$ . The water was sprayed for around 3 hours and the hourly precipitation was measured to be  $2.54\text{ mm/h}$ . Two digital scales were used to measure the weight of the accumulated ice on the APOM structure.

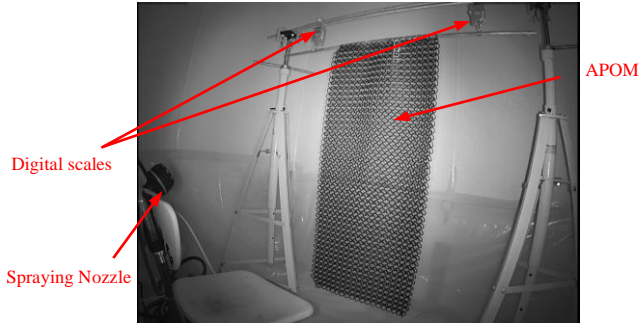


Fig. 1 Setup of the indoor freezing rain experiment.

### B. Outdoor experiments

Similar to the indoor experiment, the outdoor experiment setup consisted of a larger piece of APOM ( $156\text{ cm} \times 182\text{ cm}$ ), where a copper rod was inserted through the top row of links in such a way that the APOM was supported uniformly. A Unistrut frame was built to carry the APOM from the copper rod. Scales were hung from the top of the Unistrut frame to measure the weight of the APOM and the accumulated ice/snow as shown in Fig. 2. In the outdoor experiments, freezing rain and snow accumulation were tested. Here, the shedding of ice and snow was observed during the experiments to understand how shedding occurs from the APOM.

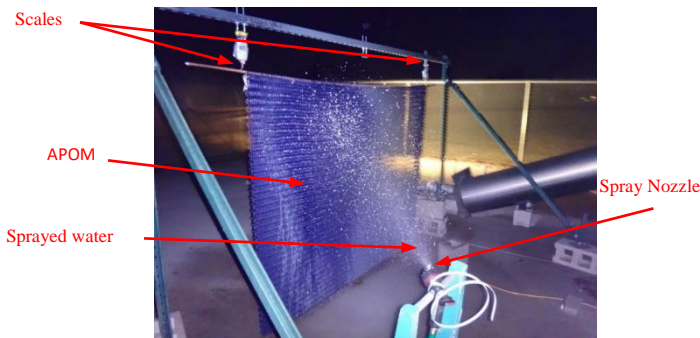


Fig. 2 Setup of the outdoor freezing rain experiment.

The first outdoor experiment was conducted for freezing rain as shown in Fig. 2. Water was sprayed on the APOM with a precipitation rate of  $12.7\text{ mm/h}$  and the ambient temperature ranged from  $-4.4^{\circ}\text{C}$  to  $-7.2^{\circ}\text{C}$ . The experiment lasted for 2 hours and 17 minutes.

The second outdoor experiment was performed for wet snow where the temperature ranged from  $-6.7^{\circ}\text{C}$  to  $-7.8^{\circ}\text{C}$ . Compressed air and water were mixed in an internal mixing nozzle to create snow. The precipitation rate was measured to

be of  $6.35\text{ mm/h}$ . The experiment duration was 2 hours and 34 minutes. Fig. 3 shows the setup of the experiment.

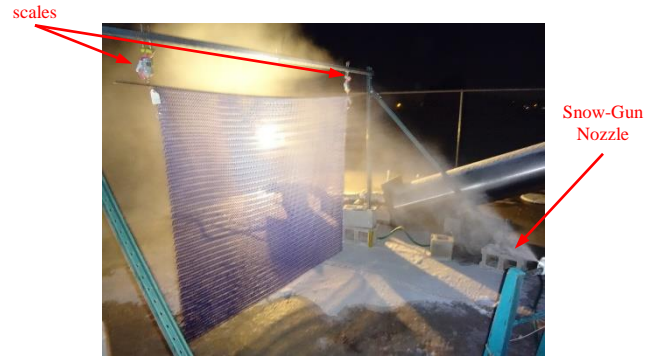


Fig. 3 Setup of the outdoor wet snow experiment.

## III. RESULTS AND OBSERVATIONS

### A. Indoor experiment results

Ice was accumulated uniformly on the APOM in which  $11.4\text{ mm}$  was accumulated on the front side (facing the spray nozzle) and  $9.4\text{ mm}$  was accumulated on the back side. The total accumulated weight at the end of the experiment was  $7.2\text{ kg}$  with  $448\%$  increase in weight compared to the initial weight of the APOM and the aluminium support bar, which was  $1.6\text{ kg}$ . Fig. 4 shows the front view of the accumulation whereas, Fig. 5 shows the accumulated ice on the APOM taken by the weatherproof camera. As shown in the figure, thick icicles were formed at the bottom of the APOM.



Fig. 4 Front view of accumulated ice on the APOM after 3 hours of spraying.



Fig. 5 Side view of accumulated ice on the APOM after 3 hours of spraying.

Fig. 6 shows a plot of the accumulated ice versus time during the experiment. As the figure illustrates, there was a high increase rate in the accumulated weight at the beginning of the spraying time, then the increase rate became slower as it reached to the end of the experiment which is shown in Fig. 7. At the beginning of the experiment, the increase rate was  $118\%$  of the original weight in the first 30 minutes then the rate decreased rapidly. The accumulated weight kept

increasing at a diminishing rate until it reached to 4% in the last 24 minutes of the experiment. This observation finding was also seen in the next experiment.

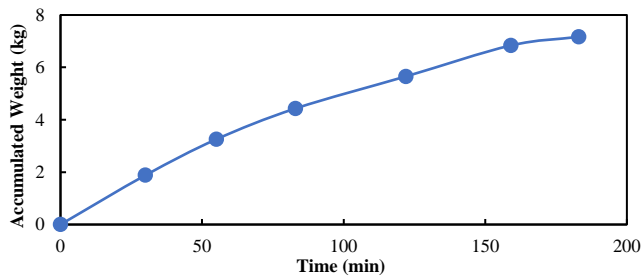


Fig. 6 Plot of accumulated ice vs. time during the indoor freezing rain experiment.

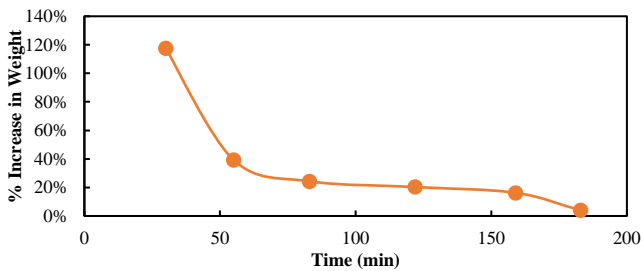


Fig. 7 Percentage increase of accumulated weight vs. time during the indoor freezing rain experiment.

#### B. Outdoor experiment results

**Ice accumulation experiment:** Once the spraying started, ice accumulation was observed on the APOM. Initially, ice filled the spaces between the rings as shown in Fig. 8, which resulted in the structure losing its flexibility and behaving like a solid sheet as shown in Fig. 9. The ice also covered the rings in a way that it formed outward icicles pointing toward the spraying direction. In addition, icicles were also formed at the bottom of the APOM. Fig. 10 shows the ice accumulation on the APOM rings and icicles formed at the bottom. The accumulated thickness was 7.62 mm on the side facing the spray nozzle, and 2.54 mm on the back side.

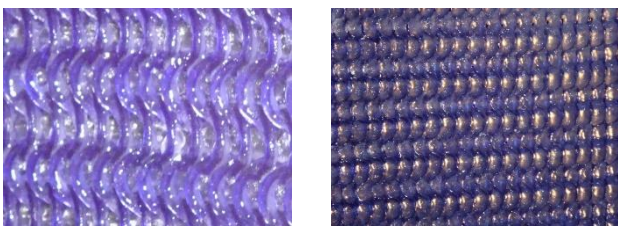


Fig. 8 Ice is filling the ring gaps in the APOM.

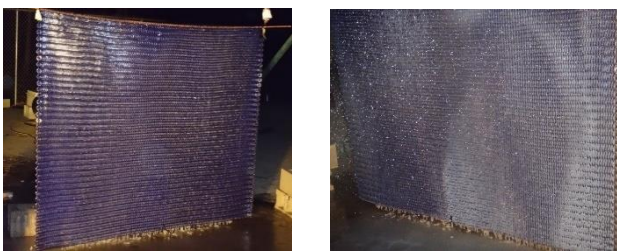


Fig. 9 APOM looks like a solid sheet after ice accumulated on the ring spaces.

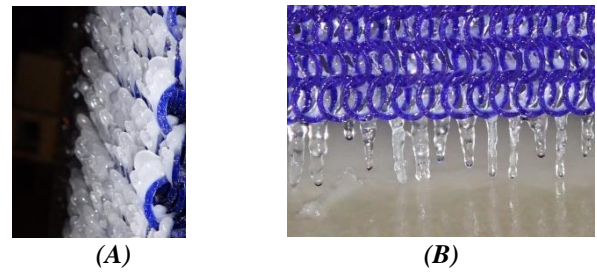


Fig. 10 (A) The ice accumulation on the APOM rings. (B) The icicles formed at the bottom of the APOM.

The accumulation rate was relatively rapid at the beginning of the experiment, but then its speed reduced. In the first 33 minutes, approximately 11.3 kg of ice was accumulated; while in the last 25 minutes, approximately 0.75 kg of ice was accumulated as shown in Fig. 11, with a total of approximately 20.4 kg of accumulation. This finding was similar to the indoor experiment observations. As shown in Fig. 12, the increase rate was 106% in the first 33 minutes but was only 2% in the last 25 minutes of the experiment. This might occur due to the spaces in the APOM, which was initially a rough surface that was being filled in and smoothed by the ice. Then, as the ice accumulated, the surface became smoother and the ice accumulation reduced.

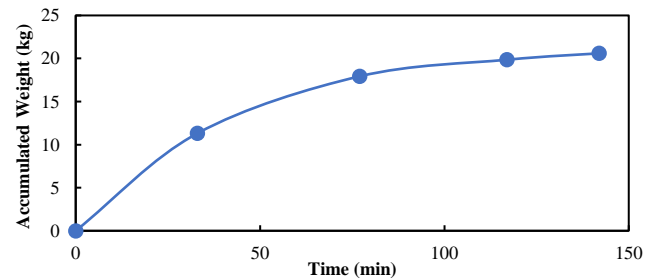


Fig. 11 Plot of accumulated ice vs. time during the outdoor freezing rain experiment.

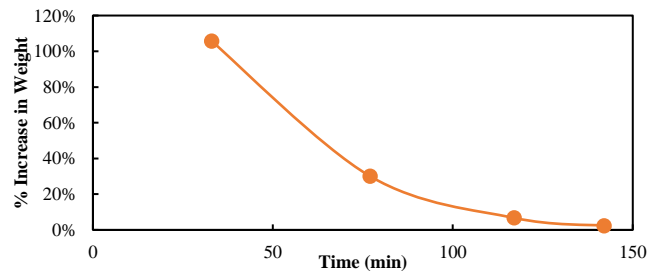


Fig. 12 Percentage increase of accumulated weight vs. time for the outdoor freezing rain experiment.

Ice shedding from APOM was observed for two days after the accumulation. The ice on the APOM resisted falling or shedding on the next day since the temperature was below freezing and the sky was cloudy. On the day after, the wind started to move the APOM, which behaved like a solid sheet due to ice accumulation, forward and backward, which caused the ice to breakdown especially when the sheet hit the supporting structure. As the temperature increased, the ice melted and water dripped down which refroze at the bottom creating icicles as the temperature went below freezing.

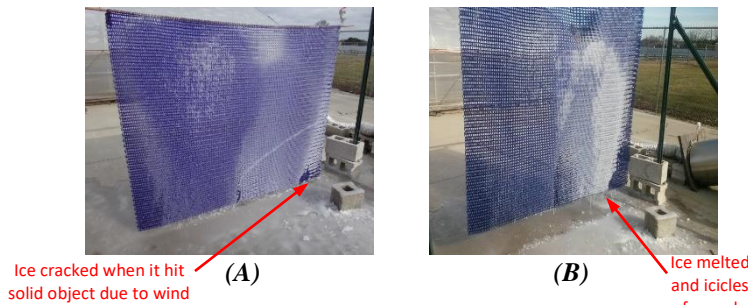


Fig. 13 Ice shedding from the APOM due to (A) wind effect and (B) the melting of ice.

**Wet snow accumulation experiment:** Initially, the wet snow stuck on the links of the APOM as shown in Fig. 14 and the increase in the accumulation weight was at a slow rate. After the wet snow covered the entire surface of the APOM, the rate of accumulation became higher which can be seen in Fig. 15 and Fig. 16. The rate of increase in accumulated weight in the first 48 minutes was 25%, then 39% in the next 31 minutes. In the last 39 minutes of the experiment, the rate of increase was 26%. It is believed that it occurred because the wet snow stuck first to the rings. However, once the spaces were filled with wet snow, wet snow stuck efficiently to the surface which caused higher increase rate in the weight.

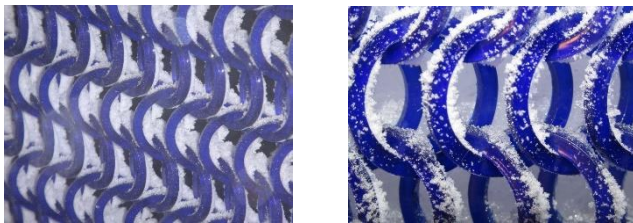


Fig. 14 Wet snow stuck to the chains of the APOM at the beginning of wet snow spraying.

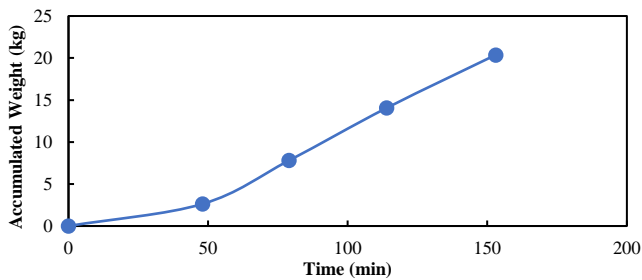


Fig. 15 Plot of accumulated wet snow on APOM vs. time during the outdoor wet snow experiment.

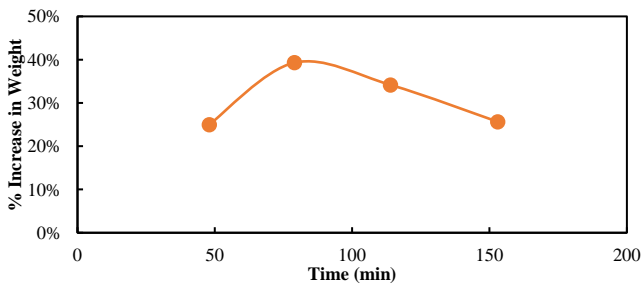


Fig. 16 Percentage increase of accumulated weight vs. time for the outdoor wet snow experiment.

This finding was opposite to what was observed in the freezing rain outdoor experiment. For wet snow experiment,

the rate of increase in weight was low at the beginning, but then increased and became constant, where the increase was approximately linear with time. In contrast, the rate of increase in ice weight on APOM was high at the beginning for freezing rain, then the rate of increase in weight decreased rapidly.

The snow spraying was performed from one side, in which the maximum thickness on that side was 50.8 mm. The other side did not have any accumulation except for some snow particles as shown in

Fig. 17. This observation was unlike what happened in the freezing rain case where the ice accumulated on both sides even though the spraying was only performed from one side.

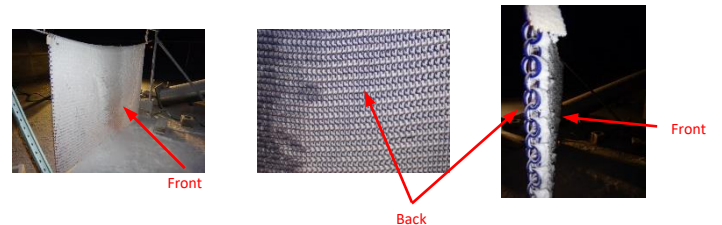


Fig. 17 Wet snow accumulation on both sides of the APOM. The front side facing the snow gun has most of the accumulation, while the back side was nearly free of snow except for some snow particles that stuck to the APOM chains.

Wet snow shedding was observed during this experiment. The wet snow on the APOM resisted falling or shedding on the next day even though the temperature was above freezing (2.2°C) and it was partially sunny. Before sunrise on the day after, a big piece of wet snow fell as the temperature went up to near 4.4°C. However, another big piece of the wet snow was still attached to the APOM. Some parts of the big piece shed early morning on the same day while the rest melted in place and the APOM was clear of snow at close to noon time and the temperature was approximately 7.2°C. The shedding process is shown in Fig. 18.

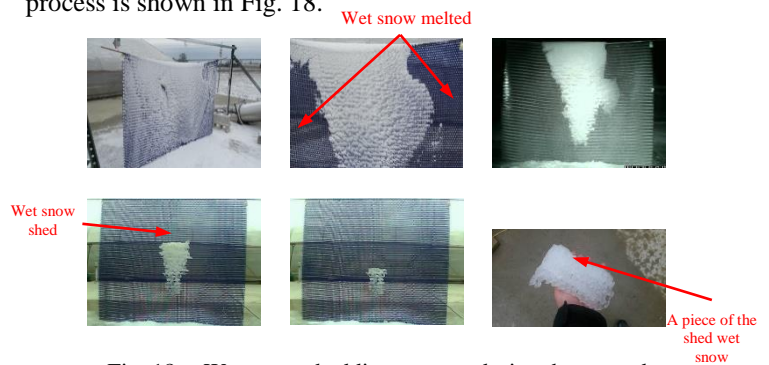


Fig. 18 Wet snow shedding process during the second outdoor experiment

#### IV. CONCLUSION

In conclusion, ice and snow can accumulate on APOM. Ice accumulated at a faster rate at the beginning, which is believed to be related to the spaces between the APOM rings, then the rate decreased with time as the spaces were filled with ice and the surface became smoother. In contrast, wet snow accumulation occurred at a slower rate at the beginning because the snow was lighter and it stuck to the APOM rings, then the rate of accumulation turned to be faster since wet snow is easier to stick to each other. Ice and wet snow shed in combination of big and small pieces which may be hazardous to public passing underneath or near to this structure.

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