ICING TEST REPORT

KfobiX - SPH Anti-Icing Coating

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1. TEST AREA & CONDITIONS:

Ice formation tests were carried out by renting the "PORTAŞ-BELKO Cold Storage" number 16 within the Ankara Metropolitan Municipality, between the dates of February 29, 2024, and March 2, 2024 (Figure 1). The ambient temperature of the cold storage was set to a constant -18°C, 24 hours before the start of the tests, and the temperature and humidity values of the depot were continuously monitored with laser thermometer measurements. The temperature in different parts/areas of the cold storage, pre-cooled before the test, was measured between -22°C and -16°C right before the start of the test (Figure 2). A military-standard trail camera, placed at a distance where it would not be affected by humidity and water droplets could not adhere to the surface, took instant photographs every 20 minutes throughout the test duration (Figure 3).

Figure 1

Figure 2

Figure 3

Figure 4

2. TEST PARAMETERS:

Figures 4 and 5 depict the pre-test visuals of the conductive wires. Approximately 2-meter-long conductive wires were placed in an arrangement with the coated wire above and the reference wire below. The conductive wire seen at the bottom in Figure 4 is the reference wire and is grey in color (the natural color of steel-core aluminum wire). The wire seen at the top in Figure 4 is coated with "KFOBIX SPH Anti-Icing" coating. As observed, after the application, ***the color of the conductive wire has changed to a pale white. It is important to note that this is not ice accumulation, but the color of the wire after the coating. Coatings of different colors could also be applied.***

Figure 5

Before the start of the test, the conductive wire coated with "KFOBIX SPH Anti-Icing" and the reference wire (uncoated) were left to cool in the cold storage for approximately half an hour. Subsequently, the test was conducted by carefully following the steps below.

1. To increase the ambient humidity, water was sprayed into the environment using a compressor-spray gun. The regional ambient humidity was continuously maintained above 70% (Figure 6).
2. A total of 1.5 liters of water was poured over each wire using a gallon bottle water (Figure 7).
3. With the help of a pipette, approximately 0.25mL of water was dripped along the conductive wires, accelerating the adherence of water droplets on the surface of the wires (Figure 8).

Figure 6

Figure 7

4. Using an air compressor-spray gun, approximately 0.5 liters of water were sprayed onto the wires to maximize their humidity. This process instantly elevated the humidity level of the wires to 100% (Figure 9, Figure 10).
5. Immediately after humidifying the wires, water was dripped onto the wires drop by drop using a Pasteur pipette, to facilitate rapid icing and nucleation formation.
6. After exiting the cold storage, the wires were left to ice over for at least 1 hour, and during the night, for at least 10 hours.

Figure 8

Figure 9

The six-step process outlined above involving "water dripping-humidity-low temperature" parameters is a simulation of accelerated icing. The six-step test conducted above was attempted within a timeframe of approximately 5 to 10 minutes inside the cold storage by at least two people. This entire six-step process constitutes a single cycle.

Figure 10

During the test process, ***a total of 15 cycles of the six-step process*** described above were completed.

3. <u>TEST RESULTS:</u>

After the first icing test cycle, no icing or nucleation was observed on the conductive wire coated with "KFOBIX SPH-Anti-Icing" (above), while nucleation had occurred on the uncoated reference wire (below), with partial icing beginning (Figure 11).

Figure 11

Figure 12

After the third test cycle, no icing was observed on the coated wire, while icing on the reference wire increased, and ice icicle became pronounced. The combination of high ambient humidity, water poured onto the conductive wires, and low temperatures resulted in the nucleation points gradually growing into icicle. By the third cycle, ice icicle approximately three times the thickness of the reference wire was observed (Figure 12).

Figure 13

As illustrated in Figure 14, following the fourth test cycle, icing on the reference wires has continued to increase, with the icicle primarily thickening rather than elongating. Meanwhile, no icicle has been observed on the coated wire. However, as shown in Figure 13, negligible nucleation has occurred at both the right and left ends of the coated wire, forming in hemispherical shapes. This occurrence is attributed to the procedure in the fourth phase of the test cycle, where the wire's humidity was quickly raised to 100% (as depicted in Figure 15), immediately followed by the application of water. This situation arises due to the coating, which has contact angle above the 160 degrees and rolling angle below the 1 degree, not being able to instantly demonstrate its full performance under these conditions. Despite this, no icicle or ice accumulations have been observed on the coated conductive wire.

Figure 14

Figure 15

The ninth stage of the cycle process is presented in Figures 16 and 17. In the ninth cycle, icing on the reference wire has dramatically increased, with ice icicle reaching approximately five times the thickness of the wire. Additionally, as seen in the leftmost part of the reference wire in Figure 16, the wire is completely encased in ice. The conductive wire is entirely covered in ice. On the other hand, no ice icicle or accumulations are observed on the coated wire. As mentioned above, only an increase in the number of nucleation's is observed. This is due to the combination of maintaining high regional ambient humidity (above 70%) (Figure 16 green circle, Figure 17 blue circle) and instantly raising the moisture level of the conductive wires to 100%, followed by pouring water on the wires. Even maintaining the regional ambient humidity above 70% has resulted in icing in the immediate area a ceiling is 8.5 meters) (Figure 17 red circle).

Figure 16

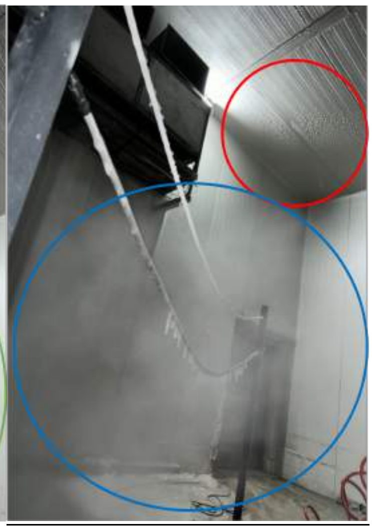

Figure 17

After the final cycle of the test, the 15th test cycle, the final states of the conductive wires are given in Figures 18, 19, 20, and 21. The images show that no ice icicle have formed on the coated wire. Only the nucleation's on the upper surface of the wire have grown, resulting in negligible accumulations. The nucleated ice spheres on top of the wire are sparse and have not shown any formation on the lower region of the wire. Additionally, laboratory tests have proven that the "KFOBIX SPH-Anti-Icing" coating not only prevents or delays icing but also reduces the adhesion strength of ice. During this test, it was observed that the adhesion force of the sparse hemispherical ice particles formed on the upper part of the wire was very low. With a slight force, the ice particles immediately detached from the wire's surface. Thanks to this critical feature, any external factor (such as wind) causes the incompletely adhered ice spheres on the conductive wire to lift from the surface. This property of the KFOBIX SPH-Anti-Icing coating is due to the low solid-liquid and solid-solid contact surface area at the nano level.

In the 15th cycle, the reference conductive wire was completely iced over. By the end of the test, the lengths of the icicle had reached approximately seven times the thickness of the wire, and the icicle had thickened further. Particularly in the middle of the conductor, it was observed that the icicle merged from their points of formation to create even larger accumulations. A more significant problem was that the ice completely enveloped the conductive wire, causing a serious increase in the wire's thickness (Figure 22). As seen in Figure 22, due to icing, the thickness of the conductive wire increased by approximately 1.5 times at the ends and 2.5 times in the middle points. This thickness is due to the ice accumulation surrounding the wire, which, together with the icicle, imposes a significant proportional load on the conductive wire.

Figure 18

Figure 19

Figure 20

Figure 21

The table above provides the ratios of ice load formed on the coated and reference (uncoated) conductive wires after the icing test.

Table 1: Weight changes of conductive wires after the icing test

	KFOBIX SPH-Anti-Icing	Reference
Initial weight	186.5 g	195.6 g
Final weight	191.1 g	274.6 g
Weight difference	4.6 g	74.0 g
Weight increase rate	2.47 %	40.38 %

Figure 22

The initial weight of the conductive wire coated with KFOBIX SPH-Anti-Icing was 186.5 grams, and after the 15-cycle icing test, its weight was measured at 191.1 grams. Only an additional 4.6 grams of ice load was added to the wire, with the ice formation increase rate by weight calculated as 2.47%. On the other hand, the reference conductive wire was measured at 195.6 grams before the test, and its weight after the icing test is 274.6 grams. The wire received an ice load of 74 grams, with the ice formation increase rate by weight being 40.38%.

Figure 23

Figure 24

At the end of the test, during the weight measurements, the coated wire still retained its flexibility and bendability, while the reference wire remained rigid in shape. The conductive wires were observed to be very difficult to detach from the metal hanger they were suspended on during the test. As seen in Figure 23, the metal hanger and the floor of the depot were also completely iced over during the test. In Figure 24, the volume of ice encasing the reference wire could only be difficultly removed by scraping off the surface with a knife. Throughout the test process, the KFOBIX team (Figures 25-a, 25-b) and the BELKO team (Figure 25-c) monitored the testing procedures.

Figure 25