Superhydrophobic coating based on silicone resin SILRES® MSE 100

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Abstract. The anti-icing properties of coatings based on the developed composition are considered. It was shown, that after wetting during 72 hours, the coatings based on the proposed composition retained a superhydrophobic effect. The wetting angle on the mortar substrate was more than 150 degrees. Adhesion of coatings to the substrate after wetting amounted to 1 point. Information is given about the results of evaluation of the adhesion of ice to a superhydrophobic metal surface. It is shown, that the force of detachment of a drop of water on a superhydrophobic metal surface is 3 times less. It ensures easier rolling of a drop of water from the surface and its anti-icing properties. It is established, that the adhesion of ice to the superhydrophobic surface is less compared to the hydrophilic one. It is shown, that there is no difference in the rate of ice evaporation on a hydrophilic and superhydrophobic surface.

1. Introduction
In order to protect the roofs of buildings from icing, various anti-icing systems are used. Superhydrophobic coatings are promising as an anti-icing protection due to their unique properties:

– a significant (more than 3 times) slowing down of the process of droplet freezing on a superhydrophobic surface [1–3];
– short duration of the contact of the superhydrophobic surface with a falling drop [4];
– small hysteresis of wetting angle - no more than 10–15 degrees [5, 6];
– low adhesion of ice to the surface [7].

Analysis of scientific and technical literature suggests, that the manufacture of superhydrophobic materials is possible with a combination of hydrophobic material and surface topography [8]. Despite the large number of proposed compositions, the problem of anti-icing remains relevant. In some cases coatings after a certain period of operation lose the superhydrophobic effect [9]. Thus, the development of anti-icing coatings for roofs of buildings is an extremely important task.

Based on the foregoing, a formulation for anti-icing coating was developed [10, 11]. When developing the composition, silicone resin SILRES® MSE 100 was used as a binder, and aerosil R 972 was used as a filler. The results of the conducted research showed, that after wetting for 72 hours a coating based on silicone resin SILRES® MSE100, 5% and 10% Noah concentration retained superhydrophobic effect – the wetting angle on the mortar substrate was more than 150 degrees. The adhesion of coatings to the substrate (estimated by the method of lattice cut in accordance with GOST 15140-78 “Paint materials. Methods for determination of adhesion ”) after wetting amounted to 1 point.
2. Results and Discussion

For an experimental study of the anti-icing properties of coatings, metal profiled roofing sheets “MR-20” with polymer coating were used as substrates.

Under the action of a negative temperature (−18 °C) when freezing, a drop of water takes on a different shape – a pointed tip appears (figure 1). Obviously, this is due to the vertical expansion of ice in combination with the surface tension on the remaining liquid [15–17].

![Figure 1. Form a drop of water when frozen on a superhydrophobic surface.](image)

It was established, that the amount of ice on the untreated surface, (the plate is located at an angle of 30 degrees when moistened) is 0.59 kg/m², and on a superhydrophobic surface – 0.15 kg/m². During the subsequent moistening of the plates with the same amount of water and its freezing, no difference in the increase in the amount of ice was revealed. The increase in the amount of ice during subsequent wetting and freezing under the given experimental conditions averages 0.109 kg per 1 m².

For assess the kinetics of freezing a drop of water on a superhydrophobic surface, the following experiment was conducted. A drop of water was placed on the superhydrophobic surface of the mortar substrate, which was placed in a freezer at a temperature of −18 °C. Studies of the dynamics of freezing drops on the surface were performed using a thermal imager TESTO 875-1. The research results are given in table 1.

| Time, minute | Temperature, °C | Temperature, °C |
|--------------|-----------------|-----------------|
|              | water drop tops | on the surface of the coating |
| 1            | 20              | 23.5            |
| 3            | 18.4            | 22              |
| 6            | 16.7            | 19.8            |
| 9            | 12.7            | 15.0            |
| 12           | 10.0            | 11.9            |
| 15           | 7.3             | 8.1             |
| 18           | 6.0             | 5.0             |
| 21           | 4.7             | 3.0             |
| 24           | 1.7             | 0.5             |
| 27           | −0.3            | −1.8            |
| 30           | −1.0            | −2.5            |
| 33           | −1.7            | −3.0            |
| 36           | −1.8            | −3.5            |

An analysis of the experimental data (table 1) shows, that in the first stage of freezing (up to 15 minutes) the temperature of the surface of the coating is higher, than the temperature of the water drop, i.e. heat is transferred from the surface of the coating to a drop of water. On the 18th minute of freezing,
the temperature of a water drop becomes 1°C lower, than the surface temperature of the coating. In the future, the temperature difference increases.

The results of studies of the temperature distribution on the surface of a water droplet indicate that its distribution is uneven. So, after 27 minutes of cooling, the temperature at the top of the droplet surface is +0.3 °C, below –0.6 °C, after 30 minutes cooling –1.0 °C and –1.6 °C, respectively, after 33 minutes –1.4° C and –2.0 °C, respectively.

To compare the adhesion of ice to a hydrophilic and superhydrophobic surface, the following experiment was conducted. Metal profiled roofing sheets “MR-20” were placed in a freezer with a temperature of -10 °C and a relative humidity of 90%. Part of the metal plates were previously treated with anti-icing composition. After curing the coating, they were moistened and placed in a freezer. It was established, that after freezing at –10 °C, the removal of ice from a superhydrophobic surface at room temperature at a plate tilt angle of 90 degrees begins after 1 minute 55 seconds, and after 3 minutes ice fell from the plate (figure 2).

The adhesion of ice to the metal hydrophilic surface is higher compared to the super-hydrophobic surface: at a plate tilt angle of 90 degrees, ice does not slip, after 6 minutes of being at room temperature, the ice on the metal plate melted (figure 3).

At a freezing temperature of –5 °C, ice on a super-hydrophobic surface began to roll at room temperature after 52 seconds, after 1 minute 35 seconds he himself fell.

**Figure 2.** Photo image of ice rolling down from superhydrophobic surface. a – the beginning of ice rolling; b – after rolling.

**Figure 3.** Image of rolling ice from a hydrophilic surface.
When the angle of inclination of the metal plate was 30 degrees in the process of moistening and subsequent freezing, ice rolling from the superhydrophobic and hydrophilic surface was not observed. However, in the process of thawing, the untreated plate had a continuous film of water on the surface, and on super-hydrophobic – the formation of individual droplets, i.e. manifestation of the hydrophobic effect.

Ice evaporation from a hydrophilic and superhydrophobic surface in a freezer was calculated. According to the experimental conditions, the relative humidity of the air in the freezer was 90%. It has been established that during evaporation there is practically no difference in the evaporation rate from the hydrophilic and superhydrophobic surface. So, after 1 hour, the evaporation rate from 1 m² of a super-hydrophobic surface is 15.12 g/hour, and from a hydrophilic surface – 14.99 g/hour. After 2 hours, the rate of evaporation from the surface decreases and amounts to 14.88–14.89 g/h with 1 m². After 6 hours in the closed space of the freezer (volume 196 l) a dynamic equilibrium is established between the processes of evaporation and condensation. The rate of condensation becomes equal to the rate of evaporation; from this point on, the amount of ice ceases to decrease. Differences in the values of the evaporation rate of ice from the hydrophilic and superhydrophobic surfaces were not recorded.

3. Conclusion
The results of the research indicate that the proposed composition forms a coating characterized by anti-icing properties that remain in service. The adhesion of ice to the metal hydrophilic surface is higher compared to the superhydrophobic surface, which makes it easier to remove from the superhydrophobic surface.

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