Icephobic and superhydrophobic silicone rubber coatings for outdoor insulators

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***Abstract**:* The present study investigates a simple, one-step and low-cost superhydrophobic coating preparation by spray coating a silicone rubber/stearic acid mixture on glass surfaces. A superhydrophobic surface with a static contact angle of about 160º and low contact angle hysteresis was obtained with the rolling-off properties of water drops. It was found that the wettability of the coatings depends on the surface morphology which is governed by the silicone rubber/stearic acid concentration, as well as the spray time and distance. This coating is attractive for the industry because of its simplicity, affordability, and application to existing insulators.

1. INTRODUCTION

Insulator flashover caused by atmospheric icing is one of the major problems faced by utilities in cold climate regions. This explains the necessity of research on anti-icing and de-icing techniques. Today, room-temperature vulcanized (RTV) silicone rubber coatings are gaining in popularity as an effective countermeasure to insulator contamination problems [1]. However, the maximum contact angle that can be attained on a flat surface by RTV silicon rubber coatings does not exceed 117°.

Superhydrophobic surfaces (water contact angle larger than 150° and low contact angle hysteresis) have shown promising anti-icing performance. Several approaches have been developed to create superhydrophobic surfaces. However these methods generally imply strict conditions and large facility costs, and may raise environmental issues. The present study investigates a very simple, one-step and low-cost superhydrophobic coating preparation by spray coating a silicone rubber/stearic acid mixture on glass surfaces. A superhydrophobic surface with a static contact angle of about 160º and low contact angle hysteresis of about 4º was obtained. It was found that the hydrophobicity of the coatings depends on the surface morphology which is governed by the silicone rubber/stearic acid concentration, as well as spray time and distance. This coating is attractive for the industry because its simplicity, affordability, and application to existing insulators.

2. RESULTS AND DISCUSSION

The results showed that the static contact angle (θs) increases drastically with the stearic acid concentration. Overall, θs increased from 115° ±2 for RTV SR to 160 ° ±3 for the coating containing 43 wt% of stearic acid.

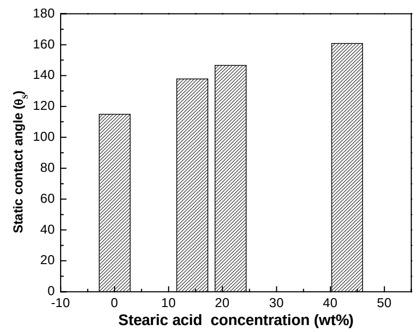

Figure 1: Evolution of water contact angle as a function of stearic acid concentration (wt. %)

Scanning Electron Microscope images of the silicone rubber/ stearic acid coated on glass surfaces showed the evolution of various morphological features as shown in Fig. 2(a–c).

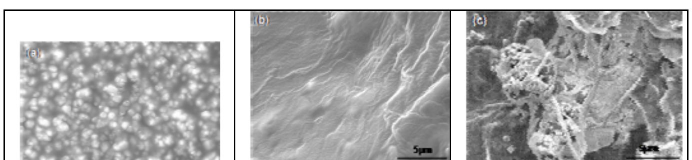

Figure 2: SEM images of sample surface coated with different weight ratio of stearic acid. (a) 0; (b) 14 ;(c)43 wt.%

3. CONCLUSION

A superhydrophobic surface was created using a simple and inexpensive one-step process. An appropriate combination of RTV silicone rubber and stearic acid resulted in micro/nano scale surface modifications with the rolling-off properties of water drops. This coating possesses potential applications, in particular for outdoor insulators, which would be beneficial for the concerned industry because of its low cost, simplicity of fabrication and uses.

4. REFERENCES

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***Abstract*—**

The present study investigates a simple, one-step and low-cost superhydrophobic coating preparation by spray coating a silicone rubber/stearic acid mixture on glass surfaces. A superhydrophobic surface with a static contact angle of about 160º and low contact angle hysteresis was obtained with the rolling-off properties of water drops. It was found that the wettability of the coatings depends on the surface morphology which is governed by the silicone rubber/stearic acid concentration, as well as the spray time and distance. This coating is attractive for the industry because of its simplicity, affordability, and application to existing insulators.

Keywords; one-step; silicone rubber ; superhydrophobic; spray coating

I. INTRODUCTION

In cold climate regions, overhead power network equipment is subjected to atmospheric icing. The ice accretion may drastically decrease the electrical performance of insulators and sometimes lead to insulator flashover and consequent power outages [1]. One of the solutions is to mitigate such problems by developing de-icing or anti-icing techniques applicable to insulators.

Today, room-temperature vulcanized (RTV) silicone rubber (SR) coatings are gaining in popularity as an effective counter-measure to insulator flashover under contamination conditions. Indeed, such coatings, due to their low energy surface, have good water repellency properties and help prevent continuous water filming on the surface [2]. However, the maximum contact angle that can be attained on a flat surface by RTV silicon rubber coatings does not exceed 117°.

Superhydrophobic surfaces (water contact angle larger than 150° and low contact angle hysteresis) have shown potential for anti-icing applications [3, 4]. Several approaches have been developed to create superhydrophobic surfaces, such as sol-gel process [5], plasma treatment [6], electrochemical method [7], template method [8], vapor deposition [9], layer-by-layer method [10], and others [11-15]. However, these methods generally require strict conditions and large facility costs, and may raise environmental issues. So, developing simple affordable and practical methods to create icephobic and superhydrophobic surfaces for the concerned industry is important and necessary. In the present study, a superhydrophobic surface was prepared by spray coating a SR and stearic acid mixture on a flat surface using a one-step process. The hydrophobicity of the coatings was found to depend on the surface morphology that was governed by the SR/stearic acid concentration, as well as the spray time distance

II. EXPERIMENTAL

RTV silicone rubber HVIC 1547 (containing 40-70 wt% alumina hydrate) was purchased from Dow Corning and the stearic acid (purity >99%) from Alpha Aesar Company. This type of SR was selected because it is used in the electric industry for outdoor insulators and related devices.

Glass substrates were ultrasonically cleaned in acetone and water for 5 minutes each. One gram of stearic acid was first dissolved in 50 ml of hexane. Then, the solution was mixed with a magnetic stirrer at 700 rpm for 15 minutes at 30 °C.

Solutions of RTV SR /stearic acid with concentrations of 14, 21 and 43 wt. % stearic acid were prepared for coatings ***a***, ***b*** and ***c***, respectively. These solutions were oscillated by ultrasonic waves followed by magnetic stirring (700 rpm) for 10 minutes. The mixture was sprayed on clean dry glass slides using a spray gun. For comparison, a simple SR solution was also sprayed on glass slides. Heat treatment of the coatings was done at 55° C in air overnight to remove residual solvents.

The morphological characterization of the surfaces was carried out using a LEO field emission scanning electron microscope (FESEM). Water contact angle measurements were conducted using distilled water and a Krüss DSA 100 contact angle measuring instrument (water drop volume ~ 4 μL). Contact angle hysteresis was measured using a common experimental procedure [16].

Spray coating techniques are widely used in industry to deposit composite films on large surfaces. This technique is fast, easy and inexpensive (as illustrated in Fig. 1)

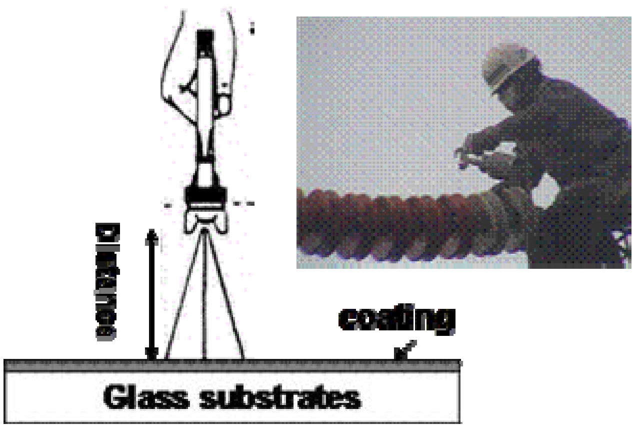


Figure 1. Demonstration of the simple operation of spray coating

III. RESULTS AND DISCUSSION

It is well known that surface roughness plays an important role on the wettability, which can be explained by the Wenzel and Cassie models. According to the Cassie model, air can remain trapped below the drop, forming “air pockets”. Thus, hydrophobicity is strengthened because the drop sits partially on the air. On the other hand, according to the Wenzel model surface roughness increases the surface area, which also geometrically modifies hydrophobicity [17]. It is conventional to relate so called moderate hydrophobicity to the Wenzel regime, whereas the Cassie scenario results in strong water-repellent surface properties. However, the Cassie regime has recently been invoked for slightly hydrophobic interfaces. Moreover, the coexistence of Cassie and Wenzel regimes has been observed on the same surfaces [17].

Several factors should be taken into account during the spray coating technique such as spray distance, time and angle. At a constant angle of 90° for a spray time of 10 s, the as-prepared coating ***c*** was applied for 10 s at four different spray distances, 10, 15, 20 and 25 cm. In Table 1, water contact angles are listed as a function of spraying distance .

Table 1: Wettability vs. spraying distance

Spraying distance (cm)	10	15	**20**	25
Water contact angle (θ°)	146.4	152.2	**160.3**	151.5

At a constant angle of 90° for a spray distance of 20 cm, the effect of spray time on the wettability of prepared coating is listed in Table 2.

Table 2: Wettability vs. spraying time

Spray time (s)	10	15	30
Water contact angle (θ°)	**160.3**	135	119

The optimized spraying condition was finalized with spraying coating ***c*** for 10 s at a distance of 20 cm from the sample, at an angle of 90°.

Here, the water contact angle of the prepared surfaces as a function of the stearic acid concentration with was examined, as illustrated in Fig.2.

The reported contact angles are averages of at least four measurements on different parts of each sample. The results showed that the static contact angle (θs) increases drastically with the stearic acid concentration, up to 160 ° ±3 for coating ***c***. The hysteresis contact angle is also an important criterion to characterize superhydrophobic and icephobic surfaces [4]. However, a different tendency was obtained for the water contact angle hysteresis (θ_H) measurements.

The as-prepared coating ***a*** showed high static contact angle and high hysteresis (θ_H), which is characteristic of the Wenzel wetting regime (Fig. 3a) When the stearic acid concentration reached 21 wt%, the sample was wetted following a mixed Cassie-Wenzel regime (Fig. 3b).

As for coating ***c,*** water droplets easily slid off the surface, implying very low hysteresis (see Fig. 3c) which has been attributed to the Cassie wetting regime.

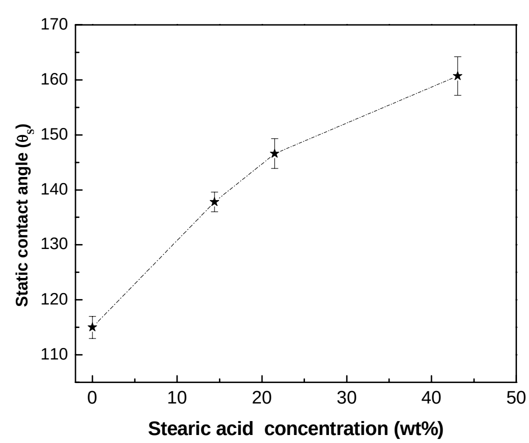


Figure 2. Evolution of water contact angle as a function of stearic acid concentration (wt. %)

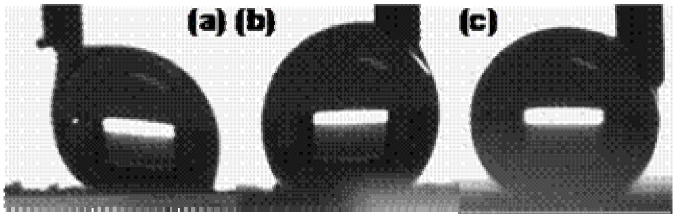


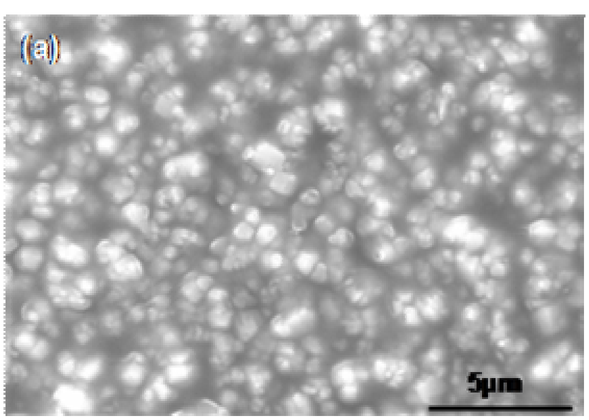
Figure 3. Water droplet moving on a surface wetted by: a)Wenzel regime; b) Cassie-Wenzel regime**;** c) Cassie regime

FESEM images of the SR / stearic acid mixture coated on the glass surfaces showed the evolution of various morphological features as shown in Fig. 4(a–c). Figure 1a exhibits a surface with a uniform coating of SR with alumina hydrate microparticles (1-2 µm) already present in its composition.

It can be observed that both surface appearance and morphology of the RTV SR coatings modified by adding stearic acid are different (Fig 4b) as a smooth surface coating with some "blade-like" structure was formed (Fig. 4c). By increasing the stearic acid concentration up to 43 wt. %, irregular island morphologies involving micro and nanostructures developed (Fig. 4c).

These images show that the surface morphology of the prepared coatings depends directly on the stearic acid concentration. Indeed, the development of nanoscale roughness superimposed on the microscale roughness observed for coating ***c*** may serve as a means of trapping sufficient air to exhibit low sliding angles, a behavior which is explained by the Cassie model.

Figure 4c suggests that the randomly distributed island morphology consists of nanostructures implying the presence of a two-length-scale hierarchical structure on the surface. It is believed that the same type of structure exists in the lotus leaf.



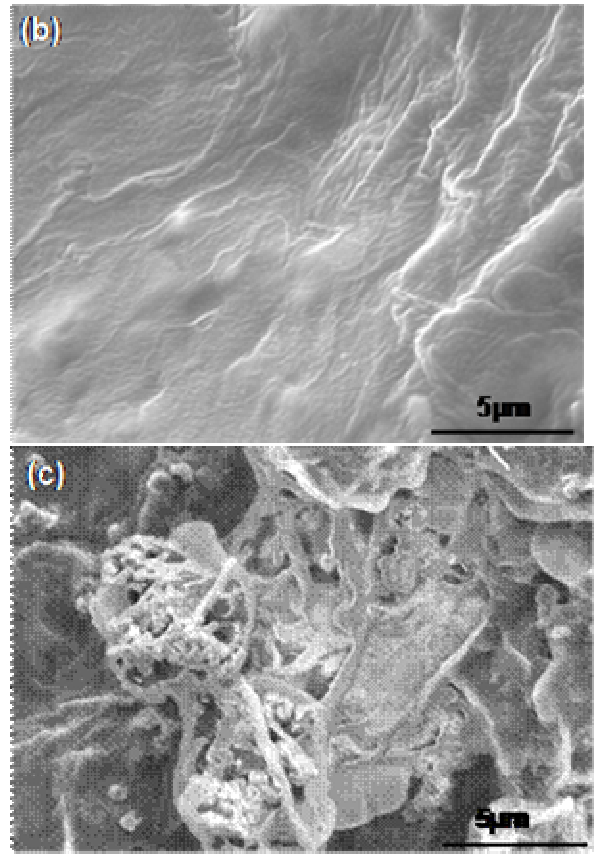


Figure 4. FESEM images of sample surfaces coated with different weight ratio of stearic acid. (a) 0; (b) 14 ;(c)43 wt.%

IV. CONCLUSIONS

A superhydrophobic surface was created using a simple and inexpensive one-step process. An appropriate combination of RTV SR and stearic acid resulted in a modified micro/nano scale surface structure trapping enough air to prevent the penetration of the water into the grooves and cavities of the surface. Morphological analyses of the as-prepared superhydrophobic surface confirmed the presence of a two-length-scale hierarchical structure. The water contact angle on this surface was found to be ~160° with the rolling-off properties of water drops. This coating has potential applications, in particular for outdoor insulators which would be beneficial to the concerned industry because of its low cost and simplicity of fabrication and use.

V. ACKNOWLEDGMENT

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