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Fabrication of a durable superhydrophobic coating for high voltage glass insulators

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SOMMAIRE

Pollution accumulation on electrical equipment and high voltage insulators is a severe problem in industrial and coastal zones, causing severe damages, power outage, flashovers, and losses of millions of dollars[1–3]. These problems have received a great deal of attention and a large number of efforts have been carried out on studying and development of methods for eradicating harmful consequences of pollution flashovers[4–6].
One of the interesting strategies to counter pollution accumulation problems, are using superhydrophobic/self-cleaning (water contact angle more than 150° and contact angle hysteresis less than 10°) coatings. These coatings can reduce the wettability of surface and pollutions can be easily washed by rolling off water droplets, consequently reduce particles accumulation on their surface[7–10].
In this paper, we have developed a superhydrophobic silicone-based coating for high voltage applications. The properties of the fabricated superhydrophobic coating were investigated using contact angle goniometry, SEM and FTIR analysis. The coating showed great self-cleaning due to high contact angle and very low contact angle hysteresis. In order to evaluate weathering resistance, QUV test was proceeded. The superhydrophobic coating could retain its properties after 100 hours of exposure.

MOTS CLÉS

Superhydrophobic coating, self-cleaning, Silicone, Porcelain insulator

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1. Introduction

Superhydrophobic surfaces have gained tremendous enthusiasm in both research and practical applications including self-cleaning[11, 12], oil-water separation[13], anti-corrosion[14–16], anti-icing[17–19], anti-fouling[20, 21] and so forth.

Generally, a surface with water contact angle (CA) of more than 150° and contact angle hysteresis (CAH) of less than 10° is categorized as superhydrophobic in term of wettability which is attained by the combination of surface chemistry and surface topography[22]. Self-cleaning or lotus leaf effect is an appealing behaviour driven by superhydrophobicity and can be used in different applications for glasses, solar cell panels, tiles and tissues[23].

Glass and porcelain are the most popular materials for high voltage insulators because of outstanding insulating properties and weather resistance. However, due to high surface energy of both these materials, they are easily wetted by rain, and covered by different pollutants. The types of contaminants in the environment are varied by geographic conditions, Local agricultural and industries. Some common types of pollutants are identified as the salt, cement/lime, dusts, bird excrement, chemicals, automobile emissions and ice and snow [24, 25].

To date, a variety of methods have been reported to impart superhydrophobicity to a surface such as chemical etching[26], lithographic processes[27], chemical vapour deposition[27, 28], electrospinning[30], etc. Large-scale application of most of these methods is not feasible due to expensive materials and complicated equipment. Coatings are widely used in every industrial application and using superhydrophobic coatings can be a very practical solution to benefit from the remarkable characteristics of superhydrophobicity in industries.

RTV insulator coatings, firstly developed for improving contamination flashover performance of electrical equipment. Poly (dimethyl-siloxane) (PDMS) is one of the main components of RTV silicone rubber coatings, the molecular chains of which contain CH3– groups providing a certain degree of hydrophobicity. Water contact angles on the surface of RTV silicone rubber coatings are around 110°, and such a low hydrophobic level cannot effectively impart self-cleaning behaviour [31].

Superhydrophobic materials are usually fabricated by dispersing nanoparticles into a matrix. Hydrophobically-modified nanoparticles modify the surface chemistry beside forming a micro/nano structure[32]. These particles can be utilized in a variety of resins i.e. epoxy resin[33], polyurethane[32], polystyrene[34], polydimethylsiloxane[35], and silicon rubber[36]. It is worth mentioning that low surface tension binders are more suitable choices for self-cleaning applications and would help in further durability issues.

A PDMS/nano-silica hybrid coating and RTV silicone rubber coating were applied on glass insulators for ice accumulation experiments. Water CA on the hybrid coating was 161°. The results showed that the rate of ice accumulation on hybrid coating was significantly lower than RTV silicon rubber insulators[31]. Wang et al. [37], fabricated a superhydrophobic coating by dispersion of modified silica nanoparticles in a fluorosilicone resin. Silica nanoparticles were modified using 1H, 1H, 2H, 2H-perflurooctyltriethoxysilane. The highest contact angle on their samples was 153° and the best sliding angle was 2.5°. Martin et al.[35], made PDMS superhydrophobic through micropatterning and spraying of hydrophobic SiO2 nanoparticles with a binder of methylphenyl silicone resin. By the addition of fluorosilane, the coatings were made super-oleophobic.

Though many superhydrophobic coatings have been successfully obtained by these methods, there are still some limitations i.e. expensive materials, fluorine contents, multiple steps, ultraviolet curing lines, lack of durability.

In this study, we have developed a simple and fluorine-free superhydrophobic coating which is only based on a composite of silicon-polyester resin/ fumed silica nanoparticles and shows excellent self-cleaning properties, non-wettability and great UV stability, which can be used on glass and porcelain insulators. Silicon-polyester resins combine the good properties of silicones (weathering resistance, low surface tension, chemical resistance) with those of polyesters (good mechanical properties, good wetting of fillers, and low cost).

2. EXPERIMENTAL

2.1. **Materials.** SILIKOFTAL HTT resin and fumed silica AEROSIL R812S were kindly prepared by Evonik Company. Tetrahydrofuran (THF) and Acetone were purchased from Sigma-Aldrich.

2.2 Preparation of coatings. 4.5 grams of fumed silica R812S was dispersed in 60-grams THF under sonication for 60 minutes. Then 10 grams of SILIKOFTAL HTT was added to the solution, stirred for 15 minutes and sonicated for 20 minutes. Glass slides were rinsed with Acetone. Two Grams of the coating formulation was placed on glass substrates and applied by use of a spin coater (Laurel Company, model WS-400B-6NPP) at 800 RPM for 30 seconds. Samples were placed in the oven at 250 °C for 15 minutes, after cooling at room temperature, another layer of coating was applied on samples and placed into the oven for another 30 minutes for complete curing. For comparison, 30 grams of SILIKOFTAL HTT was diluted with THF and applied according to the same procedure and cured for 30 minutes at 250 °C. Figure 1 is a schematic representation of the fabrication process.

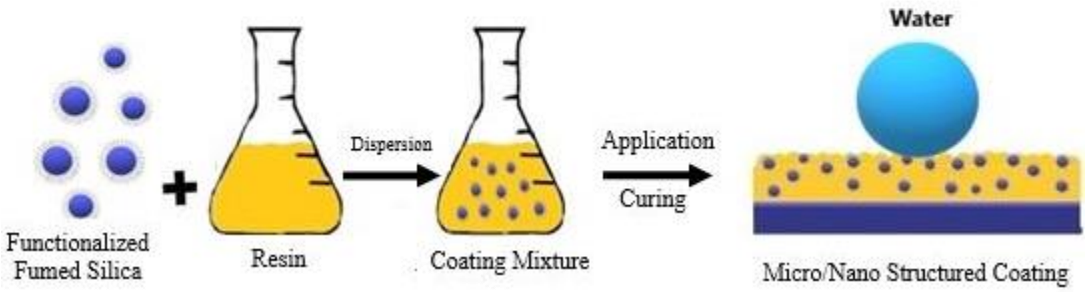

Figure 1. A schematic representation of superhydrophobic coating preparation.

2.3. Characterization

Contact angle measurement. Static and dynamic contact angles were measured at room temperature and over four different positions on samples and the average value is reported using a Kruss ™ DSA100 contact angle goniometer. A 4-µl water droplet was deposited on the sample surface and contact angles were approximated using the Young-Laplace equation.

FTIR. The chemical composition of coatings was characterized using a Cary 630 FTIR spectrometer (Agilent, USA) in attenuated total reflection (ATR) mode in the infrared range of 400-4000 cm^{-1}.

Self-cleaning evaluation. The self-cleaning ability of coatings was investigated using Kaolin powder as contaminant and a camera to record images.

Non-wetting behaviour. The non-wetting behaviour of the SHP coating was evaluated using Moose's method.

Scanning Electron Microscopy. Scanning electron microscopy (SEM) images were taken on a JSM-6480 LV SEM instrument manufactured by JEOL Japan to observe micro-nanostructure morphology of the developed coatings. Samples were sputter coated with a thin gold film before imaging.

Accelerated weathering test. In order to estimate the surface stability against natural factors, a QUV accelerated weathering tester by Q-LAB was used. Durability of coatings was evaluated according to ASTM G154.

3. RESULT AND DISCUSSION

3.1. Contact angle measurement

The wettability of untreated glass slide, pure SILIKOFTAL HTT resin and superhydrophobic coating was investigated by static and dynamic contact angle goniometry of a 4µL water droplet. Water can easily spread on glass due to the higher surface energy of glass in comparison with water. Meanwhile, the SILIKOFTAL resin showed hydrophobic properties. By introducing nano-silica particles into the coating, the hydrophobicity of the coating enhanced significantly due to the formation of a rough structure on the surface. The water contact angles and CAHs of pure SILIKOFTAL HTT resin and superhydrophobic coating (SHP coating) are illustrated in Table 1.

The water droplets were very unstable on developed superhydrophobic surfaces and could quickly roll off away under a small vibration during experiments, which is an indication of Cassie-Baxter wetting regime.

Table 1- Static Contact angle and contact angle hysteresis of water on different samples

Sample	CA	CAH
SILIKOFTAL resin	91°	6.67°
SHP coating	166.6°	1.69°
Untreated glass slide	54°	44°

Contact angle and contact angle hysteresis of water droplet on SHP coating are illustrated in Figures 2a and b. Figure 2c shows different size of water droplets gently deposited on the SHP coating.

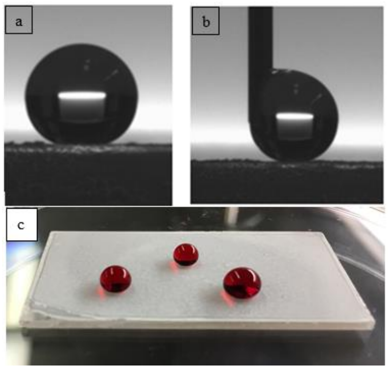

Figure 2. a) Sessile water droplet on SHP coating, b) Dynamic contact angle measurement, c) Red-colored water droplets on the SHP coating.

3.2. Electron Microscopy

In order to understand the surface morphology of samples, SEM images of the flat resin SHP coating were taken as shown in Figure 3. The images display the distinctive topographies of the pure resin and the SHP coating containing fumed-silica particles. The SILIKOFTAL HTT surface was smooth, however, when AEROSIL R812S was added to the resin, the coating displayed a rough structure. AEROSIL R812S is a fumed silica with high specific surface area (BET) equal to 195-245 m2/g and the SEM images confirm the very fine particle size of this material.

Sem image of the SHP coating shows a compact network of nanoparticles bonded with each other by resin, while the silicon-polyester resin shows good wetting properties for silica nanoparticles, since there is no sign of huge aggregations or phase separation.

The formed micro-nano structures are responsible for imparting superhydrophobic behaviour to the fabricated coating.

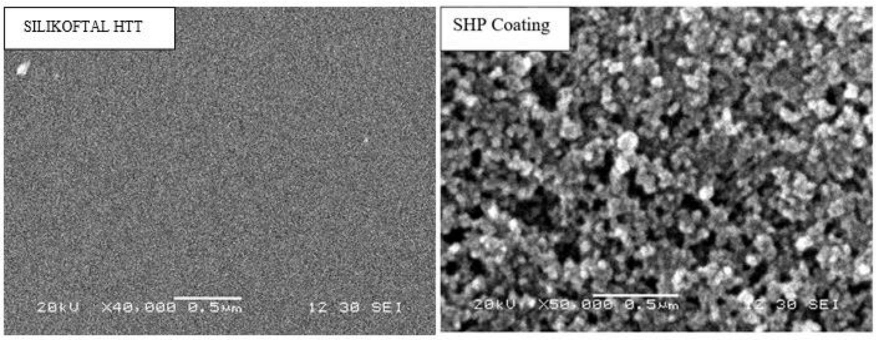

Figure 3. SEM images of SILIKOFTAL HTT resin and SHP coating.

3.3. FTIR

To assess the presence of chemical bonds on samples, FTIR analysis was performed. FTIR spectra results for resin, fumed silica and SHP coating are represented in Figure 4.

SILIKOFTAL HTT resin is a silicone polyester hybrid resin and FTIR result show both peaks regarding polyester groups and Si groups. The sharp peak at 1800 cm^{-1} represents an unsaturated ester and the peak at 1710 cm^{-1} is anti-symmetric vibration of the Si–O–Si bond, while the broad peak at 870 cm^{-1} shows stretching of Si-OR bands. The adsorption band at 1430 cm^{-1} is assigned to the asymmetry stretching of –CH3 groups. The observed peaks at 600-400 cm^{-1} in the finger print region, are related to C-C and bending of C-H bands of the polymeric chains. The fumed silica used in these experiments was AEROSIL R812S and stretching of Si-OR groups are observed at 870 cm^{-1}. The SHP coating shows all the peaks related to both resin and fumed silica.

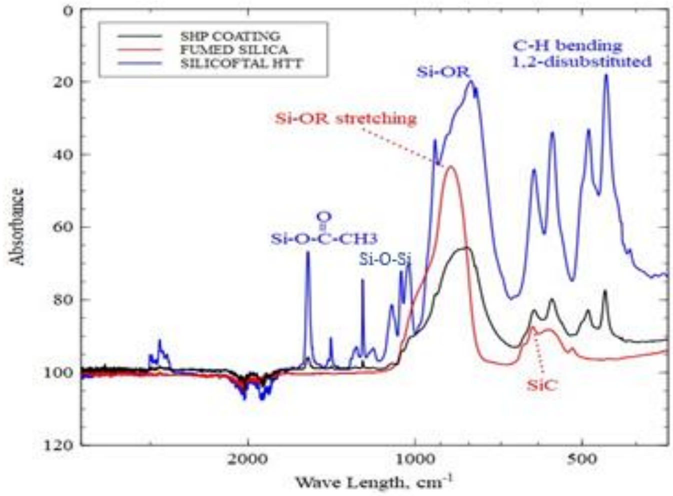

Figure 4. FTIR spectra for SILIKOFTAL HTT, AEROSIL R812S and SHP coating.

3.4. Self-cleaning ability

In nature, water droplets can easily roll off many plant leaves, such as lotus and Salvinia Molesta, and help them staying free of dirt and pollution thank to the self-cleaning behaviour. The self-cleaning of developed superhydrophobic coatings was verified using Kaolin powder as contaminant. A sparse layer of Kaolin powder was sprinkled on the coating surface and, by use of a syringe, a hanging water droplet was slowly swiped through the polluted coating. The water droplet collected the Kaolin powder efficiently while rolling on the coating (Figure 5).

Figure 5. Self-cleaning property of SHP coating (hanging water droplet efficiently collect Kaolin on its pathway).

In this test, water could successfully collect the pollutions on the SHP coating. This phenomenon happens due to the lower adhesion force of the dust particles to the coating in comparison with the adhesion force of dust to water droplet because of the low surface energy of coating combined with micro/nano rough structures.

3.5. Moses's effect

The SHP coating and an untreated glass slide were placed into two separate petri dishes and water was slowly poured in both petri dishes. For a better visibility, water was red colored by a food color. Untreated glass was simply covered with water, while an air column of nearly 6.3 mm height around the coated slide was remained (Figure 6). This test shows the ability of the superhydrophobic coating to remain dry.

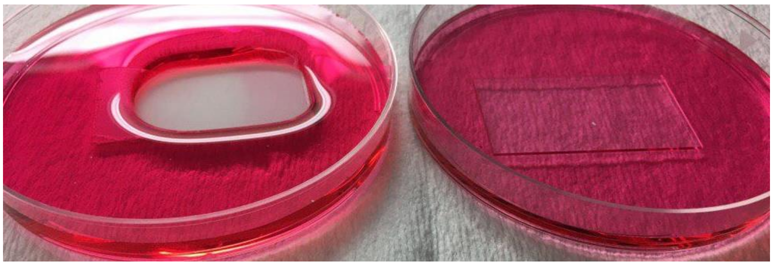

Figure 6. The ability of SHP coating to remain dry (left picture shows the SHP coating and right picture shows the un-treated glass).

3.6. Accelerated weathering test

Artificial weathering was conducted in a UV-chamber according to ASTM G154 which uses fluorescent light source simulating UVA-340. The accelerated weathering cycle was set as: UV irradiation for 8 h at 60° C with an irradiation intensity of 0.68 W/m^2, and condensation for 4 h at 50 $^{\circ}$C. Contact angle of samples after 100 hours exposure of samples in QUV chamber are presented in Table 2. This exposure time in the aforementioned condition, corresponds to about six months exposure in Ontario, Canada.

Table 2- Contact angle and CAH of samples after 100 hours exposure in QUV chamber

Sample	CA	CAH
SILIKOFTAL HTT resin	82°	20°
SHP coating	160.8°	3.53°

Contact angle of samples slightly decreased as the test proceeded. The SHP coating retained its superhydrophobicity after 100 h Of QUV tests. These results indicate that the SHP coating shows good weathering resistance keeping their roll off property.

CONCLUSION

A facile superhydrophobic coating was developed by using a silicon-polyester hybrid resin and a hydrophobically-modified fumed silica. The coating showed water contact angle of 166° and contact angle hysteresis of less than 2° which results in great self-cleaning properties. The nanoparticles were chosen due to their high surface area and very fine particle size and the morphology of the composite coating was investigated and micro-nano structures were obviously seen in SEM image. The coating showed good weathering resistance and retained its superhydrophobicity after 100 hours exposure by QUV test. This superhydrophobic coating can be used for glass and porcelain insulators in order to prevent pollutant-caused flashover.

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