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The Performances of RTV Coated Surfaces and Their Services in Transmission Lines

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Abstract. With climate change and global warming, there are extreme weather phenomena in some places. Excessive temperature can adversely affect room temperature vulcanized silicone rubber (RTV) insulators. Other factors such as air pollution, dust, fog, rain, ice and snow, and ultraviolet rays can cause damage to the surface hydrophobicity of the RTV surface and reduce its service life. Contamination from the above factors increases the risk of flashover and corona discharge, which can lead to accidents in the transmission system, resulting in economic loss or personal injury. In recent decades, scientists have investigated a variety of materials that can be compounded with RTV to improve their chemical and physical properties in order to extend the service life of RTV insulators. In this review, we conduct an extensive literature survey and summary on the development and application of RTV coated insulators.

Keywords. Composition of RTV coatings, superhydrophobic surface, anti-icing, flashover with coating damage

1. Introduction

Since the 1990s, transmission line operators have been facing contamination problem that cause corona discharge, insulators flashover, leakage current, and ultimately waste power in the distribution system and cause accidents [1]. The pollution flashover process is shown in Figure 1 [2]. In order to prevent the occurrence of the above problems, insulators have become important equipment in the electrical power system. Due to the outdoor work field, pollution, UV rays, dust, temperature will have a great impact on the insulator, so whether the surface of the insulator is covered with room temperature vulcanized silicone rubber (RTV) coating will be an important measure to protect the transmission system [3]. Compared with uncoated insulators, RTV-coated insulators have better properties in pollution flashover, lifetime, self-cleaning, hydrophobicity, etc [4-6]. The main advantages of RTV coatings are good hydrophobicity, good adhesion, nominal thickness range, and this property makes them widely used for power transmission. Several traditional insulator materials such as porcelain, ethylene-propylene-diene-monomer rubber, and RTV coated silicone rubber have been compared, and the silicone provides the best flashover performance [7]. Data on flashover voltage

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and leakage current in other literatures indicated that RTV coating can improve the performance of ceramic insulator in clean fog and salt fog circumstance [8].

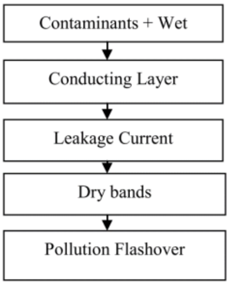

Figure 1. Pollution flashover process on insulator surface [2].

Removing the aged RTV coatings is also a problem when maintaining insulators, *Wang Xilin et.al*. proposed a solution to this problem [9, 10]. The application methods of coatings are mainly brushing, spraying and dipping [11]. At present, most of the provinces in China have popularized RTV coating. Figure 2 shows the statistical results [12].

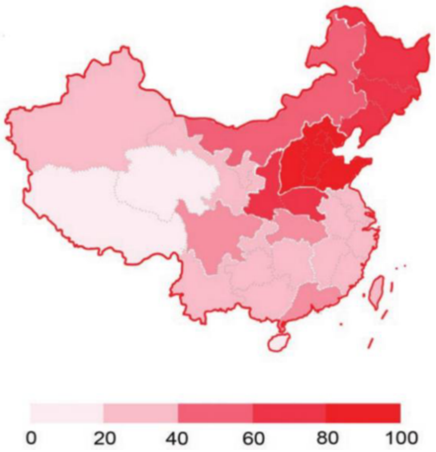

Figure 2. Use of RTV coatings in different areas of China. 100 means 100 percent porcelain and glass insulators and bushings were coated with RTV silicone coatings, and 0 means none of them were coated [12].

2. Composition of RTV Coatings

RTV coatings are composed of a polydimethylsiloxane (PDMS) polymer, reinforcing filler, PDMS fluid, alumina trihydrate filler, colorant pigment, crosslinking agent, condensation catalyst and adhesion promoter [11]. Some effects of fillers on substrate properties are summarized in Table 1 [13]. There are many factors in outdoor environments that can cause different type of stress on insulators. Figure 3. summarizes these factors and their effect on insulators.

Table 1. Different types of re-enforcing fillers and their effects on the properties / characteristics of base materials [13].

Type	Effects of fillers on properties of base materials
ATH	Increase resistance against erosion and tracking as well as enhances electrical and thermal conductivities
SiO_2	Improves anti-erosion/tracking performance and increases thermal conductivity
Al_2O_3	Enhance erosion/tracking resistance and thermal conductivity
TiO_2	Improves thermal stability and increases relative permittivity
ZnO	Increase relative permittivity, thermal conductivity and mechanical strength
$CaCO_3$	Enhances ability of retarding flames as well as improves hydrophobicity
$BaTiO_3$	Increase thermal stability and relative permittivity
Carbon black	Improve electrical and mechanical properties
Graphite	Elevates thermal conductivity
Boron nitrides	Enhance erosion and tracking resistances
Silicon carbide	Improves erosion/tracking resistance

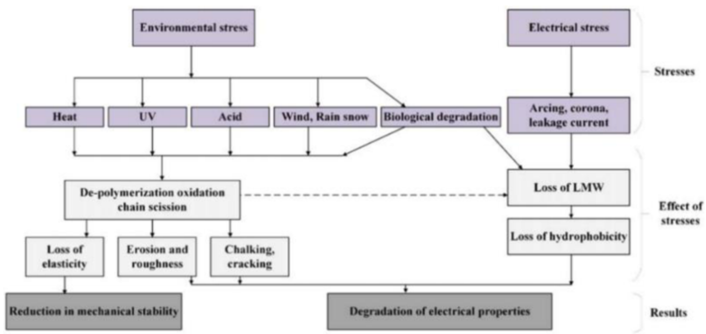

Figure 3. Different types of stress and their adverse effects on the desired properties of insulators [13].

Due to the high hydrophobicity and hydrophobicity transfer of the RTV coating, it can greatly improve the flashover resistance of porcelain insulators and glass insulators. There is a vulcanization process in RTV, as shown in Figure 4 [14].

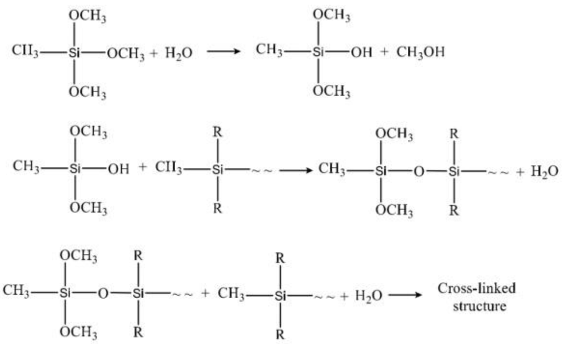

Figure 4. Chemical reaction in RTV.

3. Hydrophobicity

Hydrophobicity is a very important property of RTV coated insulators, which can prevent the formation of a water film on the surface of RTV insulations during high humidity or rainy days. Hydrophilic is defined as a wetting fluid with a contact angle less than 90°, and hydrophobic is defined as a contact angle between 90° and 180°. There is a standard that can be used to differentiate between hydrophilic and hydrophobic [2]. HC1 represents the highest hydrophobic surface, forming only discrete and extremely circular water drops, while HC7 represents the highest hydrophilic, as shown in Table 2 [2].

Table 2. Level of Hydrophobicity Classification (HC) [2].

HC	Contact Angle	Condition	Surface
1		No wetting	
2	90º<θ< 180º	Low wetting	hydrophobic
3		Low wetting	
4		wetting	
5		wetting	
6	0º<θ<90º	wetting	hydrophilic
7		Highly wetting	

To improve the hydrophobicity of the material, some researchers synthesized aluminum nitride/silicone rubber [15], which showed a significant increase in hydrophobicity compared with pure RTV coatings. Under the same conditions, the static contact angle and rolling angle of aluminum nitride (AlN) /RTV are 157.7 ± 0.9° and 4.2 ± 0.7°, respectively, while those of pure RTV are 130 ± 1.8° and 36.7 ± 0.8°, respectively. Their morphology and mechanism are shown in Figure 5 [15]. The high hydrophobicity of the AlN/RTV surface enables self-cleaning and bouncing properties to keep insulator dry and no dust on the surface, which can prevent contamination flashover voltages and extend the service life of outdoor insulators. Table 3. is a summary of the contact and rolling angles for RTV surfaces or RTV composite surfaces.

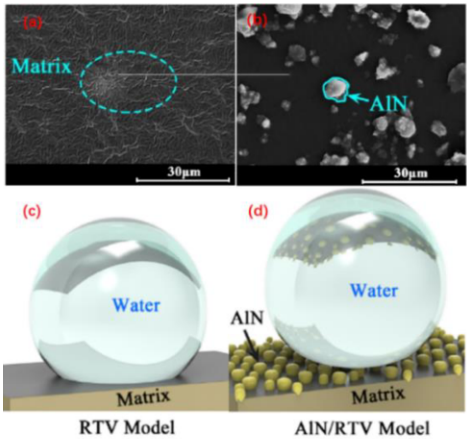

Figure 5. (a) SEM of pure RTV; (b) SEM of AlN/RTV; (c) model of contact between RTV and water; (d) model of contact between AlN/RTV and water [15].

Table 3. Contact and rolling angle of different materials.

Materials	Contact angle (°)	Rolling angle (°)	Literatures
RTV	130 ± 1.8	36.7 ± 0.8	[15]
AlN/RTV	157.7 ± 0.9	4.2 ± 0.7	[15]
RTV	130 ± 1.2	36.5 ± 1.1	[16]
Al_2O_3/RTV	156.6 ± 1.1	156.6 ± 1.1	[16]
RTV	103	-	[1]
Nano-ZnO/RTV	128	-	[1]
Nano-ZnO/SiO_2RTV	114	-	[1]
Coating A	136.5	-	[17]
Coating B	156.4	-	[17]
Coating C	154.6	9	[17]

4. Superhydrophobic Surface

Regarding superhydrophobic surface study [18], where water self-propels to coalesce droplets and jump off the surface. Since the contact angle of RTV surface is smaller than that of the superhydrophobic surface, this phenomenon does not occur on the RTV surface. Their mechanism is described in Figure 6 [18].

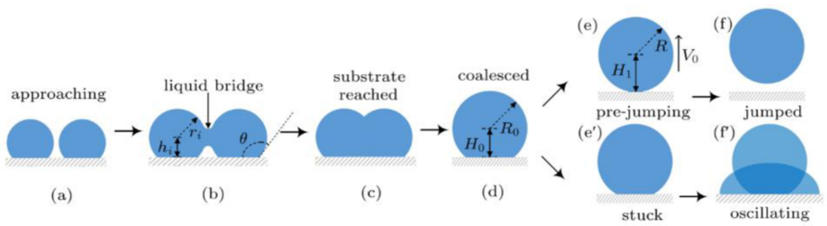

Figure 6. Schematic diagram of the dynamic behaviors of coalesced droplets on superhydrophobic surface (a)-(f) and RTV surface (a)-(f ′) [18].

The reason of this phenomenon is that the roughness of the material surface is different and causes different contact modes, as shown in Figure 7 [16].

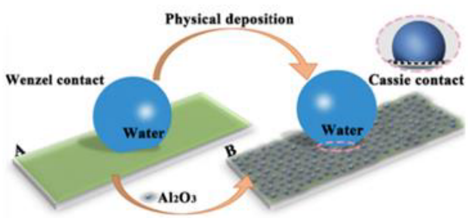

Figure 7. Change of surface contact model of sample before and after physical deposition of Al_2O_3 particles [16].

Nanoparticles combined with RTV materials are an effective way to improve hydrophobicity. By comparing the contact angles and critical flashover voltages of the three materials, it is shown that nano-RTV (I) (nano ZnO/RTV) has the best performance both in terms of hydrophobicity and critical flashover voltage. Lifetime expectation model shows that nano-RTV-coated insulators can improve the lifetime and failure probability density function of insulators, contaminated area [1]. *Zhu Jiyuan* and *Liao Kaijin* used a layer-by-layer assembly method of silica particles with different diameters and room temperature vulcanized silicone rubber to prepare flexible superhydrophobic coatings [17]. The preparation route of this material is shown in Figure 8 [17]. The results indicate that the micro-nano hierarchical structure composed of silica particles and silica nanoparticle coatings exhibited good corrosion resistance and self-cleaning properties. The contact angle and sliding angle of the coated surface are154.6° and 9°, respectively.

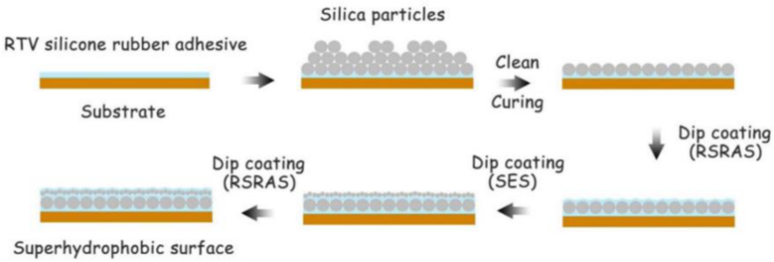

Figure 8. Preparation of superhydrophobic coating. RSRAS: RTV silicone rubber adhesive solution; SES: silica-ethanol suspension [17].

Activation energy value is another factor that affects the lifetime of the insulator. *Monire Taghvaei et.al*. reported three materials: RTV, ZnO/RTV and $ZnO/SiO_2/RTV$. Table 4 [19] is a list of thermal properties of these three materials. Compared with pure RTV, the average activation energy values of the samples containing hybrid modified ZnO/SiO_2 and ZnO nanoparticles were increased by 2.8 and 1.37 times, respectively [19].

Table 4. Thermal properties of RTV samples [19].

Sample	$T_{initial}$ (°C)	T_{1max} (°C)	T_{2max} (°C)
RTV	171.6	252.91	413.36
ZnO/RTV	217.77	276.19	417.72
$ZnO-SiO_2/RTV$	213.95	283.59	422.12

5. Anti-icing

Hu Qin et.al [20] conducted a systematic study on microencapsulated phase change materials (MEPCM). which is made of silica shell and n-tetrad cane cores and can be used as anti-icing and thermal energy storage. When the mass percentage is increased to 16.7% and the ambient temperature is -10 °C, the cooling time of the modified RTV to 0 °C is about 10 minutes, which is 6 minutes longer than that of the ordinary RTV. It can also increase leakage current and still maintain good self-cleaning ability. The schematic of silicone rubber sheet mixed with MEPCM is shown in Figure 9 [20].

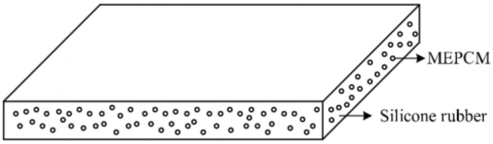

Figure 9. Schematic of silicone rubber sheet mixed with MEPCM [20].

6. Biological Contamination

China's vast territory and complex climate make biological contamination a common phenomenon, especially in Sichuan province. An insulator contaminated with algae is shown in Figure 10 [21] The effect of biological growth on the surface of the insulator can reduce the flashover voltage, which is mainly due to the hydrophilicity of the algae itself. In the environment of algae growth, the organic group Si-CH_3 in polysiloxane is decomposed from the chain in the presence of oxygen, forming a new Si-O-Si crosslinking point. Although algae can age RTV surfaces, algae cause minimal damage to RTV surfaces. It is worth noting that silicone rubber materials are more conducive to algae growth than porcelain materials [21].

Figure 10. Insulator images [21].

According to the reported of *Ouyang Xiaogang et.al.*, under the condition of steam fog, the flashover voltage is 25.2~44.0 % lower than that of the clean one due to the existence of algae [22].

7. Flashover with Coating Damage

The step of acquired the insulator damaged or normal is a very valuable messages, according this we can prevent disaster occur in the high voltage transmission power system. *Xin Lijie et.al.* have published an article on how to process defective insulators based on visible spectrum images, and refer to an image processing technology to preprocess the image collected by the UAV, and then obtain a complete image of the insulator through image splicing [23].

The damage area of the coating on the surface of the insulator is an important factor causing the drop of the flashover voltage. It is important to explore the relationship between different damage profiles of RTV coating surface and the flashover. At different equivalent salt deposit density, the relationship between the salt deposit density and the flashover voltage gradient resulted in a negative power function when RTV coating damage increases [14]. The pollution flashover voltage is affected by the minimum "effective path" distance defined in the paper [24]. Different flashover types caused by different damage areas are shown in Figure 11 [24].

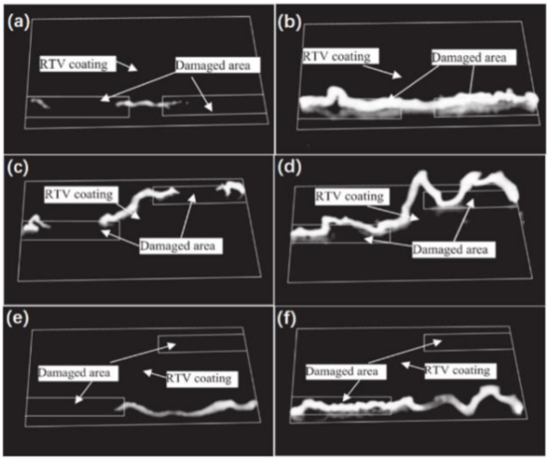

Figure 11. (a), (c), (e) Arc development process. (b), (d), (f) Final flashover [24].

Other researchers have also found that the onset of the arc usually occurs at the location where the current density is greatest [25]. The damage of different parts of the insulator leads to the change of electrical conductivity and the uneven distribution of the current density, which is the main reason why the pollution flashover characteristics are directly related to the damage mode. *S. Ilhan et.al*. concluded that bottom coated suspension insulators appear to perform as well as fully coated insulators, at least in 40 g/L salt fog [26]. Bottom coated suspension insulators are more economical than full coated insulators in this case.

8. Conclusion

This review describes the application of RTV coatings in insulators from the composition, hydrophobicity, superhydrophobic surface, anti-icing, biological contamination, flashover and coating damage of RTV coatings. Although ice, damage, contamination, biology and other factors can reduce the hydrophobicity of the surface of RTV coated insulators and shorten their lifetime, RTV coatings are still widely used, and some new RTV composite materials have also been explored.

Nomenclatures

RTV	room temperature vulcanized silicone rubber
HC	hydrophobicity classification
PDMS	polydimethylsiloxane
AlN	aluminum nitride
MEPCM	microencapsulated phase change materials

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