Effect of vulcanization temperature and humidity on the properties of RTV silicone rubber

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Abstract. In order to study the difference in performance of room temperature vulcanized (RTV) silicone rubber in vulcanization environment with different temperature and humidity, static contact angle method, FTIR and TG is utilized to depict the properties of hydrophobicity, transfer of hydrophobicity, functional groups and thermal stability of RTV silicone rubber. It is found that different vulcanization conditions have effects on the characteristics of RTV silicone rubber, which shows that the hydrophobicity of RTV silicone rubber changes little with the vulcanization temperature but a slight increase with the vulcanization humidity. Temperature and humidity have obvious effects on the hydrophobicity transfer ability of RTV silicone rubber, which is better when vulcanization temperature is 5°C or vulcanization humidity is 95%. From the Fourier transform infrared spectroscopy, it can be concluded that humidity and temperature of vulcanization conditions have great effect on the functional groups of silicone rubber, and vulcanization conditions also have effect on thermal stability of RTV silicone rubber. When vulcanization temperature is 5°C or vulcanization humidity is 15% or 95%, the thermal stability of silicone rubber becomes worse.

1. Introduction

With the rapid development of Chinese national economy, the demand of power is increasing, which results in a continuous increase of voltage level of power transmission equipment and the transmission capacity. The safe and stable operation of power system has been attracting more and more attention [1]. The pollution flashover has the characteristics of large area and low reclosing success rate. It may lead to blackout in a large area, which will bring huge economic loss and negative impact to the country and society [2]. Therefore, the pollution flashover problem has become one of the main factors affecting the safe and stable operation of the power grid.

Room temperature vulcanized (RTV) silicone rubber has excellent hydrophobicity and transfer of hydrophobicity, which can significantly improve the flashover voltage of porcelain and glass insulators [2]. As a kind of organic insulating material, the performance of RTV silicone rubber has attracted widely attention from scholars all over the world [3, 4].
Few researches on the effect of temperature and humidity on the vulcanization properties of RTV silicone rubber were carried out \cite{5,6}. Some scholars have studied the effect of vulcanization process of silicone rubber on its vulcanization degree \cite{7}, but the basic physical and chemical properties have little been involved.

Dealcoholization type RTV silicone rubber is vulcanized by absorbing the moisture in the air. Small alcohol-based molecules supplied are removed and cross-linking reaction happened. The vulcanization mechanism mentioned above is shown below \cite{8}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{vulcanization.png}
\caption{The vulcanization reaction mechanism of RTV silicone rubber}
\end{figure}

It can be seen from figure 1 that the moisture content in the air has a great impact on the vulcanization reaction. All chemical reactions are dependent on temperature because it affects the extent and speed of chemical reactions. Therefore, the study of temperature and humidity on the properties of RTV silicone rubber vulcanization is very meaningful.

According to DL/T 627-2012, the environmental requirements for RTV silicone rubber is under the temperature of 25°C±2°C, and the relative humidity of 40%~70% \cite{9}. However, in the field, due to environmental constraints, construction technology and other restrictions, it is difficult to meet the vulcanization conditions. In order to solve this problem, RTV silicone rubber vulcanization was carried out under different temperature and humidity conditions. Some basic properties including hydrophobicity, transfer of hydrophobicity, FTIR and TG of the RTV silicone rubber coating were analysed, and the conclusion provided an in-depth understanding of the vulcanization mechanism of RTV silicone rubber coating.

2. Experimental Setup

The test was conducted in a programmable constant temperature and humidity chamber. A kind of commercial available RTV silicone rubber was coated on a 10 cm×10 cm square ceramic sheet, vulcanized for 48 hours under the conditions shown in Table 1, and placed for 7 days under the laboratory environment.

The vulcanization temperatures were chosen to be 5°C/25°C/65°C, in which 25°C is the normal ambient temperature. Relative humidity of 15%, 55% and 95% were chosen, in which 15% is for some certain arid areas, 55% is for the normal humidity and 95% is for the humid areas.

In this paper, we considered the influence of single factor on the vulcanization of RTV silicone rubber. The sample numbers and vulcanization conditions are shown in Table 1.
Table 1 Sample numbers and vulcanization conditions

| Sample number | temperature(°C) | Relative humidity (%) |
|---------------|-----------------|-----------------------|
| S1            | 25°C            | 55%                   |
| S2            | 65°C            | 55%                   |
| S3            | 5°C             | 55%                   |
| S4            | 25°C            | 95%                   |
| S5            | 25°C            | 15%                   |

The hydrophobicity and transfer of hydrophobicity of RTV silicone rubber coating were studied using SL 200B contact angle measuring device. The contact angles were measured at three points and the average was plotted. In the paper, we use same method for smear treatment \cite{3, 4}. The kieselguhr was chosen as insoluble and sodium chloride as the soluble pollutant. The ash density was 1.0 mg/cm² and the salt density was 0.1 mg/cm². After brushing and drying, the samples were placed into a plastic box for hydrophobic migration. And temperature of 25°C and humidity 70% were chosen as the migration environment. The infrared analysis was performed by the United States NICOLET company FTIR 5700 Fourier infrared spectrometer, and TG analysis instruments was the Hitachi 7300 TG analyser.

3. Effect of Different Vulcanization Temperature on Properties of RTV

Figure 2 shows that, with the increase of vulcanization temperature, the change of static contact angle is not obvious, which indicates that the vulcanization temperature has little effect on the hydrophobicity of RTV silicone rubber.

From curves of in figure 3, it can be seen that the transfer of hydrophobicity of the sample after vulcanization at 5°C is significantly better. It indicates that under 5°C vulcanization environment, the cross-linking reaction occurs incompletely, resulting in more small molecules of siloxane. With the increase of vulcanization temperature, the cross-linking reaction is further deepened.

Table 2 shows the range of the wave number corresponding to the typical characteristic peak of RTV silicone rubber \cite{10}. From figure 4, it can be seen that the intensity of O-H peak decrease with the increase of vulcanization temperature. This indicates that with the increase of vulcanization temperature, the degree of cross-linking is deepened. The cross-linking reaction is slow at 5°C, and the degree of cross-linking is relatively light.

As shown in figure 5, with the increase of vulcanization temperature, the thermal stability of silicone rubber becomes better, and it can be explained as follows. Vulcanization reaction under 65°C is more thorough, 65°C makes some products degrade during the vulcanization process, and the final product does not contain such degradable substances.

Table 2 Functional groups and characteristic absorption peak

| Functional groups | Wave number (cm⁻¹) |
|-------------------|--------------------|
| O-H               | 3700~3200          |
| C-H in Si-CH₃     | 2960               |
| Si-CH₃            | 1280~1240          |
| Si-O-Si           | 1100~1000          |
| Si(CH₃)₂          | 840~790            |
Figure 2. Hydrophobicity of RTV silicone rubber at different vulcanization temperature

Figure 3. Hydrophobicity transfer ability of RTV silicone rubber at different vulcanization temperature

Figure 4. FTIR spectra of RTV silicone rubber at different vulcanization temperature
Figure 5. TG analysis of RTV silicone rubber at different vulcanization temperature

4. Effect of Different Vulcanization Humidity on Properties of RTV

Figure 6 shows that the hydrophobicity of the samples increases slightly with the increase of the vulcanization humidity, but the static contact angles differ in three cases.

As shown in figure 7, samples under high humidity vulcanization environment show a better hydrophobic migration, which means that the moisture content in the air has a great impact on the vulcanization reaction. Chemically speaking, the reaction of water and PDMS is reversible \(^\text{[12]}\), when the humidity is extreme high, hydrolysis will occur and the content of PDMS in the sample will increase.

Similarly, from figure 8 we can see, Si-CH\(_3\) peak increases with the increase of vulcanization humidity, which is in good agreement with the hydrophobicity of RTV silicone rubber. Si-O-Si peak intensity and Si-(CH\(_3\))\(_2\) peak intensity of sample in the low humidity environment are less than those of the other two, which is in good agreement with the thought that the vulcanization of the silicone rubber coating is incomplete under low humidity conditions. In the case of high humidity, Si-O-Si reacts with water due to the high content of water in the air and decompose into short chains, resulting in the generation of more PDMS\(^\text{[11]}\), thus the sample have a good characteristic of hydrophobic migration.

As shown in figure 9, both high humidity and low humidity condition lead to the deterioration of the thermal stability of the silicone rubber material. Under high humidity, the moisture in the air degrade the macro molecular chains into small molecules, and decompose at lower temperatures, leading to deterioration of their thermal stability \(^\text{[12, 13]}\). In the case of low humidity condition, the cross-linking reaction is not complete. When it reaches a certain temperature, its decomposition is aggravated, and its thermal stability is deteriorated.
Figure 6. Hydrophobicity of RTV silicone rubber at different vulcanization humidity

Figure 7. Hydrophobicity transfer ability of RTV silicone rubber at different vulcanization humidity

Figure 8. FTIR spectra of RTV silicone rubber at different vulcanization humidity
5. Conclusion

The paper study the effect of vulcanization temperature and humidity on the properties of RTV silicone rubber and make the following conclusions:

(1) Vulcanization at different temperature and humidity had little effect on the hydrophobicity of RTV silicone rubber. With the increase of vulcanization temperature, the hydrophobicity of RTV silicone rubber was not significantly affected. With the increase of vulcanization humidity, the hydrophobicity of RTV silicone rubber increased slightly. The transfer of hydrophobicity of RTV silicone rubber was affected significantly. The hydrophobicity migration of RTV silicone rubber showed a decreasing trend with the increase of vulcanization temperature. The hydrophobicity migration of RTV silicone rubber increased with the increase of vulcanization humidity.

(2) Vulcanization at different temperature and humidity have a great effect on the peak intensity of the functional groups in the RTV silicone rubber coating. When the vulcanization temperature is 65°C, the intensity of the O-H peak is significantly reduced. When the vulcanization humidity was 15%, O-H, Si-O-Si and Si(CH3)2 peak intensity are significantly reduced.

(3) The vulcanization at different temperature and humidity has an influence on the thermal stability of RTV silicone rubber. With the increase of vulcanization humidity, the thermal stability is worse, and with the increase of vulcanization temperature, the thermal stability becomes better.

(4) RTV silicone rubber vulcanization need to be paid more attention to choose the proper environment.

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