Research On the Effect of Reinforcing Filler on The Mechanical and Electrical Properties of Insulating Coated Silicone Rubber

Junting Yang1,*, Zhijuan Huang2, Zhenqi Ma1, Mingguo Zheng3, Juan Su4
1Gansu Electric Power Research Institute
2Sichuan Energy Internet Research Institute Tsinghua University
3Dingxi Power Supply Company of State Grid
4College of Information and Electrical Engineering China Agricultural University

*Corresponding author: oleoleyang@aliyun.com

Abstract. This paper studies the silicone rubber insulation coating material used for the modification of overhead bare wires. The influence of two reinforcing fillers of silicone rubber on the density, mechanical properties and electrical properties of insulating coating materials was explored. Finally, 25 copies of white carbon black were selected as a reinforcing filler to prepare a low-density, high-strength, and good insulating silicone insulating coating material.

Keywords: Overhead bare wire, Insulating coating material, Silicone rubber, White carbon black, Nano calcium carbonate.

1. Introduction
With the development of economy, a large number of distribution lines have been built in China, however, most distribution lines are bare overhead conductors. Distribution lines have operations across rivers (ponds), trees, densely populated areas, factories, which often leads to short circuits. Causing economic losses in industrial and agricultural production or casualties occurred [1-4].

To ensure the safety of power supply and distribution of overhead power lines, both State Grid and China Southern Grid have put forward clear requirements for the insulation of exposed overhead lines. At present, the more common solution is to replace the naked conductor with the insulated conductor in the whole section. However, 10kV overhead bare conductor has a large distance between poles and a long line, so it costs lots of money and time to replace the conductor, and local hidden trouble cannot be repaired timely [5-7]. Therefore, in recent years, new technologies such as "electrified coated insulating material" have been studied, it is possible to insulate a bare conductor when the line is continuously energized. The insulation materials used in overhead conductors should have the characteristics of self-curing, insulation, aging resistance, environmental adaptability and economy, etc [8-9].

Because of its unique molecular structure, Silicone rubber has excellent high and low temperature resistance, uv resistance, salt fog resistance, hate water and hate water migration performance [10-12], and it has excellent dielectric properties and adhesion to the substrate [13], which makes it become a good choice of insulating coating material. But silastic molecular chain has good flexibility and weak
interaction force between the chains, which leads to its low strength (<0.4MPa), so it is necessary to use filler to supplement its strength [14-15].

At present, there are two kinds of reinforcing filler commonly used in silicone rubber, nano calcium carbonate and silica [16], this paper will explore the influence of the types and dosage of these two kinds of reinforcement fillers on the density, mechanical properties and electrical properties of insulating coated silicone rubber, to prepare an insulating coated silicone rubber with low density, high strength and excellent insulation performance.

2. Results and Discussion

2.1. Effect of calcium carbonate on insulating coated silicone rubber
To study the effect of different kinds of calcium carbonate as fillers on the properties of insulating coated silicone rubber, add the same amount of calcium carbonate (70 copies), the specific types are shown in Table 1. The density was measured by dipping method, the prepared dumbbell shaped spline is made of insulated silicone rubber to test tensile strength and elongation at break of sample.

| No.       | Grain Size(nm) | Density(g/cm3) | Consistence | Tensile Strength (MPa) | Elongation at Break (%) |
|-----------|----------------|----------------|-------------|------------------------|-------------------------|
| LH-CaCO₃  | 50-70          | 1.38           | 8.0         | 2.45                   | 313                     |
| HY-CaCO₃  | 80-100         | 1.41           | 7.8         | 2.34                   | 295                     |
| HN-CaCO₃  | 80-100         | 1.44           | 8.1         | 2.37                   | 284                     |
| YX-CaCO₃  | 100-120        | 1.48           | 8.2         | 2.26                   | 266                     |
| YY-CaCO₃  | /              | 1.43           | -           | 1.78                   | 190                     |

LH-CaCO₃, YX-CaCO₃, HY-CaCO₃, HN-CaCO₃ are cube-like nanometer calcium carbonate, YY-CaCO₃ is coarse whiting. It can be seen from the above table that light calcium carbonate is thixotropic and more effective than heavy carbonic acid. As the particle size increases, the insulating silicone rubber with LH-CaCO₃, HY-CaCO₃, HY-CaCO₃, YX-CaCO₃ has the density increases and the mechanical properties decrease. Because LH-CaCO₃ has smaller particle size and specific surface area, and its microstructure is similar to that of carbon black and silica, partial chains [17], the area of interaction with the silicone rubber molecular chain is larger. The more joint points formed, the stronger the interaction between each other, the better the reinforcing effect. The grain size of HY-CaCO₃ and HN-CaCO₃ are similar, the density and mechanical properties of silicone rubber coated with insulation are different due to different surface treatment agents. Under the same condition, insulation coated silicone rubber with LH-CaCO₃ has low density and excellent mechanical properties.

2.2. Effect of the amount of nano calcium carbonate on insulating coated silicone rubber
To study the influence of different content of LH-CaCO₃ on the density and mechanical properties of insulating coated silicone rubber, insulating coated silicone rubber with 10, 30, 50, 70 and 90 copies of LH-CaCO₃ contents was prepared.
Tab. 2 The properties of silicone rubber prepared with different amounts of nano calcium carbonate

| No.       | Density (g/cm³) | Consistence | Tensile Strength (MPa) | Elongation at Break (%) |
|-----------|----------------|-------------|------------------------|------------------------|
| LH- CaCO₃-10 | 1.12          | 13          | 1.03                   | 263                    |
| LH- CaCO₃-30 | 1.22          | 10.8        | 1.22                   | 281                    |
| LH- CaCO₃-50 | 1.32          | 9.1         | 1.64                   | 298                    |
| LH- CaCO₃-70 | 1.38          | 8.2         | 2.45                   | 313                    |
| LH- CaCO₃-90 | 1.46          | 7.2         | 2.39                   | 296                    |

As can be seen from the above table, with the increase of the number of nano calcium carbonate components, the density, consistency, tensile strength and breaking elongation of the insulation-coated silicone rubber increased first and then decreased, because within a certain limit, With the increase of the amount of nano calcium carbonate, the larger the area in contact with the silicone rubber and the more the working points between them, the higher the cross-linking density of the whole system will be, and the better the strengthening effect of silica on the silicone rubber will be. But, when the amount of nano calcium carbonate exceeds 70 copies, the restriction of molecular chain movement of the filler is intensified, which makes the silicone rubber become brittle, and the tensile strength and elongation rate decrease. In general, when the filling amount of LH-CaCO₃ is 70 copies, the mechanical properties of silicone rubber are better.

2.3. Effect of silica species on insulating coated silicone rubber

Insulation coated silicone rubber not only to consider whether the performance meets the requirements, but also good construction performance. It has been found in previous studies that the rheological properties and reinforcing effects of gas phase silica and precipitation silica on room temperature solidified silicone rubber are quite different, SiO₂ by gas phase method is an open branched chain condensation, and most of the surface of SiO₂ can effectively interact with the matrix polymer, but in the precipitation method, SiO₂ is agglomerated in a grape-like manner, which makes less effective interaction surface area between it and the matrix. Under the condition of the same number of additives and specific surface area, the gas phase method has better rheological properties and reinforcement effect. Therefore, the influence of different kinds of gas phase silica on the density and mechanical properties of insulating coated silicone rubber was investigated.

V-15, A-200, T-30 and A380 were selected in 25 copies each of silica, other conditions being unchanged. Silicone rubber coated with different silica types was prepared. The density, consistency and mechanical properties of the test results are shown in the table below.

Tab. 3 The properties of silicone rubber prepared with different kinds of fumed silica

| No. | Specific Surface Area(m²/g) | Density (g/cm³) | Consistence | Tensile Strength (MPa) | Elongation at Break (%) |
|-----|----------------------------|----------------|-------------|------------------------|------------------------|
| V-15 | 150                        | 1.07           | 9.3         | 2.49                   | 327                    |
| A200 | 200                        | 1.09           | 8.5         | 2.67                   | 301                    |
| T-30 | 300                        | 1.08           | 8.0         | 2.91                   | 373                    |
| A380 | 380                        | 1.08           | 6.7         | 3.12                   | 384                    |

All of the above silica are silica prepared by gas phase method. It can be seen from the table that the density difference of insulating coated silicone rubber is not significant under the condition of the same amount of silica, and the breaking elongation strength and breaking elongation increase with the increase of specific surface area. The main reason is that the greater the specific surface area of silica, the greater the area of interaction between silica and silicone rubber, the more binding points formed, the stronger the interaction between silica and silica, and the better the reinforcing effect. In addition, the larger the specific surface area of silica is, the smaller its particle size will be, and its dispersion in silicone rubber will be more uniform, the better the reinforcing effect will be. The insulation coated
silicone rubber made of A380 has the largest specific surface area. The insulation coated silicone rubber made of A380 as the filler has the largest breaking elongation and breaking elongation, and the best mechanical properties. However, the consistency value is small, which is not conducive to automatic coating construction. After comprehensive consideration, T-30 is selected as the best performance for silica.

2.4. Effect of silica content on insulating coating silicone rubber.

In order to investigate the effect of silica content on mechanical properties of insulating coated silicone rubber, the insulated silicone rubber with 15, 20, 25, 30 and 35 copies of T-30 were prepared.

**Table 4** The properties of silicone rubber prepared with different amounts of fumed silica

| No.     | Density (g/cm³) | Consistence | Tensile Strength (MPa) | Elongation at Break (%) |
|---------|----------------|-------------|------------------------|-------------------------|
| T-30-15 | 1.03           | 9.8         | 2.49                   | 294                     |
| T-30-20 | 1.05           | 9.5         | 2.68                   | 335                     |
| T-30-25 | 1.08           | 8.0         | 2.91                   | 373                     |
| T-30-30 | 1.10           | 7.3         | 2.89                   | 371                     |
| T-30-35 | 1.12           | 6.5         | 2.61                   | 339                     |

As can be seen from the above table, with the increase of silica content, the tensile strength and tensile elongation of silicone rubber first increased and then decreased. Because within a certain limit, With the increase of silica content, the larger the area of silica in contact with silicone rubber and the more the point of action between silica and silicone rubber, the greater the cross-linking density of the whole system will be, and the better the silica's reinforcing effect on silicone rubber will be, the greater the tensile strength and elongation at break will be [18]. However, as the amount of silica further increases, the dispersion in silicone rubber is limited, and the dispersion effect becomes worse. However, the interaction between silica itself is weak, and cracks are likely to occur under the influence of external forces, and the reinforcement effect declines, so the tensile strength and elongation at break begin to decrease. After comprehensive consideration, the performance of insulating silicone rubber is the best when the additive amount of T-30 is 25 copies.

2.5. Comparison of electrical properties of insulating coated silicone rubber prepared by calcium carbonate and silica

In order to investigate the electrical properties of insulating coated silicone rubber prepared by calcium carbonate and silica in actual use conditions, 70 copies of LH-CaCO₃ and 25 copies of T-30 were used to prepare silicone rubber for naked wire coating respectively. Then the normal state of the two materials coated wires and the breakdown voltage after 7 days of immersion were tested, the results are shown in Table 5.

**Table 5** The comparison of Breakdown voltage

| No.     | Ordinary State Breakdown Voltage (KV) | 7 Days Soaked in Water Breakdown Voltage Retention Rate (%) |
|---------|--------------------------------------|-----------------------------------------------------------|
| LH-CaCO₃-70 | 42.7                                  | 25.8                                                      | 60.4                     |
| T-30-25      | 43.1                                  | 37.3                                                      | 86.5                     |

It can be seen from the data in the table that the normal breakdown voltage of the wire coated with silicone rubber prepared with nano calcium carbonate and silica is basically the same. After 7 days of soaked in water, the breakdown voltage decreases somewhat, among which the breakdown performance of silicone rubber prepared with silica black decreases less and the retention rate is higher.
This is mainly because after silica reacts with silane coupling agent, its water absorption rate is lower than that of calcium carbonate, so it absorbs less water after soaking and maintains better electrical properties. So, the electrical properties of silica coated silicone rubber are better.

3. Conclusion
In this paper, the influences of the types and amounts of nano calcium carbonate and silica on the density, consistency and mechanical properties of insulating coated silicone rubber were investigated, and the optimal types and amounts of nano calcium carbonate and silica were selected. Among them, the insulating coated silicone rubber prepared by silica had lower density and better mechanical properties. By comparing the breakdown performance of insulating coated silicone rubber coated wires prepared by calcium carbonate and silica, it is further shown that the comprehensive performance of insulating coated silicone rubber prepared by silica is better. The density of 1.08 g/cm³ and the tensile strength of 2.91MPa can be prepared by using Wacker T-30 silica with an additive amount of 25 copies. After the coated wire is immersed in water for 7 days, the breakdown voltage retention rate can reach 86.5%.

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