Study on aging index of mechanical and electrical properties of high temperature vulcanized silicone rubber

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Abstract. Composite insulators are affected by various factors in operation. With the increase of operation time, the shed of silicone rubber composite insulators will become hard and brittle. In this paper, it is found that the hardness of long-term silicone rubber shed meets the standard requirements. The tear strength, tensile strength, elongation at break, resistance to electric tracking and corrosion loss decrease significantly after 5-10 years of operation. The decline of silicone content on the micro surface and the escape of inorganic fillers are the reasons for the deterioration of macro performance. Finally, the evaluation system for aging performance of insulators is preliminarily established, according to the aging degree of insulator, operation and maintenance suggestions are proposed.

1. Introduction
Composite insulator has been widely used at home and abroad for its advantages of light weight, high mechanical strength, strong hydrophobicity and hydrophobicity transfer, high pollution flashover voltage and convenient installation and maintenance. At present, there are more than 10 million composite insulators in China, which is one of the countries with the largest use of composite insulators in the world. Composite insulators are affected by a variety of factors in operation, including electrical, mechanical and environmental factors. With the increase of operation time, silicone rubber composite insulators will appear hydrophobicity decline, shed discoloration, hardening, embrittlement, chalking, cracking, leakage traces or electrical erosion, end seal failure, unexplained flashover and other phenomena. The aging problem of composite insulator under the action of long-term electrification and operating environmental factors has attracted great attention of insulator production, operation and scientific research departments [1-5].

The external insulation material of composite insulator is mainly high temperature vulcanized silicone rubber. It is a kind of three-dimensional network structure elastomer, which is made of polysiloxane with linear chain number of 5 000 ~ 10 000 siloxanes as raw rubber, adding various coordination agents such as reinforcing filler, structure control agent, flame retardant, colorant, etc., and then cross-linking reaction by sulfurizing agent. The bond energy of Si-O bond in the main chain of silicone rubber is 444 kJ / mol, which is much higher than 356 kJ / mol of C-C bond and 339 kJ / mol of C-O bond in common organic polymers, so it has good stability; The shielding effect of side chain non-polar methyl group makes silicone rubber have low surface energy and excellent hydrophobicity. At the same time, the migration of incomplete crosslinked small molecular siloxane to the surface and pollution layer makes silicone rubber have good hydrophobicity recovery. However, in the process of operation, under the action of external environmental factors such as pollution, corona or arc discharge, ultraviolet, moisture, high temperature and chemical substances, the molecular chain...
on the surface of silicone rubber breaks, and methyl is oxidized to form hydroxyl, carbonyl and other strong polar groups, resulting in the destruction of the surface structure and hydrophobicity of silicone rubber. The performance of insulator is gradually deteriorated and even failed.

At present, China is making great efforts to build the backbone grid of UHV and UHV AC / DC transmission. It is an urgent problem to determine the service life and aging evaluation index of composite insulator external insulation.

This paper analyzes the electrical and mechanical performance indexes of insulators commonly used by power departments, and summarizes the relationship between these indexes and service life of insulators, hoping to be beneficial to the operation, maintenance and technical management of composite insulators.

2. Aging test item

2.1. Test sample

This test sample is 21 batches of composite insulators produced by Zibo Taiguang in China. The longest service life is 23 years. The test items involved are contamination measurement, hardness test, tear strength test, tensile strength, elongation test, resistance to electrical corrosion, Fourier infrared spectrum, etc.

2.2. Test method

2.2.1. Hardness test. Two samples were taken from the umbrella sleeves of the two insulators. The surface of the samples was smooth, and the thickness was 4 mm. The size of the samples was large enough. Measure the hardness of the sample, and boil it in boiling water for 42 hours, then cool it and measure the hardness again. The hardness of the two samples was measured and recorded with shore A hardness tester, and the ambient temperature was recorded. The hardness measuring instrument is shown in Figure 1.

![Figure 1. Hardness measuring instrument](image)

Tear strength test. Tear strength test is one of the mechanical properties tests of shed. The method is to cut the sample from the test piece with uniform thickness. As shown in Figure 2, the thickness of the test piece is (2.0 ± 2) mm, the force error of the tensile testing machine is controlled within 2%, and the moving speed of the gripper is kept constant during the test.
2.2.2. **Tensile strength test and elongation at break.** Similar to tear strength, tensile strength is also one of the indexes to measure the mechanical properties of silicone rubber. The tensile strength sample is shown in Figure 3.

![Figure 2. Tear strength test sample.](image2)

![Figure 3. Tensile strength test sample.](image3)

2.2.3. **Testing equipment for resistance to electric tracking and erosion.** The resistance to electric tracking and erosion test is one of the main tests to test the electrical properties of silicone rubber. The number of samples is 5, and the length is not less than 60mm. The width is 40mm ~ 50mm, and the thickness is 3mm ~ 6mm. The constant electric tracking voltage method is adopted, the voltage is 4.5kv, and the time is 6h. The test equipment and samples for resistance to electric tracking and erosion are shown in Figure 4.

![Figure 4. Testing equipment for resistance to electric tracking and erosion.](image4)
3. Test results

3.1. Hardness
There is a positive correlation between the insulator hardness and the service life. With the increase of service life, the insulator shed is becoming hard. However, there is no obvious linear relationship between the hardness of silicone rubber and its service life due to the influence of filler ratio, production process and operating environment. The insulator hardness distribution by sampling inspection is shown in Figure 5.

![Insulator hardness distribution by sampling inspection/Shore A.](image)

3.2. Tear strength
On the contrary, the tear strength of insulator has a negative correlation with the service life. With the increase of service life, the tear strength of insulator shows a downward trend. However, as shown in Figure 6, there is no obvious linear relationship between tear strength and service life of silicone rubber due to the influence of filler ratio, production process and operation environment.

![Distribution of tear strength of insulators/kN/m.](image)
3.3. Tensile strength
Similar to tear strength, tensile strength is also one of the indicators to measure the mechanical properties of silicone rubber. As shown in Figure 7, the tensile strength of insulator has a negative correlation with service life. With the increase of service life, the tensile strength of insulator shows a downward trend. However, there is no obvious linear relationship between tear strength and service life of silicone rubber due to the influence of filler ratio, production process and operation environment.

![Figure 7. Distribution of tensile strength of sampled insulators/MPa.](image)

3.4. Elongation at break
The standard value of elongation at break of new silicone rubber is 150%. As shown in Figure 8, the elongation at break of silicone rubber basically maintains at the level of new silicone rubber within 5 years of operation, and decreases significantly after 5 years. The elongation at break of silicone rubber more than 15 years is less than 100%. There is a strong negative linear correlation between elongation at break and operation time.

![Figure 8. Relation between elongation at break and operation life of insulator/%.](image)

3.5. Distribution of erosion depth
The standard value of corrosion depth of new silicone rubber is no more than 2.5mm. As shown in Figure 9, the electrical corrosion resistance of silicone rubber after 10 years of operation is basically...
maintained at the level of new silicone rubber, and the electrical corrosion resistance of silicone rubber after 15 years of operation is significantly decreased.

![Figure 9. Distribution of the depth of composite insulator erosion/ mm.](image)

4. Summary of test
The hardness of the long-term silicone rubber shed meets the standard requirements. The tear strength, tensile strength, elongation at break, electrical corrosion loss obviously decreased after 5-10 years of operation. The reasons for the degradation of macro properties are the decrease of organosilicon content on the micro surface, the escape of inorganic filler, the main chain fracture, the decrease of crosslinking degree and the crack in the micro morphology; The decrease of hydrophobic group is lower than that of the main chain, which indicates that the diffusion of siloxane molecules to the surface makes the silicone rubber retain hydrophobic mobility.

The absorption peaks of Si-O-Si and Si-O in the cross-linking group are obviously weakened, which indicates that the organic components, whether in the long chain content or the degree of crosslinking, have no significant difference, the intensity of these two methods has decreased. In addition, the intensity of the C-H absorption peak in the side chain methyl Si-CH3, which is closely related to the hydrophobicity, is similar to that of the internal material, indicating that the number of methyl groups on the surface side chain is reduced. The organic components and hydrophobic groups in the surface materials of umbrella group are lost in long-term operation.

5. Conclusions
The evaluation system of insulator aging performance is preliminarily established, and corresponding operation and maintenance measures are taken according to the aging degree of insulator. The comprehensive aging state of composite insulator is divided into four grades: no obvious aging (grade I), slight aging (grade II), obvious aging (grade III), and complete aging (grade IV). The single index is divided into three levels: A, B and C. There are two or more indexes of macro performance of aging assessment test as grade C, which means that it is judged as grade III aging; One of the macro performance indexes of aging assessment test is grade C or more is grade B, which means grade II aging is determined; The rest of the cases can be judged as grade I aging.

Level I can continue to operate, while level II continues to operate, and monitoring shall be strengthened. Repeat sampling test is required for level III. If the result of repeated sampling test is level II, operation and maintenance measures such as strengthening monitoring or partial exit operation shall be taken according to the actual situation on site; If the repeated sampling test results are still grade III, it is determined as class IV. The batch of composite insulator judged as grade IV aging must be out of operation.
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