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Research on the Ageing Detection and Assessment Method of Silicone Rubber Materials Based on the Multi-Technology Fusion

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***Abstract*—The ageing properties, detection technology and assessment method were researched in the paper. First, the influence on the silicone rubber materials of transmission and distribution equipment was analyzed. Second, based on the muti-technology fusion of macroscopic and microscopic detection method, the mechanical performance, electrical performance, hydrophobicity and microscopic structure of 110kV and above silicone rubber materials was tested. Then, the strong characteristics reflecting the ageing properties were extracted and graded. Finally, the linear weighting method was used for the assessment of ageing state, and the maintenance strategy was mapped out. The assessment results can well reflect the ageing state of the silicone rubber materials, and also are available and helpful for the equipment management departments.**

Keywords-silicone rubber materials; ageing; muti-technology fusion; weighting; assessment

I. INTRODUCTION

The silicone rubber materials are usually used in composite insulators and bushings of power transformers, arresters, voltage or current transformers, and so on. The composite insulators, which are mainly made of the fiber reinforced plastic rods and silicone rubber materials, have the performance of light, high strength and strong pollution resistance. They overcome the problems of easy ageing of conventional polymer materials such as epoxy resin, and are widely used in the power system. However, due to the reasons of material, formulation, process, manufacturing level, and adverse environmental impact of perennial running outdoors, high temperature, high humidity, acid rain, dust, and so on, silicone rubber insulation appears hard, brittle, surface cracking, hydrophobic, local heating, mechanical strength decreasing and other phenomena[1]. The silicone rubber with the decreasing insulation performance causes multiple flashover and damage accidents, which affect the safe and stable operation of the power grid[2-3]. At present, there is no uniform standard for evaluating the ageing status of silicone rubber materials at home and abroad. Many ways have been presented to evaluate ageing condition, however, it is still difficult to effectively judge the ageing status of materials and to formulate operational maintenance strategies.

In the paper, based on the analysis of the influence factors on the performance and the muti-technology fusion of macroscopic and microscopic detection method, the strong characteristics of the ageing characteristics of the silicone rubber insulation materials were extracted and classified, and the linear weighting method was used to evaluate the ageing status.

II. INFLUENCE FACTORS ANALYSIS

A. Characteristics of the Silicone Rubber Materials

The silicone rubber is an elastomer made by ring-opening polymerization of cyclic polysiloxanes, of which molecular backbone consists of a silicon-oxygen bond (Si-O) with higher bond energy (459.8 kJ/mol). The commonly used silicone rubber is room temperature vulcanized (RTV) silicone rubber, liquid vulcanized silicone rubber (LSR) and high temperature vulcanized silicone rubber (HTV). Considering the influence of material, formulation, process, manufacturing level, the performance between RTV, LSR and HTV is shown in Table I. It is shown that HTV has the highest molecular weight, the most stable bond energy, and the best curing conditions of high temperature glue[4]. That means the heat resistance, oxygen ageing, weather resistance, UV resistance, electrical leakage resistance and corrosion resistance are the most excellent in silicone rubber insulation.

TABLE I. THE PERFORMANCE BETWEEN RTV, LSR AND HTV

Parameter		The Silicone Rubber Type		
		RTV	***LSR***	***HTV***
Raw rubber state		liquid	liquid	semisolid
Viscosity(mPa.s)		5×10^3~ 1×10^5	2×10^2~ 1×10^4	2×10^7
Curing condition	Temperature(ºC)	80~100	25	150~170
	Pressure(MPa)	5~10	0.1	10~15
	Time(min)	30~60	1440~2160	30~60
Molar mass($\times10^5$g/mol)		1~10	1~10	30~80
Polymerization degree($\times10^3$)		0.1~1	0.1~1	5.0~10
Volume resistivity (Ω•cm)		10^{13}~10^{15}	10^{13}~10^{15}	10^{13}~10^{15}
Dielectric strength (kV/mm)		20.0~26.0	20.0~22.0	20.0~24.0
Dielectric constant		2.0~5.0	2.0~5.0	2.0~5.0

B. Influence Factors

The factors that affect the performance of the silicone rubber materials are not only related to the quality problems of material structure, formulation, process and manufacturing level, but also are related to the harsh environment outdoors, such as compounding agent, high temperature, high humidity, acid rain, dust, ozone, UV and so on. The ageing phenomenon of the silicon rubber insulation materials such as Hard brittle powder, cracking, loss of hydrophobicity, local heating and mechanical strength decreased will appear under the factors mentioned before.

The silicone rubber ageing is mainly manifested in the following aspects: 1) the surface hydrophobicity decreases, hydrophobicity migration time gets longer, and recovery ability weakens; 2) powder phenomenon appears on the surface; 3) tracking and erosion or other serious phenomenon appears in the heavy pollution area; 4) hardness and tear resistance weakens; 5) the surface of the umbrella skirt and other impurities of chemical elements increases, and the chemical structure of silicone rubber has been severely destructed; 6) surface roughness appears, or number of pores increases, and the material loses.

III. THE MULTI-TECHNOLOGY FUSION DETECTION METHOD

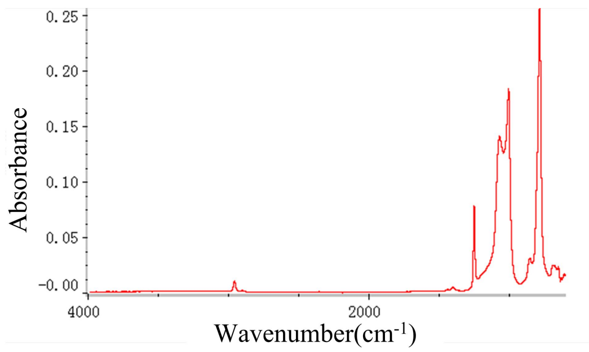
A. *The Detection Method and the Strong Characteristics*

At present, the macroscopic detection method such as the hydrophobicity class (HC) detection[5], leakage current detection, hardness detection, tensile strength detection are used to research the characteristics of the silicon rubber materials. For example, the higher the grade of hydrophobicity measurement, the worse the ageing degree of insulators. The macroscopic detection method focus on the mechanical, electrical and hydrophobic properties. Besides, the microscopic detection method is also used such as the scanning electron microscope (SEM) detection, the fourier transform infrared spectroscopy (FTIR) detection[6], thermally stimulated current (TSC) detection, and so on.

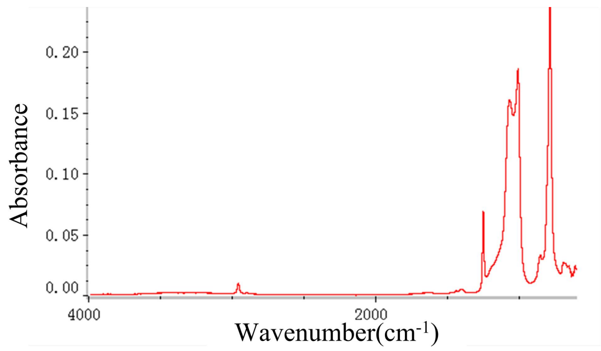
Compared with the advantages and disadvantages between the macroscopic and microscopic detection method, detection was performed on the samples related to the arresters, voltage or current transformers and composite insulators. The detection consists of the visual inspection, tracking and erosion detection, hydrophobicity detection, tearing strength detection, tensile strength detection, tensile elongation detection, hardness detection, Flame retardancy detection, fourier transform infrared spectroscopy detection, X-ray diffraction, X-ray photoelectron spectroscopy and scanning electron microscopy. The detection results of seven samples are shown in Table II. As is shown, the samples, of which appearance is normal, have the lower hardness, higher tensile strength, tensile elongation and hydrophobicity, and less variation than the other same type ones. The appearance of obvious cracks and powder, high hardness and low mechanical properties, is indicating that the brittleness of materials increases. The results of fourier transform infrared spectroscopy of #5 sample are shown in the figure. The content of Si-O bond increases, while the content of Si-C bond decreases. It shows that the Si-O bond is bonded by the free silicon and oxygen when the Si-C bond breaks. Comparing the absorbance between the surface and the inside of the sample, the ageing state can be derived. Synthesized the detection results, #2,#4 and #6 sample has the severe ageing status.

TABLE II. THE DETECTION RESULTS

Detection Items	**Number of the Samples**					
	#1	**#2**	**#3**	**#4**	**#5**	**#6**
Visual inspection	normal	crazing, powdering	normal	crazing, powdering	normal	crazing, powdering
Hardness	70.5	39.5	34.5	76.0	65.0	83.0
Flame retardancy	Failed	FV-0	FV-0	FV-0	FV-0	FV-0
Tensile strength	5.17	2.33	3.85	1.99	3.57	1.78
Tensile elongation	186.50	244.65	285.75	72.2	227.6	43.1
Tearing strength	9.71	15.08	/	10.63	14.07	13.75
Tracking and erosion	burn through(17min)	pass	burn through(12min)	burn through(75min)	burn through(3h)	pass
Hydrophobicity	HC2	HC7	HC1	HC3	HC5	HC2
Fourier transform infrared spectroscopy	normal	More Si-O,less Si-C	normal	More Si-O,less Si-C	More Si-O	More Si-O,less Si-C
Scanning electron microscopy	Little Rough surface	Big pit,Rough surfaces,grain	Little Rough surface	Big pit,Rough surfaces,grain	Big pit	Big pit,Rough surfaces,crackle



(a)



(b)

FIGURE I. FOURIER TRANSFORM INFRARED SPECTROSCOPY OF #5 SAMPLE:(A) THE SURFACE (B)THE INSIDE

From the results shown above, the appearance, hardness, hydrophobicity, tensile strength and fourier transform infrared spectroscopy detection method extracted can be effectively reflecting the ageing properties. They are the strong characteristics for the ageing state measurement and assessment.

B. The ageing Assessment Method

The ageing assessment method based on the linear weighting method is presented. First, based on the classification of the strong characteristics detection results, the assessment level of the classification detection result is divided into four levels: I, II, III and IV. The weights are assigned against each assessment level. The detection result classification methods are shown in Table III. The ageing result assessment level, which synthesize the detection result, is also divided into four levels: I, II, III and IV, of which Level I is no obvious ageing that means the equipment can continue to run; Level II is the minor ageing that means the equipment can continue to run, but need tracking detection; Level III is the obvious ageing that means the equipment requires maintenance which is taken the spray paint or outsourcing new insulation coat; Level IV is the severe ageing that means the equipment need to withdraw from the operation, in addition, the source and the same batch equipment need to be integrally detected. The result assessment method is shown in Table IV.

TABLE III. THE DETECTION RESULT CLASSIFICATION METHODS

Characteristics		The Detection Result Classification Level				Weight (%)
		Level I	Level II	Level III	Level IV	
1	appearance	No cracks and powers	several cracks and powers	A few cracks, but no powers	Many cracks and powers	20
2	Hardness	HC1-HC2	HC3-HC4	HC5	HC6-HC7	20
3	Hydrophobicity	＞4.5	4.0～4.5	2.5～4.0	＜2.5	20
4	Tensile strength	50～65	65～70	70～80	＞80	10
5	Fourier transform infrared spectroscopy	normal	Small changes	Medium changes	Big changes	30
Scores		300	200	100	0	--

TABLE IV. THE RESULT ASSESSMENT METHODS

Ageing assessment level		Meaning	Scores	Operation and maintenance strategy (for the same batch)
1	**Level I**	no obvious ageing	200-300	continue to run
2	**Level II**	the minor ageing	140-199	continue to run, but need tracking detection
3	**Level III**	the obvious ageing	91-139	requires maintenance
4	**Level IV**	the severe ageing	0-90	need to withdraw

While using the ageing assessment method, it can be seen that the ageing assessment level of the sample #2, #4 and #6 are Level IV. And the ageing assessment result is consistent with the detection result shown in Part A, Section III. So the equipment need to withdraw from the operation, in addition, the source and the same batch equipment need to be integrally detected. Again, the ageing assessment level of the sample #1 and #3 are Level I, and the ageing assessment level of the sample #2 is Level II. The operation and maintenance strategy is shown in TABLE IV.

IV. CONCLUSION

Through the research on the ageing characteristics and factors, detection technology and ageing evaluation methods of silicone rubber materials, the following conclusions are obtained:

1) The insulation performance of silicone rubber materials has inevitably declined in different degrees after a period of operation;

2) By using the multi-technology fusion methods for detection, five strong characteristics such as appearance, hardness, hydrophobicity, tensile strength, and Fourier transform infrared spectroscopy are extracted and can better reflect the performance of materials;

3) The ageing assessment method based on the linear weighting method is established, which help the operators take corresponding maintenance strategy.

4) The ageing assessment result (severe ageing) is consistent with the detection result.

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