Research on the Multi-factor Aging Resistance for the materials of Composite Poles

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Abstract. A multi-factor faster aging test with 5000h was carried to evaluate the aging resistance of running composite tower materials outdoor, which accelerates aging test includes different factors such as solar aging, mechanical aging, electrical aging, heat aging and environmental aging of materials. The flexural modulus retention rates of resin-based and resin-system composite samples decrease with aging time, except for the sample made of isophthalic unsaturated polyester, the flexural modulus retention rates of other composite samples are above 90%. Meanwhile, the modulus of the unsaturated polyester resin and E44 epoxy resin decreased significantly, the modulus retention of unsaturated polyester rate was 88% after aging test, and the damage flextural strength for E44 epoxy based glass fiber composite sample was 92%, while the bending strenght retention ratioes of other composite materials were higher than 96%. The multi-factor accelerated aging test results show that the modified polyurethane resin and vinyl resin have good aging resistance, and meet the application for composite materials’ poles and crossarms outdoor.

1. Introduction
The use of outdoor composite power equipment must be thoroughly evaluated for the aging resistance and service life to ensure the safety of operation. Composite Poles and crossarms are exposed to the erosion and destruction due to various factors in the natural environment, especially the erosion and aging due to high humidity, high and low temperature alternating, ultraviolet radiation, rain and acid rain under atmospheric environment, with the aging degree increasing over time. Wind deviation and conductor galloping will also keep the pole body and crossarm in irregular stress vibration and swing for a long time, causing stress fatigue and aging. Meanwhile, the loaded high-voltage electromagnetic field will cause polarization trend of material polar groups and affect material properties, thus resulting in aging of composites under strong electromagnetic field.

Current research on the aging property of power composite pole materials at home and abroad mainly focuses on the aging behavior under a single external condition [1-4], while the actual pole operation is faced with faster aging under the combined effects of various conditions. The composite pole ‘materials’ life is affected by various aging factors with different importance. The aging factors and characteristics of composites are complicated, such as shrinkage, bed separation, crack and deformation at thermal aging [5-7], tree discharge, partial discharge corrosion and surface leakage scar at electrical aging [8-9], abrasion, bed separation and crack at mechanical aging [4], and leakage current increases, erosion and chemometamorphism at environmental aging [10].
Therefore, we carried on a comprehensive aging test with 5000h faster aging. This research mainly uses the multi-factor aging test method of composite insulators for reference, improves the 5000h multi-factor test method recommended in IEC 62217: 2005/FDIS, and performs 5000h multi-factor aging test on the power composites. The research on aging behavior of power composite materials under various external conditions will make it get closer to the actual operating environment of composite Poles, and the evaluation results will be of great significance to the selection of composite pole and crossarm materials, operation safety and service life prediction.

2. Experimental Part

2.1 Design and Procedures of Aging Test Cycle Process

The artificial accelerated aging simulates the real operating environment of the transmission pole. The crank-connecting rod pulled by the motor is made to swing at a low frequency of 0.6 Hz to simulate the vibration of the pole body and crossarm under the stringing. In the meantime, the accelerated aging test of the pole and the crossarm is carried out with a vibration force of 1200N and a frequency of 0.6Hz under the combined factors of rain (about 1.2 L/h), acid-base salt fog (7kg/m³), high temperature (50°C), high humidity (95%), low temperature (-30°C), ultraviolet irradiation (ultraviolet light of 310nm wavelength and light energy of 0.26w/m²) and rated high voltage (10kV). The basic composition of the whole multi-factor aging system is shown in Table 1.

| Humidification RH = 95% | Heating 50°C | Low temperature -30°C | Rain | Salt fog 7kg/m³ | Ultraviolet irradiation | 0.6 Hz vibration | 10 kV voltage |
|-------------------------|--------------|------------------------|------|----------------|------------------------|------------------|--------------|
| 80                      | 80           | 80                     | 80   | 80             | 80                     | 80               | 80           |

Note: The black parts represent operating, and the white parts represent no operating.

Different system resin, different resin-based/glass fiber composites, composite samples with different processing technology and composite Poles are placed in the accelerated multi-factor aging chamber, which is operated according to the parameters in Table 1. The retention rate of the bending modulus R after different time is calculated in accordance with the provisions in GB/T3857-2005 for each group of samples under test conditions. Assuming that the elapsed time is t, the average modulus for each group of samples is \( \overline{X}_t \), and the initial modulus for each group of samples is \( \overline{X}_0 \), the sample modulus retention rate after that elapsed time should be calculated as follows:

\[
R = \frac{\overline{X}_t}{\overline{X}_0}
\]

The sample inspection time t is scheduled according to the time in Table 2, the bending modulus of the corresponding sample is tested under the internal load of elastic deformation respectively, and then the modulus retention value will be calculated according to the formula. Prior to the test, the sample temperature should be restored to room temperature.

| Table 2. Sampling test time |
|-----------------------------|
| Sampling sequence | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Aging time (h)       | 0 | 500 | 1000 | 1500 | 2000 | 2500 | 3000 | 4000 | 5000 |
2.2 Test Materials and Associated Equipment
The multi-factor aging behavior of the resin-based system, resin-based/glass fiber composite system and composites with different processing technology for modified polyurethane composite is studied, the aging characteristics of different system resin, resin-based/glass fiber composites are analyzed, and the effects of various factors on the aging resistance of composites are discussed.

3. Results and Discussions

3.1 Bending Modulus and Strength Changes of Power Composites
Fig. 1 is adopted for each composite sample so that the position of each material can be moved regularly and the same aging conditions can be ensured. Different numbers made of iron wire were hung at the lower end of each sample to prevent confusion after prolonged aging. It’s found that surfaces of the resin and composite band samples are intact, without embrittlement, cracking or deformation, while the metal clips are significantly rusted. During the test, it’s found that the fittings that hang the samples had to be replaced every 500 hours as they were nearly damaged due to corrosion. It’s also reflected by comparison that resin and composite materials have better corrosion resistance than unprotected iron and steel.

3.2 Analysis of Multi-factor Aging of Different resin-based Samples
Figure 2 Curves of Flexural Modulus Retention Rates of Different Resin-Based Samples. After the 5,000-hour multi-factor aging test, flexural modulus of the resin-based samples is stable at 2.60-2.99 GPa. Flexural modulus retention rates of resin samples with 5,000-hour multi-factor aging are still above 90%, except for isophthalic unsaturated polyester UP. Flexural modulus retention rates of the modified polyurethane PU, vinyl resin VE and self-made modified polyurethane PUR samples are all close to 100% and have a trend of increasing first and then decreasing. The reason for the increase in flexural modulus is that the test was started when the samples were cured incompletely after being prepared in the laboratory. Gaps in the cross-linking networks of these samples were “repaired” under the multi-factor environment. The reason for the decrease in flexural modulus is quite complicated, as the environment conditions such as humidity, temperature, rain, salt spray and light during the test process may cause modulus deterioration of resin materials.

3.3 Analysis of Multi-factor Aging of Different resin-system/1:1 Woven Roving Sample
It can be seen from Fig. 3 that, after the 5,000-hour multi-factor aging test, all the flexural modulus retention rates of different resin-system/1:1 woven roving composite samples decrease with aging time. Except for the isophthalic unsaturated polyester UP/1:1 woven roving, the flexural modulus retention rates of the other four materials are above 90%. Compared with different resin-based samples, different resin-system/1:1 woven roving may age under the impact of multi-factor aging environment.
on the fiber/matrix interface. The fiber/matrix interface is a “bond” connecting reinforced fibers and the matrix. Multi-factor aging environment has a destructive effect on the fiber/matrix interface. Interface of fiber/resin composite material may be seriously damaged due to water and chemical medium entering in through cracks and holes on the matrix and attacking hydroxyl groups on the fiber surface, which could decrease the flexural modulus.

![Figure 3. Curves of flexural modulus retention rates of different resin-system/1:1 woven roving samples](image)

3.4 Flexural Strength of Different Composite Samples before and after the Aging Test

After the 5,000-hour multi-factor aging test is completed, a flexural strength test is carried out on different resin-system/1:1 woven roving. From the flexural strength values of the composite samples before and after the test in Table 3, it can be seen that the flexural strength of the other four samples, except for the vinyl resin VE/1:1 woven roving sample, reach 400 MPa or more, comparable to high-grade alloy steel. In addition, the composite material itself is light, high-strength, good electrical performance, high insulation, density less than a quarter of that of carbon steel, which is more suitable for transmission pole.

| Table 3. Flexural strength of COMPOSITE SAMPLES before and after AGING TEST |
|--------------------------------------------------|
| Composite material                           | Flexural Strength before Test | Flexural Strength after Test | Retention Rate |
| Modified polyurethane PU/1:1 woven roving   | 428.4 MPa                     | 419.5 MPa                     | 97.9%          |
| Epoxy E44/1:1 woven roving                  | 437.0 MPa                     | 405.5 MPa                     | 92.8%          |
| Vinyl resin VE/1:1 woven roving             | 361.5 MPa                     | 348.0 MPa                     | 96.2%          |
| Isophthalic unsaturated polyester UP/1:1 woven roving | 441.4 MPa                    | 437.1 MPa                     | 99.0%          |
| Self-made modified polyurethane PUR/1:1 woven roving | 415.0 MPa                    | 401.5 MPa                     | 96.7%          |

4. Conclusion

The composite poles’ materials were designed for a 5,000-hour multi-factor aging test, the flexural modulus retention rates of resin-based and resin-system composite samples decrease with aging time. Except for the sample made of isophthalic unsaturated polyester, the flexural modulus retention rates of other composite samples are above 90%, and the aging resistance is good and meets the application for composite materials’ poles and crossarms.
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