Research on the aging characteristics for different FRP composite material before and after 5000h multi-factor aging

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Abstract. In order to reveal the the aging characteristics for different FRP composite material before and after 5000h multi-factor aging, different resin-based/glass fiber composites are prepared, and the effects of various factors such as mechanical strength, microscopic interface and thermal stability on the aging resistance of composites are discussed. The results shows that the flexural strength retention rates of the composite samples are above 90% after 5000h multi-factor aging, and the aging resistance is good and meets the project requirements, SEM scanning displays that there is no obvious cracks on the interface between the glass fibers and the resin matrix after multi-factor aging test, and the interface is not affected obviously by various aging factors, the modified polyurethane PU and modified polyurethane PUR composite materials also show good aging resistance.

1. Introduction
The use of outdoor composite electric power equipment must be thoroughly evaluated for the aging resistance and service life to ensure the safety of operation [1, 2]. 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 [3-5]. 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 [6-8]. Herin, different resin-based/1:1 woven roving composite material system were studied to reveal the material characteristics changes, and master the aging laws of materials in order to guide outdoor applications.

2. Test Materials and Associated Equipment preparation
The multi-factor aging behavior of resin-based/1:1 woven roving composite material system is studied, the aging characteristics of different resin-based/glass fiber composites and composites under the same
processing technology are analyzed, and the effects of various factors such as mechanical strength, microscopic interface and thermal stability on the aging resistance of composites are discussed. The hanging methods as shown in Fig. 1 are 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 wires are hung at the bottom of different samples and different clips are used to prevent confusion of composite samples after aging for a long time.

3. Results and discussion

3.1. Flexural strength of different composite samples before and after the aging test

Flexural strength refers to the maximum stress that a material can withstand till it ruptures under a flexural load or reaches a specified flexural moment. It is the maximum normal stress in bending, which reflects and measures the flexural properties of the material. 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 1, 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 1. Flexural Strength of Composite Samples Before and After 5000h Aging Test

| Composite Material                        | before Test | 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%          |

3.2. Microanalysis of Composite Materials

In addition to some macroscopic performance characterization, SEM scan is an effective method to analyze the micro-morphology of composite materials. It is also an important method to measure interface variation before and after salt-spray corrosion occurs. SEM imaging is generated through secondary electrons, backscattered electrons and absorption electron. Since it provides a clearer focus on the uneven surface of the sample, we can observe the flatness of sample surface based on SEM imaging. In the aging test, surface of a sample can be analyzed with a SEM to clearly understand the
morphology of the sample before and after corrosion aging occurs, which is very important to study aging damage of composite materials.

Because of the hygroscopic diffusion of water onto the resin matrix, some tiny cracks and lines would occur inside the material, along with some other morphological changes; water would not only lead to crack propagation, but also make the matrix to rupture. Moreover, water penetration would result in changes in the interface morphology and enlarge the cracks on the interface. The interface is where the fibers and the matrix combine to react, so when the composite material is subjected to external action, it would be reflected on the interface for the first time. For example, when a force acts on a composite material, the external force would be transmitted through the resin and re-distribute it to the fibers. Therefore, interface quality is very important for the performance of an entire composite material. Interface change of composite samples is mainly analyzed here. A small piece is cut from the end of the epoxy E44/1:1, self-made modified polyurethane PUR/1:1 and modified polyurethane PU/1:1 woven roving respectively, cleaned with an ultrasonic cleaner and the moisture is absorbed from the surface with filter paper. All samples are then wrapped in plastic wrap and scanned with a SEM after metal spraying.

![Fig. 2 SEM Imaging of Modified Polyurethane PU/1:1 Woven Roving](image1)

![Fig. 3 SEM Imaging of Modified Polyurethane E44/1:1 Woven Roving](image2)

The above photos of the interface between reinforced fibers and resin taken with a SEM magnified 2500 times show the morphology change of composite interface caused by 5,000-hour multi-factor aging. Before the artificial accelerated aging test, fracture of the sample appears relatively flat, without obvious fiber pull-out, indicating that the glass fibers and the resin matrix are bonded well; after 5,000-hour of multi-factor aging, we can see that, except for the epoxy E44/1:1 woven roving, fibers of the other two composite materials are pulled out a little, and there is no obvious interface cracking on the interface between the glass fibers and the resin matrix, which indicates that the interface is not greatly degraded due to aging factors. The reason of performance degradation is the water spray...
during the artificial accelerated aging test, in which part of the water may enter, making the resin matrix swell and reducing its strength. And the swelling could generate a shearing force on the fibers. When the shearing force is greater than the interfacial adhesion between the glass fibers and the resin matrix, debonding would occur on the interface. Thus, the resin matrix could not transmit stress as effectively as before. In addition, the moisture that penetrates into the micro-cracks on the interface would enlarge the cracks on the interface, which further causes the change of the interface morphology. From the above, both the self-made modified polyurethane PUR/1:1 and modified polyurethane PU/1:1 woven roving samples remain good micro-morphology with excellent aging resistance.

3.3. Thermal oxidation analysis

Thermogravimetric Analysis (TG) is a thermal analysis technique that measures the relationship between weight and temperature of a sample to be tested at a programmed temperature to study the thermal stability and composition of the material. What affect the thermal stability of composite materials include chemical and physical factors: chemical factors include rigid main-chain structure, main-chain strength, bond cleavage mechanism, degree of cross-linking, degree of branching, Van der Waals force, hydrogen bond, molecular resonance stability and molecular symmetry; physical factors include molecular weight and distribution, crystallinity, molecular dipole moment and purity. After a 5,000-hour comprehensive aging test, the above chemical and physical factors of a composite sample would change under the combined action of high and low temperature, humidity, ultraviolet, rain, pollution and high pressure, which affects the aging resistance of the material. TG is used to test the thermal stability of different resin-system composite samples with different aging periods to indirectly study the influence of the comprehensive aging test on the micro-chemical and physical properties of the samples, estimating the aging resistance performance of composite materials used for power poles and Poles and selecting the best samples. TG is made in N₂ ambient condition, with a flow rate of 20 mL/min, a ramp rate of 10°C/min, and a temperature range of 30-650°C. Each composite sample is cut into pieces, each weighing 5 mg, dried at room temperature for 12 hours first and then dried under reduced pressure in a drying oven for 24 hours. Then TG was started to record data and draw TG curves.
From the above TG curves, it can be seen that the epoxy E44/1:1, self-made modified polyurethane PUR/1:1 and modified polyurethane PU/1:1 woven roving samples without aging test have different initial weight loss temperature. This temperature is the decomposition temperature of a certain component in the samples. The decomposition temperature of the modified polyurethane PU/1:1 woven roving sample is up to 308°C, and the epoxy E44/1:1 woven roving sample, self-made modified polyurethane PUR/1:1 woven roving samples have similar decomposition temperature, basically around 250°C. As time goes on, each composite material has different thermal weight loss. Residual rate of the epoxy E44/1:1 woven roving sample is the lowest, close to 40%, lower than 50% of those of the self-made modified polyurethane PUR/1:1 and modified polyurethane PU/1:1 woven roving samples. Some researches show that adding fibers may improve the heat resistance of epoxy resins, but suffer the impact of factors such as functionalization, amount, etc. With different fiber contents in the samples, more fibers react with the epoxy resin matrix to form more cross-linking points, which further increases the crosslink density of the sample, and the strong chemical bond between the fibers and the matrix hinders diffusion and volatilization of small molecules generated during molecular chain cleavage to some extent. After the 5,000-hour multi-factor aging test, it can be
seen from TG curves that the initial weight loss temperature of self-modified polyurethane PUR/1:1 woven roving sample does not change much, while the other two reduce. The final residual rate of the epoxy E44/1:1 woven roving sample is 46%, still lower than those of the self-made modified polyurethane PUR/1:1 and the modified polyurethane PUR/1:1 woven roving samples, which are 67% and 56%. TG of the composite samples before and after the aging test indicates that the epoxy E44/1:1 woven roving has the worst heat resistance.

4. Conclusion
The flexural strengt retention of the composite samples are above 90%, except for the vinyl resin VE/1:1 woven roving sample, flexural strength of the other samples all 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. It is also found after SEM scanning that there is no obvious cracks on the interface between the glass fibers and the resin matrix after the 5,000-hour multi-factor aging test, and the interface is not affected obviously by various aging factors. It can be seen from TG that modified polyurethane PU and modified polyurethane PUR composite materials show good aging resistance and can be used to make composite poles, Poles and cross-arms for power transmission.

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