Study on the electrical properties of itaconic acid-based epoxy resin

Yuntian Guo¹,a
¹Department of Electrical Engineering of North China Electric Power University, Baoding, Hebei province, China
aemail: 201801000205@ncepu.edu.cn

Abstract: Plastic limit orders have been upgraded successively, and the pressure on environmental protection has continued to increase. In the field of electrical insulation, the use of bio-based epoxy resin as a substitute for petroleum-based resin reduces the consumption of petroleum resources while also reducing environmental pollution, which is an effective way to realize environmental pollution of electrical materials. In this paper, bisphenol A epoxy resin (DGEBA) and an important bio-based epoxy resin-itaconic acid-based epoxy resin (EIA) were cured under the same conditions to obtain their epoxy network. And its electrical performance has been tested in terms of breakdown field strength, leakage current and dielectric loss factor. It is concluded that EIA has the potential to replace DGEBA in a certain field of power system.

1. Introduction
In recent years, China's economy has changed from a stage of rapid development to a stage of high-quality development. This transformation is an opportunity and a challenge, and it has put forward new requirements for the development of all walks of life. The power industry is a pillar industry of the national economy. Under the current situation, the development of the power industry is also facing unprecedented opportunities and urgent problems to be solved. my country's rapid development in the field of AC and DC high-voltage power transmission requires more reliable insulation materials. But on the other hand, a large number of insulating materials from raw material production, product processing, using, and disposal after use have brought tremendous pressure to environmental protection throughout their life cycle0. This is a paradox to the problem. This article attempts to find a solution to achieve a balance at a certain point. The epoxy resin is mixed with the curing agent and then reacted to form a thermosetting plastic with a cross-linked structure. This product is excellent in adhesion, mechanical properties, thermal stability and electrical properties[2].

Bisphenol A glycidyl ether resin is a common and widely used epoxy resin. Because of its wide range of raw materials and low cost, it has been well applied in various fields. This material has low viscosity at low temperatures, is easy to process, and has a short molding time. However, in terms of biological safety, there are many problems [3]. The bisphenol A used to make epoxy resins will have a great impact on health from both short-term and long-term perspectives. Since 2011, the European Union has issued relevant policies to restrict its use.

Itaconic acid, also known as methylene succinic acid, is an unsaturated dibasic organic acid that contains unsaturated double bonds and carboxyl groups in the molecule. The molecule is active in nature and is prone to self-polymerization and various esterification reactions. At the same time, the
double bond in the molecule can also undergo polymerization and addition reactions with other molecules. It is a good comonomer [4]. Some studies have successfully synthesized bio-based epoxy resin using itaconic acid as a raw material. The process is simple, easy to operate, and has good application prospects [5]. At the same time, it also has high biological safety.

2. Experiment

2.1 Experimental materials
This article uses bisphenol A epoxy resin (E51). Use itaconic acid (IA) and epichlorohydrin (ECH) to prepare itaconic acid-based epoxy resin (EIA). Use curing agent MHHPG and DMP-30 epoxy resin curing accelerator and other experimental raw materials. The chemical formula of the raw materials used this time is as follows.

![Figure 1 Bisphenol A epoxy resin](image1)

![Figure 2 Itaconic acid-based epoxy resin](image2)

2.2 Characterization of Itaconic Acid Based Epoxy Resin
After self-preparing itaconic acid-based epoxy resin, the product was analyzed by hydrogen nuclear magnetic resonance spectroscopy to analyze the composition of the product. The result is shown in the figure below.
2.3 Preparation of epoxy network
Measure bisphenol A epoxy resin-E51 (itaconic acid-based epoxy resin-EIA) and curing agent-MHHPA in a mass ratio of 100:80. Place the two in a container and mix them evenly with a stirrer. Add the accelerator (calculated based on the total mass of E51 (EIA) and MHHPA) according to 0.5% of the total mass, and stir again to fully mix. Preheat the drying box, maintain the temperature of the vacuum drying box at 60 degrees Celsius, put it into the mixed system after stirring, and vacuum deaeration for 30 minutes. Preheat the mold of the required size after the release agent treatment at 60°C. Finally, the mixture is injected into the mold, and then placed in a vacuum drying oven for high temperature curing. When curing, the selected temperature is 100°C for two hours, 120°C for two hours, and 150°C for two hours. After completion, wait for the sample to cool and take it out.

2.4 Electrical performance test
In this section, the electrical performance of EIA and E-51 is tested from the breakdown field strength, dielectric loss factor and leakage current.

2.4.1 Breakdown field strength test
The breakdown voltage test is a destructive test. The test product is tested to determine its electrical strength under the conditions of possible overvoltage in a laboratory environment, and it has a high degree of validity and credibility. When a power frequency AC test voltage is applied to the medium, the voltage will be distributed according to the ratio of the dielectric constant and size of the material. In the power frequency breakdown experiment, a constant boost rate of 2kV/s is used, and pressure is applied until the material breakdown occurs. In order to reduce the occurrence of surface discharge flashover during the test and affect the reliability of the test results, the entire electrode system is immersed in transformer oil. According to the current breakdown theory of solid dielectrics, the breakdown voltage of the dielectric has a great relationship with the temperature and frequency of the applied voltage. In this test, the boost speed is faster, and the voltage frequency is maintained at a power frequency of 50 Hz. Therefore, it can be considered that the heat generated by the destructive polarization during this period is not large, so the breakdown voltage reflects the electric breakdown voltage to a greater extent[6]. In this test, a 150mm*150mm*1mm square sheet of the test product was prepared through a mold. Because the breakdown voltage is dispersive, the experimental results are statistically analyzed by using the Weibull distribution by measuring the value of multiple power frequency breakdown field strengths.
2.4.2 Dielectric loss factor test
All dielectrics have polarization and conductance phenomena in electric fields. The dielectric loss angle is the ratio of the active current and the reactive current flowing through the medium(1). It is a characteristic parameter that characterizes the loss of insulation under the action of alternating voltage. It is a property of the insulating material itself, which is only related to the characteristics of the material and has nothing to do with the specific shape or size. This parameter is related to temperature, field strength, and frequency of the electric field, and to a certain extent can reflect the characteristics of the constituent molecules. If the measured value of an insulating material is too high, too much heat will be released under the power frequency, and thermal breakdown may occur[7], which will affect the life of the insulating material. In this paper, the YG9100 automatic anti-interference precision dielectric loss tester is used to measure the dielectric loss angle at room temperature 25°C and power frequency 50Hz.

\[ \tan \delta = \frac{I_R}{I_C} \]  

(1)

2.4.3 Leakage current test
When measuring the leakage current, a certain DC high voltage is applied to the tested product, and the leakage current flowing through the insulation of the tested product is measured. This data is a good response to the insulation resistance of the tested product. In order to better reflect the insulation defects of the test product in the test, before the test, the cured sample is cut into the test product 30±0.1mm in length, and it is boiled in a 0.1% NaCl solution for 100±0.5h. After boiling, use its ionized water to cool the test product and wipe off the surface moisture. Within 1h, use the YD-20 insulator core rod leakage current test device to test it, and record the leakage current results.

3. Analysis of results
This section analyzes the above experimental results.

3.1 Breakdown field strength test
Weibull distribution is widely used in the reliability analysis of engineering problems, and it is especially applicable when there is no large number of samples. It can reflect the reliability and life of the test object very well. In this paper, E(breakdown field strength) is selected as a random variable, and the data is processed through Weibull distribution to obtain the breakdown probability under a certain electric field intensity. Its probability density is (2). According to the breakdown field strength data tested in this article, using this distribution model, the plot can be drawn as follows.

\[ F(E) = \frac{K}{\lambda} \left(\frac{E}{\lambda}\right)^{\alpha-1} e^{-(E/\lambda)^{\alpha}} \]  

(2)

![Figure 4 Weibull distribution of breakdown field strength](image)
The k and λ in the Weibull probability density function F(E) are the scale parameter and shape parameter, respectively. The proportional parameter k is related to the dispersion of the breakdown field strength. The larger the proportional coefficient k, the smaller the dispersion of the breakdown field strength[8]. λ reflects the breakdown field strength when the probability density is 63.2%. The measured data is calculated, at 50Hz frequency, the 63.2% probability breakdown field strength, E-51 and EIA were 37.39kV/mm and 31.90kV/mm.

The shape parameters of E-51 and EIA are 14.78 and 21.54, respectively. According to the above analysis, it is easy to know that compared with the traditional bisphenol A epoxy resin E-51, the breakdown field strength of the bio-based epoxy resin EIA is slightly lower. However, in the dispersion of breakdown voltage, its performance is better than E-51, which is conducive to the design and coordination of insulation to a certain extent.

### Table 1 Weibull distribution parameters

| Epoxy network | scale parameter λ (kV/mm) | shape parameter k |
|---------------|---------------------------|-------------------|
| E-51          | 37.40                     | 14.78             |
| EIA           | 31.90                     | 21.54             |

### 3.2 Dielectric loss factor test

Some of the data obtained in this paper for the dielectric loss factor test are as follows.

### Table 2 Dielectric loss factor

| Epoxy network | Test voltage / (kV) | Dielectric loss factor tanδ(%) |
|---------------|---------------------|-------------------------------|
| E-51          | 2                   | 0.3                           |
|               | 3                   | 0.33                          |
|               | 4                   | 0.32                          |
|               | 5                   | 0.37                          |
| EIA           | 2                   | 0.40                          |
|               | 3                   | 0.42                          |
|               | 4                   | 0.42                          |
|               | 5                   | 0.43                          |

According to the data, under the power frequency, the dielectric loss factor of EIA is slightly higher than that of E-51. In general, the dielectric loss factor increases by less than 20%.

### 3.3 Leakage current test

Under the experimental conditions described above, the leakage current was measured.

### Table 3 Leakage current

| Epoxy network | Test voltage / (kV) | Leakage current/ (mA) |
|---------------|---------------------|-----------------------|
| E-51          | 2                   | 34                    |
| EIA           | 2                   | 39                    |

Therefore, compared with the bisphenol A epoxy resin E-51, the leakage current of EIA is slightly increased, but the difference is not big. It can be considered that EIA also has good insulation resistance parameters.

### 4. Conclusion

This article mainly tests the breakdown field strength, dielectric loss angle and leakage current of the bio-based epoxy resin-itaconate epoxy resin (EIA) from the perspective of electrical properties. From the test results, the itaconic acid epoxy resin The electrical performance is slightly weaker than the widely used bisphenol A epoxy resin E-51, but the insulation performance is not significantly reduced. Moreover, from the data of this small sample, the experimental data is processed through the Weibull distribution, and it can be found that the dispersibility of the breakdown field strength of the EIA epoxy resin is slightly less than that of the bisphenol A epoxy resin E-51. Therefore, it is believed that EIA has important use value in the electrical field.
5. Outlook
Under the current environmental pressure, it is a general trend to replace non-renewable petroleum resources with bio-based renewable resources, which can not only reduce dependence on non-renewable resources, but also reduce environmental pollution during the production process of petrochemicals. Iaconic acid has many preparation methods, is easy to produce, and has low cost. The bio-based epoxy resin (EIA) synthesized with it has many advantages, and has good mechanical and thermal stability. At the same time, it has also been found to have good electrical properties through the experiments in this article. At the same time, due to the introduction of a large number of ester groups during esterification and polycondensation of IA and ECH, under certain conditions, EIA can undergo a hydrolysis reaction[9] to achieve degradation. Today, when the plastic limit order is widely implemented, it further reduces Environmental hazards. There are a large number of double bonds in EIA, which can undergo addition reactions, and there is still room for further improvement. Therefore, it is believed that it should be promoted and used.

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