Effects of Reactive Diluents on the Electrical Insulation Breakdown Strength and Mechanical Properties in an Epoxy System

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In order to study the effect of reactive diluents on the electrical insulation breakdown strength and mechanical properties of, a polyglycol and an aliphatic epoxy were individually introduced to an epoxy system. Reactive diluents were used in order to decrease the viscosity of the epoxy system; polyglycol acted as a flexibilizer and 1,4-butanediol diglycidyl ether (BDGE) acted as an aliphatic epoxy, which then acted as a chain extender after curing reaction. The ac electrical breakdown strength was estimated in sphere-to-sphere electrodes and the electrical breakdown strength was estimated by Weibull statistical analysis. The scale parameters of the electrical breakdown strengths for the epoxy resin, epoxy-polyglycol, and epoxy-BDGE were 45.0, 46.2, and 45.1 kV/mm, respectively. The flexural and tensile strengths for epoxy-BDGE were lower than those of the epoxy resin and those for epoxy-polyglycol were lower than those of the epoxy resin.

Keywords: Electrical insulation breakdown strength, Mechanical strength, Epoxy resin, Reactive diluent, Weibull statistical analysis

1. INTRODUCTION

Epoxy resins are well-known materials in the field of insulation systems for heavy electric equipments, due to their good mechanical and thermal properties and excellent electrical properties [1-3]. In order to improve these properties, many types of inorganic fillers such as silica (SiO₂) [4], alumina (Al₂O₃) [5], mica (6), aluminum nitride (AlN) [7], and titanium dioxide (TiO₂) [8], etc. have been incorporated into the epoxy resins. Messersmith and Giannelis [9] reported that the storage modulus of epoxy resin increased 58% at the glass transition region and increased 450% at the rubbery plateau region by loading of only 4 vol.% of clay. Mülhaupt et al. [10] demonstrated that the toughness and stiffness of epoxy resin were modified by adding nano-sized mica, bentonite or hectorite. T. Tanaka et al. [11] showed that epoxy/layered silicate nanocomposite had much better insulation breakdown strength than that of the non-filled epoxy resin system in needle-plate electrodes geometry. We previously reported that the insulation breakdown strength of the epoxy/layered silicate nanocomposites was 33% higher than that of the system without nano-silicate [12].

However, when inorganic filler was incorporated into an epoxy resin, the viscosity became too high. Therefore, it was very difficult not only to disperse the fillers homogeneously and to remove bubbles from the epoxy/filler mixture but also to inject the viscous mixture into a mould during the curing process. Therefore, in order to decrease the viscosity, plasticizers, organic solvents and reactive diluents were individually introduced to the epoxy/filler composites so that the bubbles were easily removed from the composites after injecting into a mould.

However, the plasticizers disturbed the cure reaction of the epoxy system so that the crosslink density decreased. This caused a decrease in the electrical, mechanical, and thermal properties of the epoxy system. In addition, when organic solvent is used, it should be removed completely after mixing the epoxy, fillers,
breakdown strength data were estimated by Weibull statistical model. Data were automatically collected every 5 seconds, and all insulation thicknesses to measure the ac insulation breakdown strength. The electrodes were made of copper and their diameters were 7.40 mm. The specimen and electrodes were then dipped into an insulating oil of 30°C.

The specimen and electrodes were then studied. The specimen thickness was 1 mm, and the parameters such as shape and scale parameters, and the B10 value were obtained from the Weibull plots and are listed in Table 2. Here, the shape parameter could be obtained from the slope, indicating that the data distribution and the scale parameter represented the ac electrical breakdown strength by which 63.2% of the cumulative probability was expected to fail. The B10 value referred to the ac electrical breakdown strength at which 10% would fail (90% would survive) under a given electrical stress. The statistical analysis of the epoxy resin without a diluent showed that the scale parameter was 45.1 kV/mm with the shape parameter of 45.4. As the polyglycol was added to the epoxy system, the scale parameter became slightly higher and the shape parameter was ca. 10 higher. The values for the scale and shape parameters for the epoxy system with BDGE were almost the same as the epoxy system without the diluent. When examining the decreasing crosslink density and the scale parameters of Table 2, it can be seen that the negative effect of crosslink density on the electrical breakdown strength increased slightly in the epoxy-polyglycol system. However, in this study, the breakdown strength increased slightly in the epoxy-polyglycol system or there was no change in the strength of the epoxy-BDGE system as shown in Fig. 2.

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Figure 2 shows Weibull plots of ac electrical breakdown strength for the epoxy systems with and without reactive diluents. The specimen thickness was 1 mm, and the parameters such as shape and scale parameters, and the B10 value were obtained from the Weibull plots and are listed in Table 2. Here, the shape parameter could be obtained from the slope, indicating that the data distribution and the scale parameter represented the ac electrical breakdown strength by which 63.2% of the cumulative probability was expected to fail. The B10 value referred to the ac electrical breakdown strength at which 10% would fail (90% would survive) under a given electrical stress. The statistical analysis of the epoxy resin without a diluent showed that the scale parameter was 45.1 kV/mm with the shape parameter of 45.4. As the polyglycol was added to the epoxy system, the scale parameter became slightly higher and the shape parameter was ca. 10 higher. The values for the scale and shape parameters for the epoxy system with BDGE were almost the same as the epoxy system without the diluent. When examining the decreasing crosslink density and the scale parameters of Table 2, it can be seen that the negative effect of crosslink density on the electrical breakdown strength increased slightly in the epoxy-polyglycol system. However, in this study, the breakdown strength increased slightly in the epoxy-polyglycol system or there was no change in the strength of the epoxy-BDGE system as shown in Fig. 2.

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breakdown strength was compensated by the positive effect of the diluents. In addition, the higher value of the shape parameter indicated the homogeneous composition of the reactants, leading to a low degree of dispersion. Therefore, if the polyglycol were used as a reactive diluent in an epoxy/inorganic filler system, it could be used in order to decrease the viscosity of the epoxy system.

Figure 3 shows Weibull statistical analyses of flexural strength for epoxy systems with and without reactive diluents, and the parameters such as shape and scale parameters, and B10 value were obtained from the Weibull plots and are listed in Table 3. The statistical analysis showed that the scale parameter of the epoxy resin without reactive diluent was 146.7 MPa with the shape parameter of 67.0, and that of the epoxy system with polyglycol was 132.4 MPa with the shape parameter of 82.3. Moreover, the scale parameter of the epoxy system with BDGE...
was 141.4 MPa with the shape parameter of 91.1. As predicted, the flexural strength decreased when the reactive diluents were added. This meant that the reactive diluents acted as flexibilizers in the epoxy systems and some of the reactive diluents withstand-curing reaction so that the diluent monomers disturbed the cure reaction between the epoxide group of the epoxy resin and the carboxyl group of the curing agent. Therefore, the molecular weight between the two crosslink points increased and many end-chains were generated. These results caused easy mobility of the epoxy chains at lower temperature as the surrounding temperature increased. Therefore, Tg decreased by the addition of reactive diluents.

According to the addition of the reactive diluents, the same tendency was observed in the tensile strength as shown in Fig. 4 and the Weibull parameters obtained from Figure 4 are listed in Table 4. The scale parameter of the epoxy system without reactive diluent was 94.0 MPa with the shape parameter of 57.4, and as the BDGE was added to the epoxy system, it was 89.8 MPa. The scale parameter of the epoxy-polyglycol was 78.5 MPa, which was ca. 17% lower than that of the epoxy system without diluent. The shape parameter of the epoxy-polyglycol was 63.7, which was ca. 11% lower than that of the epoxy system without diluent.

4. CONCLUSIONS

The effect of reactive diluents on the ac electrical insulation breakdown strength and flexural and tensile properties was studied. All the data were estimated using Weibull statistical analysis. In the ac electrical insulation breakdown strength, the scale parameter of the epoxy system without reactive diluents was 45.1 kV/mm and its shape parameter was 45.4. As the polyglycol was added to the epoxy system, the scale parameter slightly increased and the shape parameter was ca. %. The higher value of the shape parameter meant that the polyglycol could be used as a reactive diluent. In the flexural strength, the scale parameter of the epoxy resin without reactive diluent was 146.7 MPa, while that of the epoxy system with polyglycol or BDGE was 132.4 MPa or 141.4 MPa, respectively. Tensile strengths of the epoxy resin, epoxy-BDGE, and epoxy-polyglycol systems were 94.0 MPa, 89.8 MPa, and 78.5 MPa, respectively. These mechanical strengths meant the reactive diluents acted as flexibilizers.

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REFERENCES