Electrical Tree Aging of Epoxy-Based Nanocomposites at Cryogenic Temperature

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1. Introduction

Epoxy nanocomposites (mainly inorganic nano-fillers) with superior mechanical strength and electrical insulation properties have attracted more and more attention as new insulating materials. The limited investigations of epoxy nanocomposites in the electrical insulation field at cryogenic temperatures make it difficult for superconducting power devices to determine better insulation materials and optimal insulation dimensions. In this work, we focused on the tree resistance of epoxy nanocomposites in liquid nitrogen (LN_2). In order to verify the application possibilities of epoxy nanocomposites at cryogenic temperature, we performed electrical tree tests of epoxy/Al_2O_3 nanocomposites. In addition, COMSOL Multiphysics® software was used to simulate the electric field at needle tip in the neat epoxy resin and epoxy/Al_2O_3 nanocomposites.

2. Sample and Experimental system

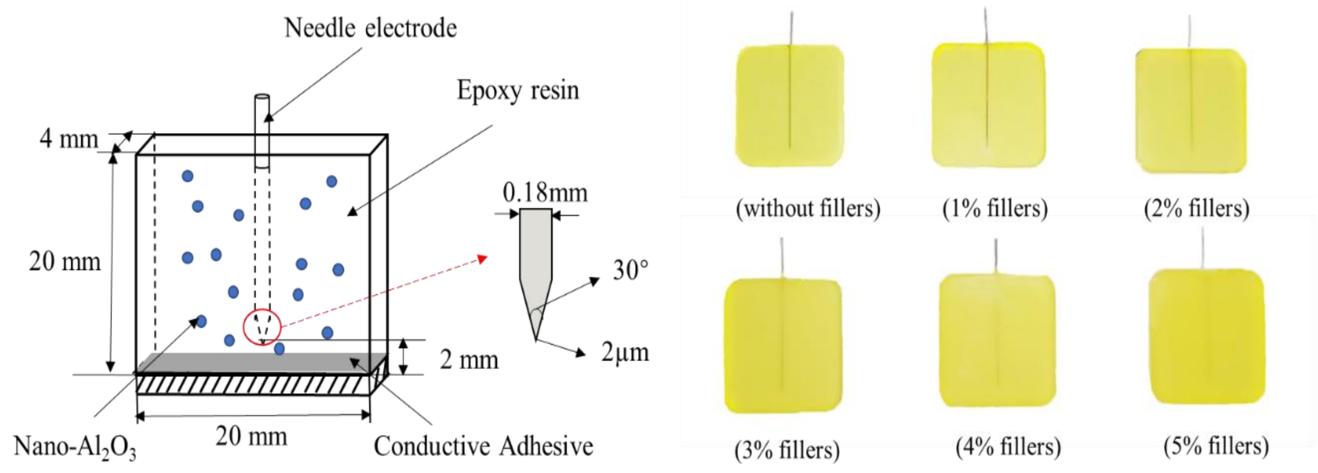

Figure 1. The test samples for treeing experiments.

In this work, Two types of samples were prepared: (a) neat epoxy (without fillers), (b) epoxy composites (with spherical Al_2O_3 fillers). The scale of the filler was around 100 nm. The filler content was fixed at 1%, 2%, 3%, 4%, 5% (parts per hundred parts of resin by weight ratio. As shown in figure 1, the size of the sample was 20 mm × 20 mm × 4 mm (length × height × width).

An AC voltage test system (model BGCZX) with a capacity of 5 kVA was used as shown in figure 2(a). The test sample was held tightly between the high voltage electrode and the ground electrode by two non-conductive polytetrafluoroethylene (PTFE) screws, as shown in in figure 2(b). The prepared epoxy samples were immersed in liquid nitrogen and insulating oil respectively.

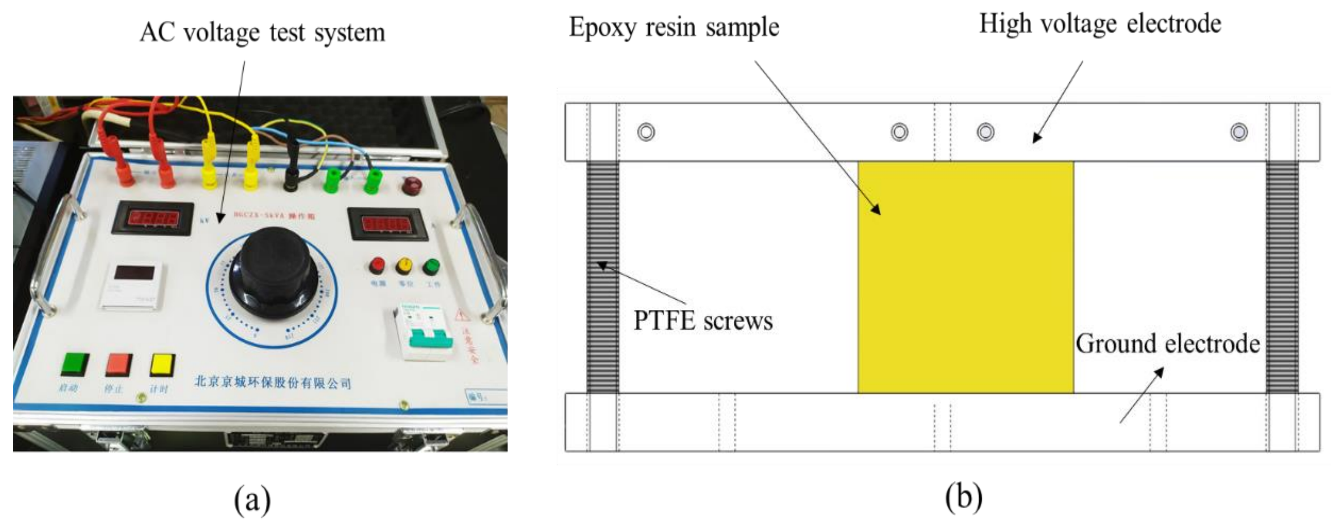

Figure 2. AC test system and electrodes configuration (a) 5 kVA AC test system, (b) sample jig for AC breakdown test.

3. Effect of nano-filler on electrical tree inception voltage

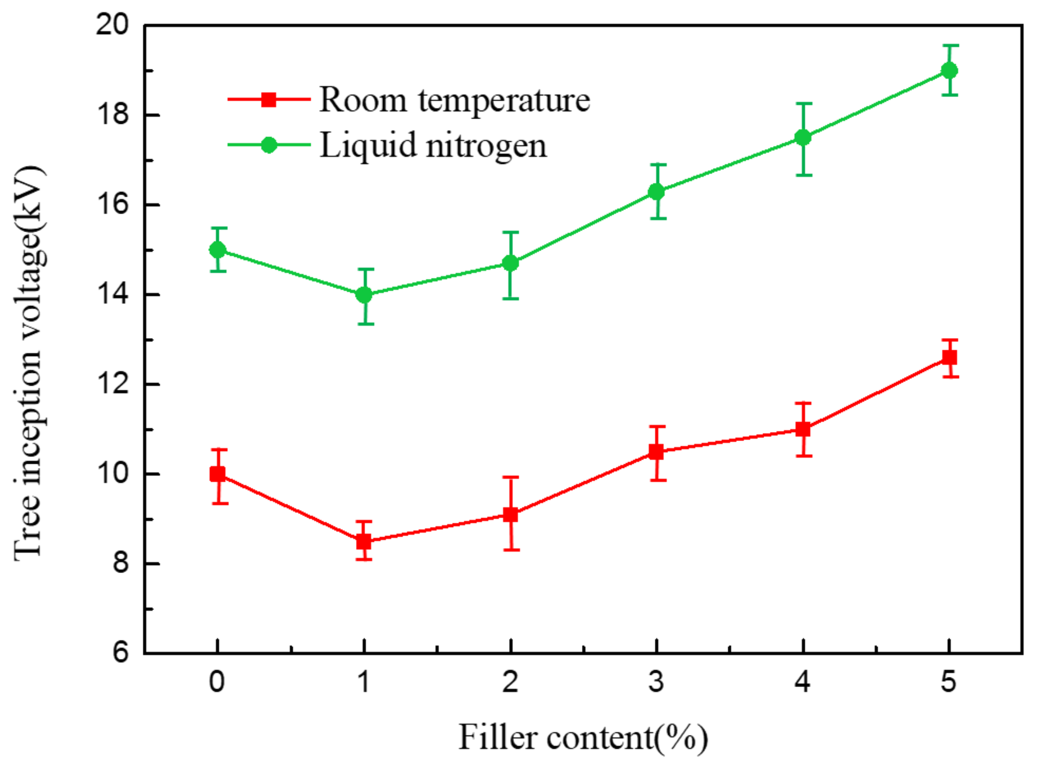

Figure 3. The tree inception voltage for the neat epoxy resin and nanocomposites.

At room temperature, when the filler content is less than 3%, the average tree inception voltage of the "without filler" samples is higher than that of the " with filler " samples. When the filler content is higher than 3%, the trend is the opposite. At low temperature, the tree inception voltages of all samples is much higher than those at room temperature and the electric field distortion caused by the filler is significantly weakened.

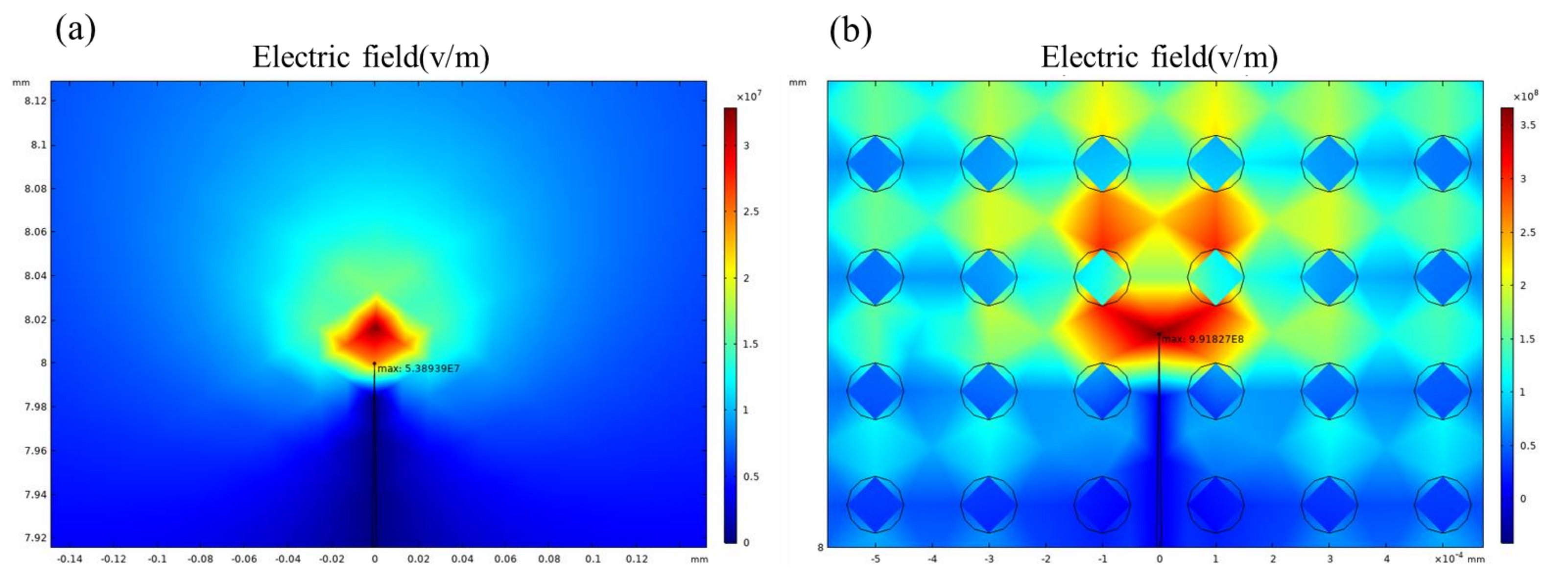

Figure 4. The simulated electric field at the needle tip by COMSOL.

The simulated electric field at the needle tip in epoxy/Al_2O_3 nanocomposites is about 18 times higher than that in neat epoxy sample. It’s a perfect explanation why the filler reduces the tree inception voltage when the filler content is lower than 3%, but this model is not suitable when the filler content is greater than 3%.

4. Effect of nano-filler on electrical tree propagation

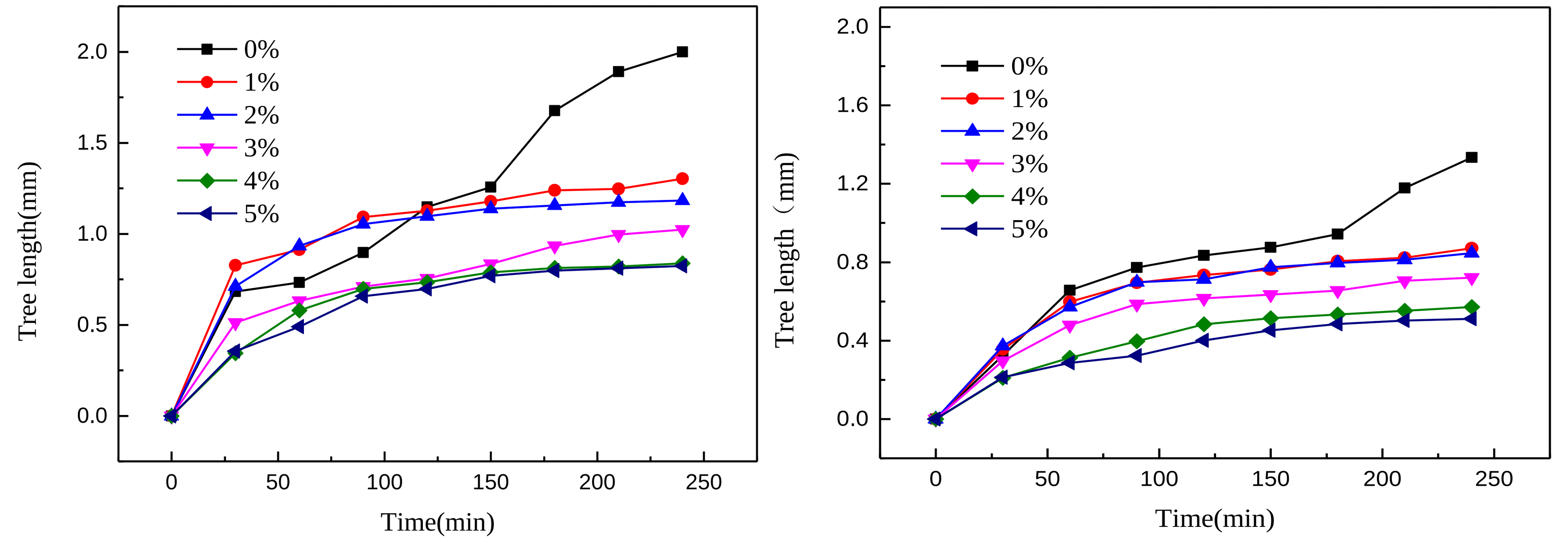

Figure 5. The changes in tree length over time in the samples in (a) insulating oil and (b) LN_2.

The electric field distortion caused by the nano-fillers below 3% promotes the tree propagation in composite samples at room temperature before 120 min. After 120 min, the tree propagation in the neat epoxy sample is in the lead. At low temperature, the tree growth rate decreases sharply with the increase of the content of the nano-filler.

5. Conclusion

We focused on the electrical tree characteristics of the neat epoxy and composite sample in liquid nitrogen. Tree inception voltages and tree length measurements were carried out at different temperatures. The following conclusions can be drawn:

Nano-fillers below 3% are easy to cause the electric field distortion at the needle tip, which reduces the tree inception voltage in the composite sample compared to that in the neat epoxy sample, while the nano-fillers above 3% will wrap the needle tip with great probability, causing the increase of tree inception voltage. At low temperature, the effect of electric field distortion on the tree inception voltage is significantly weakened and the tree growth rate decreases sharply with the increase of the content of the nano-filler.