§13. Development of New Electric Insulation Materials for Fusion Magnet

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Fusion devices will generate a lot of high energy neutrons, and some of them will pass through the blanket and reach the superconducting magnet. Therefore, the superconducting magnet will be irradiated by neutrons. At the same time, gamma ray irradiation will occur because of the radio isotopes which will be created by neutron irradiation. On the other hand, the electric insulation materials are needed to avoid an electric break. From a view point of the materials handling in a fabrication process, an organic insulation material has been used for a large scale superconducting magnet. Among the constituent materials of the superconducting magnet, the organic insulation material is the weakest against radiation. Therefore, the development of the new insulation material is one of the key issues for design and construction of the magnets for fusion. In this study, the some new insulation materials are manufactured by way of trial and the performance after irradiation was investigated.

The organic materials for the electric insulation are cyanate ester and epoxy resins. The cyanate ester has been proposed by K. Hummer et al as the insulation material [1]. Although the mechanism of excellent property against radiation was not clarified, they showed that the irradiated samples had almost no degradation of fatigue properties.

Three kinds of cyanate ester resin were used [2]. The first was CTD403 provided by Composite Technology Development, Inc. and the second was ARoCyL-10 by Huntsman Advanced Materials, and the last was the trial product by Japanese company designated as MCE. The cyanate ester was blended with epoxy at a certain weight fraction. The GFRP had laminate structure with 11 glass cloth (s-glass fibers) sheets and 10 polyimide films, which were laminated alternatively. After the lamination in the mold, a cover plated was bolted and the mold was set in a vacuum chamber. To reduce the water in the mold, the mold was warmed up and kept at about 50 C for over 10 hours, and a vacuum impregnation was performed with the blended resin (cyanate ester + epoxy). The sequence of curing process was determined considering the avoidance of bubbling, for the cyanate ester has exothermic hardening property. The maximum temperature for CTD and ARoCyL-10 resins was 150 C and 160 C for MCE, though normal epoxy resins with Jeffamin hardener (D230 and D400) were cured at the maximum temperature of 125 C.

The results of the glass transition temperature (Tg) are shown in Fig. 1. The epoxy resins with Jeffamin hardeners showed rather lower Tg of about 45 C (D400) and 70 C (D230). However, when the cyanate ester was blended, Tg increased up to 150 C (CTD/EP = 40/60) depending on the bend ratio. The sample of MCE/EP = 30/70 showed the highest Tg of about 160 C. It seems that Tg is affected by the maximum curing temperature.

The cyanate ester makes triazine ring with trimerization reaction when it is cured at over 200 C. Below the temperature, oxazoline ring forms between cyanate ester and epoxy during cyclization. These rings are considered to have stronger resistance against radiation than polymerization of epoxy. The products formed after the cure treatment and the temperature range producing the ring structure will be investigated in near future.

Figure 2 shows the interlaminar shear strength (ILSS) of trial samples measured at 77 K against dose of gamma ray. In case of EP+D230, ILSS dropped drastically by 10 MGy irradiation, though it did not show the lower ILSS by 1 MGy. As for the GFRPs with the blended resins, the ILSS decreased with an increase of the weight fraction of cyanate ester. Also, it is clear that the gamma ray irradiation up to 10 MGy does not degrade the ILSS remarkably. From these results, it is noticed that the 60/40 blend ratio of epoxy with cyanate ester would be acceptable for the fusion magnet.

1) K. Bittner-Rohrhofer, K. Humer, Z.D. Wang, H.W. Weber, P.E. Fabian and N.A. Munshi, Fusion Engineering & Design, 66-68, 1209 (2003).
2) A. Nishimura, Y. Izumi, S. Nishijima, T. Hemmi, N. Koizumi, T. Takeuchi, and T. Shikama, Advances in Cryogenic Engineering, 56, 127 (2010).

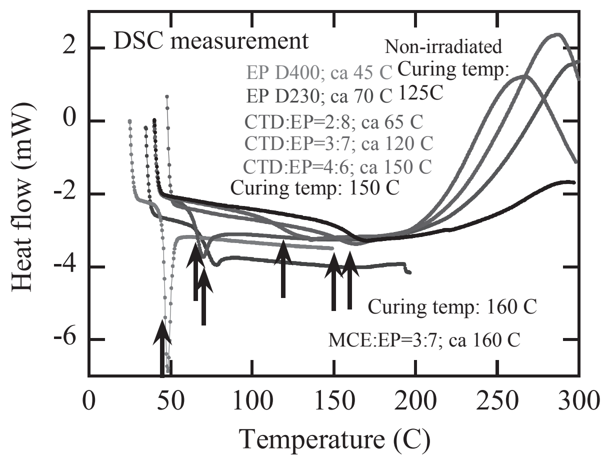

Fig. 1. Results of glass transition temperature of blended resins using differential scanning calorimetry .

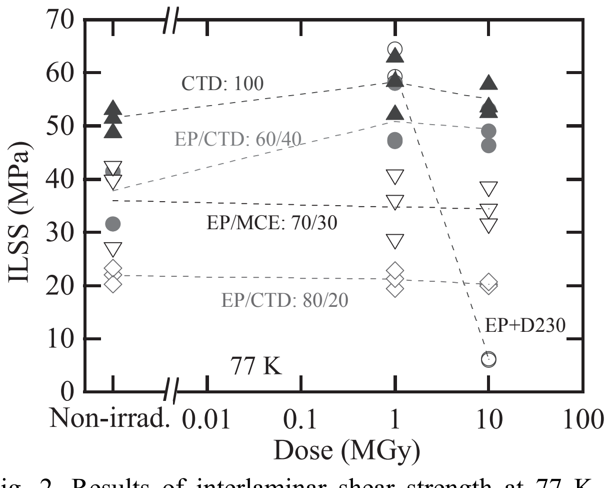

Fig. 2. Results of interlaminar shear strength at 77 K after gamma ray irradiation with ^{60}Co.