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Irradiation effect on the interface of the composites used as the insulation materials in the nuclear fusion reactor

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Abstract

In ITER (International Thermonuclear Experimental Reactor), the insulation materials containing polymeric matrix are the most radiation-sensitive among the materials constituting the superconducting magnet in the nuclear fusion reactor. Insulation materials are fabricated by impregnating the polymeric material into the stacks of alternating layers of polyimide films and glass cloth. There are a lot of studies about irradiation property of each constituent material, whereas few studies are reported about the irradiation effect on the resin -glass cloth and the resin –polyimide film boundary. In this study, we focused on the degradation of the resin-glass cloth boundary. The influence of the surface treatment and the weaving density of the glass cloth on the boundary degradation was evaluated by the mechanical properties before and after irradiation. The composite material specimens were prepared using the glass cloth with different surface treatment, and with different weaving density. The inter laminar shear strength (ILSS) test was conducted to examine the influence of the boundary on the radiation effect. In addition, the fracture mechanism were evaluated by optical micro-scope. Based on the results, it was indicated that the weaving density of the glass cloth is small influence on the irradiation effect and the radiation resistance was improved by the surface treatment.

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Keywords: Insulation materials; Irradiation effect; Boundary; GFRP; Surface treatment; Weaving density; Inter laminar shear strength

1. Introduction

It is known that Glass Fiber Reinforced Plastic (GFRP) used for electric insulation in the superconducting fusion

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magnet for ITER is the most radiosensitive among the magnet components, and the mechanical strength is decreased by gamma and neutron irradiation. When the electromagnetic force is applied, mechanical defect, which degrades the electric strength, would be generated in the insulation materials [1]. Therefore, the insulation materials are required that keeping ILSS more than 45 MPa, in spite of the degradation due to irradiation during the operating period. Insulation materials are fabricated by impregnating the polymeric material into the stacks of alternating layers of polyimide films and boron-free S-glass cloth.

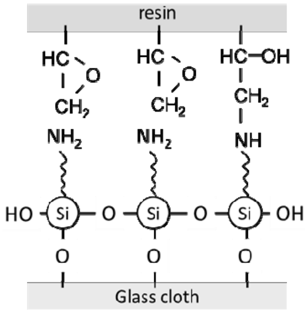

Fig. 1. Schematic structure of the silane-treaded glass cloth surface.

It is considered that the degradation in the insulation material is caused at resin layer, resin-glass cloth boundary or resin-polyimide film boundary. The researches in the insulation material have been conducted focusing on the resin, whereas few studies are reported about the irradiation effect on the boundary in the insulation material. In this study, we focused on the degradation at the resin-glass cloth boundary. Specifically, the resin-glass cloth boundary was examined from two points of view. One is microscopic boundary which changes according to surface treatment of the glass cloth. The other is macroscopic boundary which changes according to the weaving density. Silane treatment is performed on the glass cloth surface in order to improve the adhesive to the resin matrix. The glass cloth with silane treatment forms covalent bond to silane coupling agent as shown in Fig. 1. The organic functional group (amino group) in silane coupling agent reacts and forms a chemical bond with resin (epoxy group), which makes the adhesive property between resin and glass cloth improved [2]. Therefore it is considered that the state of microscopic boundary is changed according to surface treatment. Meanwhile, the form of macroscopic boundary changes according to the weaving density which causes the change of undulation in glass cloth as shown in Fig. 2.

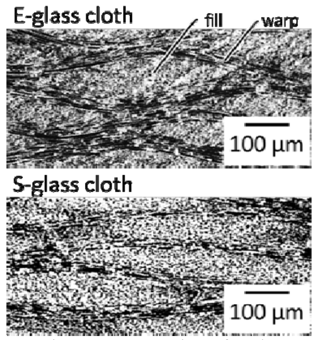

Fig. 2. Cross section of each S-glass and E-glass GFRP.

In this study, GFRP as the model material was prepared by using glass cloth and epoxy resin in which the radiation effect appears at low dose. The glass cloth with different surface treatment and weaving density were used. These specimens were irradiated up to 10 MGy γ-radiation in maximum, which adsorbed dose were equivalent to the absorbed dose as a fast neutron fluence up to 1×10^{22} m^{-2} (E>0.1MeV) in order to simulate degradation caused by neutron. The ILSS test was conducted by using these specimens to examine how the condition of the boundary affected by irradiation. In addition, the change in fracture mechanism were also evaluated by micro-scopic observation.

2. Experiment

The GFRP specimens were made of heat cleaned E-glass cloth (warp fiber: 18 bundles/cm, fill fiber: 14 bundles/cm; Arisawa Manufacturing Co., Ltd.) or silan-treated E-glass cloth. The GFRP specimens with different weaving density were made of silane-treated S-glass cloth (warp fiber: 10 bundles/cm, fill fiber: 10 bundles/cm; Arisawa Manufacturing Co., Ltd.) as shown in Fig. 2. Glass cloth were stacked 45 layers and dried in vacuum at 100 °C for 24 h. Epoxy resin (Epikote828®, Diglycidyl ether bisphenol A, Mitsubishi Chemical Corporation) and hardener (Jeffamine® D230(HUNTSMAN)) were stirred in vacuum, and the resin was impregnated into the glass cloth in vacuum at 40 °C. Then, the mixture was cured by heat treatment (70 °C-3h, 110 °C-2h). Three kinds of GFRP plates (6mm in thickness) were fabricated and cut off into the specimen geometry shown in Fig. 3.

The GFRP specimens were irradiated by γ-ray in 5 MGy and 10 MGy at the dose rate of 42 kGy/h under air atmosphere and at room temperature. The irradiation was carried out in ^{60}Co γ-ray irradiation facility, Research Laboratory for Quantum Beam Science, Institute of Scientific and Industrial Research, Osaka University.

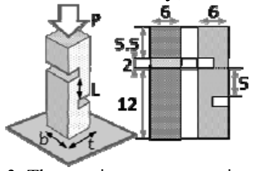

Fig. 3. The specimen geometry in mm

The specimens were used for ILSS test performed at the liquid nitrogen temperature by using Shimadzu Autograph AG-X 10kN (Shimadzu.Inc.). In this test, 8 specimens were used in each condition. The maximum load when inter laminar shear fracture occurred was applied to the equation (1), and the