Rapid Communications

Development of a Heat-Resistant Neutron Shielding Resin for the National Centralized Tokamak

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A 300°C heat-resistant neutron shielding material was newly developed. The material consists of phenol-based resin with 5 weight-% boron. The neutron shielding performance of the developed resin, which was examined by using a ^{252}Cf neutron source, was almost identical to that of polyethylene. The resin can be applied to the port section of the vacuum vessel of the DD plasma device to suppress the streaming neutrons and to reduce the nuclear heating of the superconducting coils.

Keywords:
Neutron shielding resin, Heat-resistance, Phenol-based resin, Nuclear heating, Superconducting coil

The National Centralized Tokamak (NCT) is planned to demonstrate the steady-state high-β plasma with a nationwide collaboration in Japan. The facility design of the NCT was described in Ref. [1]. The NCT will operate using deuterium plasmas with deuterium beam injection. Because the NCT has no blanket, some shielding structure against the DD neutrons (E_n = 2.45 MeV) will be needed to suppress the nuclear heating of the superconducting coil. The DD neutrons will be mainly shielded by the water-filled double-wall vacuum vessel in the NCT. However, at the port duct, where the double-wall structure is not available, another neutron shield material is required. This material must have heat resistance against the 300°C baking temperature of the vacuum vessel, which is higher than the heat-proof temperature of the present neutron shielding resins. For example, the heat-proof temperature is 90°C in polyethylene and 200°C in eponite, a resin developed by Hazama Co. Therefore, we developed a boron-loaded resin with heat resistance to 300°C as a neutron shielding material.

To facilitate the design of the neutron shielding resin, we have investigated several of the characteristics of the resin as follows.

In order to decrease the nuclear heating, the attenuation of DD neutrons as well as attenuation of the secondary γ-ray emitted from the recoil nucleus due to the elastic scattering is essential. For the neutron attenuation process in the neutron shielding resin, both a 'moderator' and an 'absorber' are required. Fast neutron is thermalized by the moderator through elastic scattering, and then absorbed by the absorber. The most effective moderator is hydrogen because it has almost the same mass as a neutron. The absorber should be selected so as to minimize the effect of capture γ-ray emission during absorption of the thermalized neutron. The nuclear heating efficiency, indicated by the KERMA (kinetic energy released in materials) factor [2], depends on the capture γ-ray energy (E_γ). Compared to hydrogen, which has an energy of E_γ = 2.225 MeV, boron has a much lower energy of E_γ = 0.48 MeV. Much of the nuclear heating in the superconducting coil is generated by the copper wire within the cable in the conduit. The KERMA factor of copper in the γ-ray by hydrogen is about three times larger than that by boron. This is an effective method to dope boron for decreasing the nuclear heating of the coil.

To determine the amount of boron to include in the neutron shielding material, the neutron and the γ-ray flux through the resin are evaluated by 1D model analysis in NCT. This analysis was performed using the 1D code, ANISN [3], with a group constant set FUSION-40 [4]. By multiplying the calculated fluxes by the KERMA factor, the nuclear heating of the toroidal magnetic field superconducting coil was estimated. The amount of boron was chosen as 5 weight-% to minimize the nuclear heating of the superconducting coil.

The neutron shielding resin was developed by mixing boron carbide (B_4C) with a phenol-based resin with improved heat resistance. The measured chemical composition of the developed resin is summarized in Table 1. The density of the resin was 1.8 g/cm^3. The heat-proof temperature was more

Table 1 Chemical compositions of the developed resin.

Element	C	H	N	O	B	Ca	Al	Si
Contents (wt%)	29.4	1.94	0.31	30.4	6.1	7.4	6.8	14

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than 300°C by the determination of the temperature of deflection under load on the Japanese Industrial Standard (JIS).

The neutron shielding characteristic was observed by a neutron penetration test with a ^{252}Cf neutron source (average energy: $<E_n> \sim 2.1$ MeV) performed for the sample ($40 \times 40 \times 5$ cm^3) of the boron-loaded resin and the polyethylene at room temperature (~20°C). The neutron penetrations were measured by a neutron rem counter. Figure 1 shows the neutron dose attenuation of the developed resin and the polyethylene as a function of the thickness of the sample. The neutron shielding performance of the resin was almost the same as that of the polyethylene. The neutron shielding characteristics were also estimated by 3D Monte Carlo Code MCNP-4C2 [5] using continuous energy cross section data sets based on the JENDL-3.3 [6] for the composition of the developed resin based on Table 1. As shown in Fig.1, the calculation results agreed well with the experimental results of the resin.

To use the developed resin in the cryostat, it is necessary to suppress outgas in the high temperature region. The main outgas components from the resin at 150~300°C were CO_2, NH_3 and H_2O as detected by thermal desorption spectroscopy. In addition, the amount (µg/g) of 13 different organic gases, including pyridine and phenol, were determined by gas chromatography and mass spectrometry. The weight of the resin sample (0.022 g) decreased by 1.1% in the ~300°C region. H_2O is an important element in order to shield the neutrons and some of the H_2O molecules are lost by the first baking; however, the neutron shielding performance of the resin after baking was the same as that before baking. After a second baking, the volumes of the gases were below the limits of detection.

In conclusion, a 300°C heat-resistant neutron shielding resin for decreasing the nuclear heating of the superconducting coil in NCT was developed. This resin is suitable for application to the port section of the vacuum vessel and as a neutron shielding material for the plasma diagnostics around the vacuum vessel.

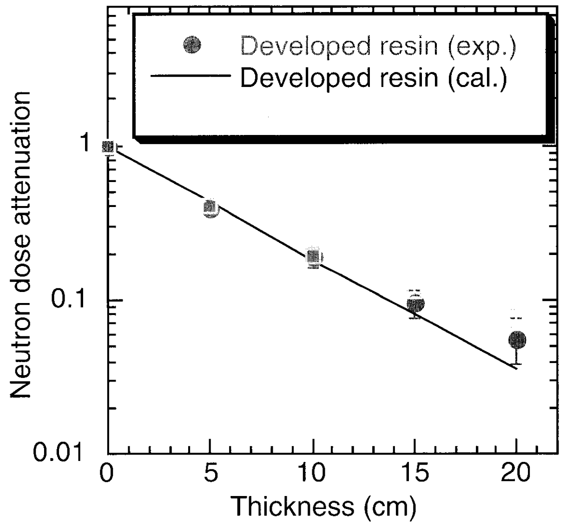

Fig. 1 Neutron dose attenuation in boron-loaded resin and polyethylene.

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