§33. Establishment of Material Database Including High Temperature Irradiation Effect and Material Design of SiC/SiC Composites for Inertial Fusion Dry Wall Chamber

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The first wall of an Inertial Fusion Energy (IFE) chamber will suffer serious damage from intense pulsed neutrons and other energetic particles. In particular, a dry wall chamber demands extremely severe conditions for the first wall material, although a dry wall chamber has the advantage of simplicity for design. Due to excellent mechanical properties at high temperatures, chemical stability and low activation following neutron irradiation, SiC/SiC composites is attractive both for Magnetic Fusion Energy and IFE. Irradiation experiment for SiC and SiC/SiC composites over 1500 °C had not been carried out due to technical difficulty, although the knowledge about irradiation resistance at high temperature over 1500 °C is indispensable, in particular for designing dry wall chamber of IFE. Up to now, irradiation effect on swelling behavior of SiC fabricated by chemical vapor deposition (CVD) process have been evaluated up to 1600 °C using the DuET facility at Kyoto University. It was found that the magnitude of swelling of the CVD SiC was limited to very low level. The objective of this work is to understand the stability of SiC/SiC composites to high temperature irradiation over 1500 °C including mechanical properties to establish design window for IFE dry wall chamber.

A high purity polycrystalline 3C-SiC produced through CVD process were irradiated with 5.1MeV Si^{2+} for inducing displacement damage at DuET facility, Kyoto University. The damage level was up to 2.1 dpa (2.1×10^{25} n/m^2, E>0.1 MeV) at surface of the material, and irradiation temperature was up to 1600 °C. Microstructure including fracture surfaces of the irradiated materials were examined by optical microscopy and scanning electron microscopy (SEM) at MUSTER (multi-scale testing and evaluation research) facility. In case of ion-irradiation, irradiated region in the material is limited to a few μm. Nano-indentation and three-point flexural tests, where tensile stress was applied for the irradiated region, were carried out to evaluate mechanical properties. The evaluation by three-point flexural test is based on the fact that strength of dense ceramics is determined by the defect at surface and adjacent to surface.

Hardness and elastic modulus obtained by nano-indentation and flexural strength of non-irradiated and irradiated CVD SiC are summarized in Table 1. Following irradiation, hardness increased and elastic modulus decreased, although the values at 1600 °C irradiation were close to those for a non-irradiated material. Evaluation of ion-irradiation effect on mechanical properties by flexural test is novel method. From observation of fracture surface by SEM, it was found that crack initiation and propagation of both non-irradiated and irradiated materials concentrated on the region within a few μm from surface, where mostly corresponded to irradiated region. Obvious irradiation effects on flexural strength were obtained, although the magnitude of the strength seems too large. Figure 1 shows a Weibull plot of flexural strength of non-irradiated and irradiated CVD SiC. Flexural strength increased significantly with irradiation at all conditions in this work. Weibull modulus, which shows distribution of data, of materials irradiated at 600 °C and 800 °C decreased following irradiation, where Weibull modulus of materials irradiated at 1600 °C was larger than that of non-irradiated material. The results for materials irradiated at 600 °C and 800 °C were consistent with previous neutron irradiation results. It is said that the novel evaluation method of three-point flexural for ion-irradiated materials can be used to evaluate irradiation effect on mechanical properties of SiC ceramics. Although the results for materials irradiated at 1600 °C require more analysis and discussion, it can be concluded with the swelling results obtained previously that CVD SiC doesn't degrade following irradiation at up to 1600 °C.

Table 1: Summary of hardness and elastic modulus obtained by nano-indentation and flexural strength of non-irradiated and irradiated CVD SiC

	Hardness (GPa)	Elastic modulus (Gpa)	Flexural strength (MPa)
Non-irradiated	789	35.9	410
2.1dpa, 600 °C	1251	40.8	381
2.1dpa, 800 °C	1092	41.4	395
2.1dpa, 1600 °C	1421	37.0	407

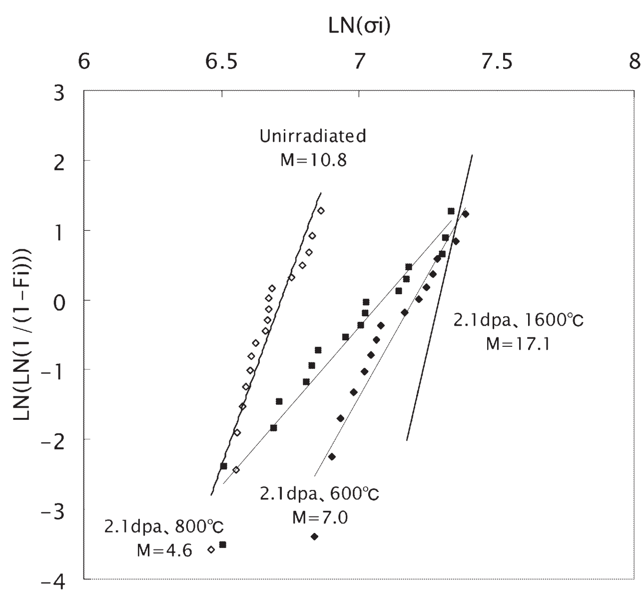

Figure 1: Weibull plot of flexural strength of non-irradiated and irradiated CVD SiC