§32. Establishment of Material Database Including High Temperature Irradiation Effect and Material Design of SiC/SiC Composites for Inertial Fusion 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 and fracture strength increased. 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 chamber.

A high purity polycrystalline 3C-SiC produced through CVD process and CVI-SiC/SiC composites reinforced with Tyranno SA (1st grade) fibers 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) and transmission electron microscopy (TEM) at MUSTER (multi-scale testing and evaluation research) facility. The amount of swelling was determined by means of a precision surface profilometry following irradiation through molybdenum meshes as shown in Figure 1. 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.

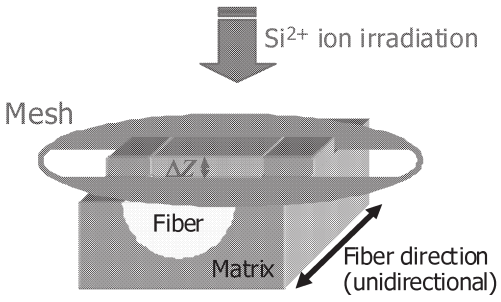

Figure 1: Procedure of ion irradiation for evaluation osf swelling for SiC/SiC composites

In figure 2, the swelling values of CVD SiC irradiated by ion irradiation are plotted as a function of irradiation temperature, along with reported neutron irradiation data. The magnitude of swelling of fiber and matrix of CVI composites irradiated by ion irradiation and monolithic SiC correspond to matrix SiC of NITE-SiC/SiC composites are also plotted in Figure 2. The magnitude of swelling decreased with increasing of irradiation temperature. Void formation at high temperature (Tirr > 1273 K) has been concerned about severe increase in swelling. The trend curve of swelling shown in figure 2 indicates that the void formation have little influence on the swelling value below 1873 K. It was also confirmed by TEM examination. To understand the irradiation effect on SiC/SiC composites, it is required to understand the irradiation effect on the constituents including mechanical properties, physical properties and swelling behavior. In particular, swelling of fiber and matrix affects residual stress at fiber/matrix interface. The magnitude of swelling of Tyranno SA fiber, CVI SiC matrix and monolithic NITE-SiC are on the trend curve for the CVD SiC irradiation induced swelling. It was also reported that strength of CVD SiC didn't degrade following ion irradiation up to 1600 °C. From these results, it is assumed that mechanical properties don't degrade significantly in the SiC/SiC composites consist of high purity fibers and matrix under irradiation up to 1600 °C.

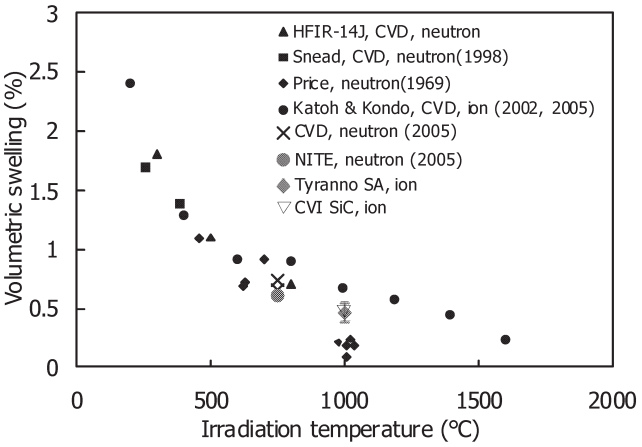

Figure 2: The swelling values of CVD SiC irradiated by ion irradiation, along with reported neutron irradiation data, swelling of fiber and matrix of CVI composites and monolithic SiC correspond to matrix SiC of NITE-SiC/SiC composites as a function of irradiation temperature