§ 4. Development of Advanced Mechanical Test Techniques for Severe Environment Performance Evaluation of Fusion Materials

Katoh, Y., Kohyama, A., Nozawa, T., Park, K.H. (Kyoto Univ.)
Noda, N., Muroga, T.

SiC/SiC composites are one of the promising candidates for plasma-facing components in fusion devices, due to the inherently possessed superior radiation-resistance, reduced activation and low after-heat properties. In fusion application, these components are exposed extremely harsh environments such as high-temperature heat-flux, neutron irradiation and mixture of them. Radiation-induced defects are not uniformly induced in the structural materials. Hence high-accuracy test technique to evaluate these local events has been strongly required and it is very important for the precise understanding of the defect evolution process of radiation-induced defects and their effects on the physical and mechanical properties. In addition, this technique is essential to identify the influence of the microstructural change on the mechanical and thermo-mechanical properties of bulk composites. The key objective in this study is to establish the small specimen test technique to identify the microscopic mechanical properties such as hardness and fracture toughness for ion-irradiated SiC and SiC/SiC composites. In addition, related issues such as thermal property and specimen size effect issues were also discussed, in order for the profound understanding of the relationships between micro/macro scopic thermo-mechanical properties.

Conventional micro/nano indentation test technique developed in NIFS was applied for the evaluation of mechanical properties of ion-irradiated SiC and SiC/SiC composites and the optimization of this technique was also carried out for further discussion about the defect evolution, the microstructural change of the fiber and matrix (F/M) interface and the fracture mechanism of them. For the profound understanding of radiation effects, microstructural observations by scanning electron microscopy and transmission electron microscopy were conducted and the relationships between microstructure and mechanical properties were also discussed for the generalization of radiation effects. On the while, thermal properties were evaluated by the finite element method (FEM) analysis and the experimental measurement of thermal conductivity. In the specimen size effect issue, in-plane shear properties, closely related to the off-axis tension, were identified by Iosipescu shear test.

By using modified indentation test technique, irradiation temperature and dose dependencies of hardness and modulus of β-SiC, irradiated by the single silicon ion and dual-beam ion of silicon and helium at the DuET facility in Kyoto University, were identified. In both single- and dual-beam irradiations, hardening due to the accumulation of radiation-induced defects and modulus decreasing due to the lattice expansion were identified. In particular, it was revealed that induced helium accelerated these radiation effects at larger dose level (Fig. 1).

In the FEM analysis on thermal conductivity of SiC/SiC composites, it was revealed that the F/M interfacial material played an important role and, in particular, carbon, generally used as F/M interface, was a primary heat path due to its high thermal conductivity. This indicated that it is very important to design the best use of carbon not to minimize the performance of high thermal conductivity SiC fibers and to protect carbon from oxidation, on considering the availability of the anisotropy of the thermal conductivity of carbon.

In the analysis of specimen size effect issue, it was identified that there was no significant size dependency of the in-plane shear strength and the size-dependent change of the key fracture mode in off-axis tension should be a significant size-limiting factor (Fig. 2). In particular, poor interfacial strength was a critical to the degradation of composite strength in smaller size composite. From these facts, it was strongly emphasized that the interfacial stability under the harsh environments, including the ion/neutron irradiation, should be the most important issue to be solved.

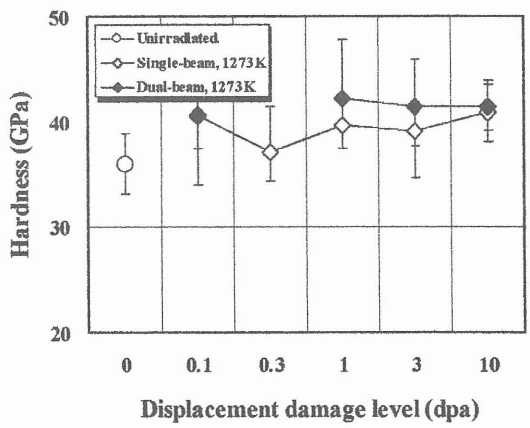

Fig. 1. Single- and dual-ion irradiation effects on hardness of CVD-SiC at 1273K.

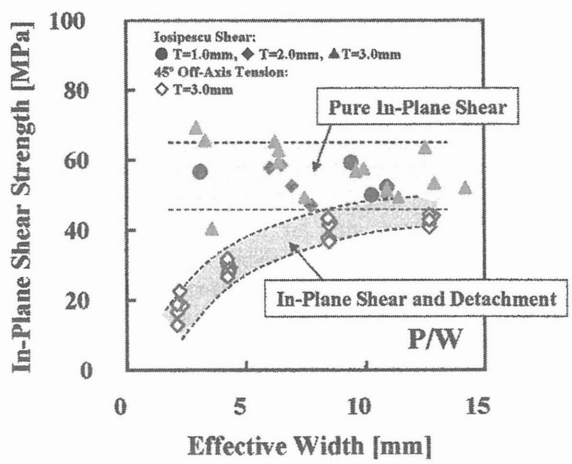

Fig. 2. Specimen width effects on in-plane shear properties of PIP SiC/SiC composites obtained from off-axis tension and Iosipescu shear tests.