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高線量中性子照射後の原子力グレードSiC/SiC複合材料の強度特性と微細組織

Mechanical Properties and Microstructures of Nuclear-grade SiC/SiC Composites after High Dose Irradiation

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Silicon carbide fiber-reinforced silicon carbide matrix (SiC/SiC) composites are promising candidate materials for advanced fusion reactor blankets (eg. DEMO) owing to its excellent thermo-mechanical / -chemical properties and intrinsic irradiation tolerance. The irradiation response of highly-crystalline and near-stoichiometric SiC fiber has been assumed to be the same as that of high purity monolithic β-SiC. Unfortunately, based on recent data this assumption appears not to be correct [Katoh, et al. J. Nucl. Mater. 462 (2015) 450]. In the case of high dose irradiation, SiC/SiC composites reinforced with one of the "nuclear-grade" fibers (Hi-Nicalon™ Type S (HNLS)) irradiated to 70 dpa at various irradiation temperatures, undergo a moderate to significant drop in the ultimate tensile strength depending on the irradiation temperature. The degradation is primarily attributed to fiber deterioration, though details remain unclear. The current study mainly aims to investigate mechanical and microstructural changes in the SiC/SiC composite after neutron irradiation to higher dose.

Materials for the present study include plain-weave HNLS composites produced via the chemical vapor infiltration process with the multilayered interface of $(PyC^{20\ nm}/SiC^{100\ nm})_5$ sequence. Neutron irradiation was conducted in the HFIR at ORNL. The peak neutron fluence was ~1.0×10^{26} n/m^2 (E > 0.1 MeV, equivalent to ~100 dpa) at nominal irradiation temperatures of 319 and 629°C. Post irradiation experiments included 1/4-four-point flexural tests (size: 6.3×2.8×62.8 mm) and SEM observations. Parallel, ion irradiation tests at DuET and TIARA facilities were used for comparison. Ion irradiation dose was ~100 dpa and temperatures 300 and 600°C. FE-TEM microscopy and EELS were used for microstructural evaluations.

In the post neutron irradiation experiments, ~50% degradation of proportional limit stress and ultimate flexural strength was observed for the composite irradiated at 629°C, while the one irradiated at 319°C exhibited brittle behavior, as shown in Fig. 1. In the ion-experiment results, shrinkage of the HNLS fiber was observed for specimens irradiated at 300 and 600°C to 100 dpa. The FE-TEM results, EELS analysis and our previous work suggest that the shrinkage would be result of ballistic mixing and transport of excess carbon atoms from the intergranular phase into SiC grains, and resulting production of excess C_{Si} antisites [S. Kondo et al. Acta Mater. 83 (2015) 1].

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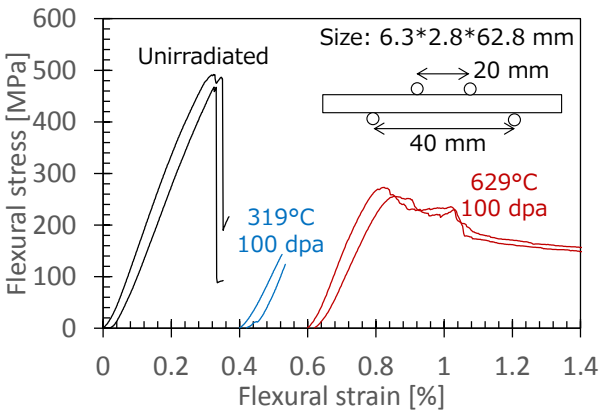

Fig.1 Flexural stress-strain curves. Curves are offset for visible purpose.