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論 文 要 旨

THESIS SUMMARY

専攻： Department of	Nuclear Engineering 専攻	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of Engineering
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要旨（英文 800 語程度）
Thesis Summary （approx. 800 English Words ）

Silicon carbide (SiC) has been used extensively in harsh environments due to its resistance to high-temperatures, heavy loads, and corrosion. SiC has been developed into high quality engineering ceramics with very spectacular mechanical and chemical properties. It has been proposed to be a promising material for aerospace engine parts and nuclear applications, such as a component in tri-structural-isotropic (TRISO) fuels of high-temperature gas-cooled reactors to retain the fission products at elevated temperatures and to provide structural integrity. However, SiC exhibits inherent brittle nature that can lead to a high probability of catastrophic failure under excess load. Therefore, to ensure sufficient mechanical properties and reliability, the proposed materials for future various applications are SiC fiber-reinforced SiC (SiC_f/SiC) composites composed of infiltrated SiC matrix into SiC-fiber-preforms. The composites have a potential for fusion reactor blankets owing to quick decay and are capable to retain integrity in extreme irradiation environment at temperature up to 1573 K and neutron fluence of up to 70 dpa. Therefore, SiC_f/SiC composites have been proposed as one of the candidates for components of commercial fusion reactors.

The objectives of this study are to investigate the fundamental neutron irradiation effects on high purity SiC, SiC containing sintering additives and SiC_f/SiC composites after exposure to moderate fluence at low irradiation temperature. Furthermore, recovery behavior of monolithic SiC was determined by post-irradiation annealing to understand the defects stability. Finally, microstructure of irradiated and annealed SiC were observed using a high-resolution electron microscope to scrutinize the microstructure evolution.

Seven materials were chosen and were divided into two groups, namely monolithic SiC and SiC_f/SiC composites. Monolithic SiC specimens consist of PureBeta-SiC, CVD-SiC and NITE-SiC, while SiC_f/SiC composites fabricated by CVI, NITE and EPD processes are the composite specimens. All the specimens were concurrently neutron-irradiated in the BR2 reactor up to fluences of $2.0\sim2.5\times10^{24}$ n/m^2 (E>0.1 MeV, 0.20~0.25 dpa) at 333-363 K. To understand the basic irradiation effects, macroscopic lengths of unirradiated and irradiated specimens were measured using a micrometer and lattice parameters were determined by X-ray diffraction (XRD) technique. Further, microstructure of SiC_f/SiC composites was observed by SEM. Recovery behaviors of high purity SiC and SiC containing sintering additives were investigated by using a precision dilatometer. Length changes were measured in-situ continuously from RT up to 1673 K with a step heating temperature interval of 50 K in helium atmosphere. Each step was kept for 6 h. After completing the annealing process, macroscopic lengths and lattice parameters were determined again. Furthermore, microstructure of high purity SiC and SiC containing sintering additives for unirradiated and irradiated specimens have been observed using a high-resolution electron microscope.

High purity SiC showed slightly smaller swelling (1.2%) compared to the specimens contained oxide sintering additives (1.3%). However, the SiC_f/SiC composites showed less swelling (1.1%) than the monolithic SiC, due to the smaller swelling of SiC fibers. From the XRD profile, peaks of all irradiated specimens were shifted to lower angles, indicating swelling owing to the formation of point defects. Microstructure observations of the SiC_f/SiC composites revealed that there is no debonding of fibers from the matrix was occurred, and no significant difference between the unirradiated and irradiated specimens was observed.

Investigations on recovery rates at every isochronal annealing step revealed that all specimens were recovered completely except for SiC containing 18 wt.% of sintering additives because of crystallization of secondary phases during the annealing process. From the analyses of recovery rates at each isothermal annealing step for determination of their activation energies, it was clarified that they have similar recovery stages. Below ~1223 K the recombination possibly occurred for closely positioned C and Si Frenkel pairs. In addition, at 1323-1523 K, recombination of slightly separated C Frenkel pairs and more long-range migration of Si interstitials may have occurred.

Observations of microstructures of irradiated SiC disclosed that there are no black spot defects or dislocation loops. It is suggested that the swelling induced by intermediate neutron fluence at low irradiation temperature occurred mostly due to the formation of point defects. Nevertheless, black spots and small dislocation loops have been observed in high purity SiC after post-irradiation annealing due to the interstitials that have not annihilated out were coagulated and formed small interstitial clusters. Furthermore, anomalous-shaped grains with inhomogeneous contrast were found in irradiated SiC containing sintering additives, therefore, amorphous grain boundary phases were crystallized through post-irradiation annealing and could affect their recovery behavior.