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先進炉に跨がる材料開発の現状と課題

Present status and issues for material development for advanced reactor

Microstructural stability of SiC under irradiation

~Progress in Fundamental Understanding of Irradiation Response of SiC~

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Recent interest in silicon carbide (SiC) and its composites (SiC/SiC) has been motivated by its possible utilization as a structural material for advanced reactors including accident tolerant light water reactors, gas-cooled reactors, and fusion reactors. For more than three decades these materials have been subjected to extensive irradiation experiments. The irradiated properties of high purity SiC is now widely understood, demonstrating the promise of those materials for use in severe irradiation environments without significant degradation of most properties (though still not fully understood especially at very high DPA). This irradiation stability, along with other attributes such as very high temperature capability and very low induced radioactivity are reason for the attractiveness of SiC composites to the future reactors. The purpose of this seminar is to provide a comprehensive look at the microstructural evolution of this material. The primary investigative tool utilized is transmission electron microscopy and the suite of samples include a catalog of samples irradiated with neutrons or ions.

In the recent past, it has been demonstrated that the strength of the so-called "nuclear-grade" SiC/SiC composite retain their initial strength after irradiation over a wide temperature range from 200-1200 ºC. Moreover, even for the highest temperature SiC/SiC appear to retain mechanical properties without undergoing measurable void swelling. Such outstanding mechanical and dimensional stability infers a very stable microstructural evolution in cubic SiC crystal, which is main constituent of the recent SiC/SiC and often called as β-SiC or 3C-SiC, under irradiation. The defect clusters, so called "black spots" and/or small SIA loops are dominating irradiation induced matrix defects in the temperature regime discussed above, and their populations are saturated at an early stage of the irradiation (<~1 dpa) due primary to the very high sink strength of practically immobile vacancies and tiny vacancy clusters. In concert with this, modification of the irradiated properties, such as swelling and thermal diffusivity degradation, was reported to be saturated at <~1 dpa. The evolutions of dislocation and void microstructures become significant in very high temperature regime (>~1200 ºC). Because the fundamental microstructures of SiC matrix and SiC fibers in SiC/SiC composites are similar to those in foregoing SiC crystals, the most properties of SiC/SiC resemble in those of SiC crystals to some degree. However, for example, unexpected shrinkage of SiC fibers irradiated at low temperature and very high fluence have been reported recently. Furthermore, the helium effects on some material properties are still unclear for SiC and SiC/SiC, even though the helium production rate in fusion-first wall region for SiC is expected to be higher than the other candidate materials. Therefore, understanding the microstructural development still need to predict the material properties in various irradiation conditions expected in a variety of reactors. This talk will cover the recent results described above and touch on some new topics associated with the microstructural development of the nuclear grade SiC/SiC composites.