

The Effects of Neutron Irradiation on Thermal Properties of SiC_f/SiC CMC: An overview

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Abstract:

SiC_f/SiC CMC are under investigation to work in a high temperature, highly radioactive and corrosive environment with superior thermal oxidation resistance in both fission and fusion type nuclear power plants. This paper gives a review on the effects of neutron irradiation on major thermal properties like thermal diffusivity, defect thermal resistance of SiC_f/SiC composites fabricated with HNLS, Tyranno fibers fabricated by CVI process. Thermal diffusivity/conductivity of SiC_f/SiC composites primarily depend on irradiation temperature. Following neutron irradiation at high temperature, HNLS fiber reinforced CMC shows instant fluctuation in thermal diffusivity. As irradiation temperature increases from 400°C to 500°C, Hi-Nicalon fibers show a steep decrease in defect thermal resistance while that of very limited decrement in defect thermal resistance of Tyranno fiber composites. The SIA of both Si and C types generated due to high temperature irradiation plays major role in deciding effect on thermal properties of SiC_f/SiC.

Keywords: - Ceramic-matrix composites (CMC); Chemical vapour infiltration (CVI); Hi-Nicalon Type -S Fiber (HNLS); Self interstitial atoms (SIA). Tyranno SA3 (SA3)

Introduction and Irradiation Thermal Properties:

SiC_f/SiC composites are under investigation to use in nuclear environment. In both fusion and fission type reactor, high in energy high speed electron impact on material, it alters microstructures, induces defects like frankel defects, antisite defects in both Si and C sub lattices. This affects to CTE, conductivity which redistributes residual stresses causing debonding between fiber and matrix which affects mechanical properties. In fiber reinforced CMC interphase also plays important role. Yutai Katoh (8) fabricated samples with CVI SiC-matrix, woven SiC-fiber of HNLS and SA3 SiC with pyrocarbon/SiC multilayered interphase. Then Specimens irradiated up to 5.3 dpa. Post irradiation conductivity and diffusivity values are summarized in Table 1. Same are plotted in the figure 1 and 2. It will clear from the figures that up to the point of thermal recovery of irradiation produced defects; the composite specimens are showing linear interdependence between reciprocal thermal diffusivity and temperature. HNLS composites show less ambient temperature thermal diffusivity than SA3. Effect of neutrn irradiation is intense for HNLS composite. Also at higher temperature i.e. above 800°C, there is instant fluctuation in thermal diffusivity. The defect thermal resistance i.e. the difference in reciprocal thermal conductivity before and after irradiation, (1/K unirr and 1/K irradi), respectively of both composites is as shown below (8). The defect thermal resistance of Tyranno composite sample decreases limited as the irradiation temperature increases. While in case of Nicalon type composite, it decreases very steeply. SiC_f/SiC composites with higher density have better conductivity and it shows larger reduction of thermal diffusivity. In case of lower density materials, gas is trapped in pores which act as heat barrier and irradiation has not any significant effect on diffusivity of pores as compared that with fibers and matrix. For the near-stoichiometric SiC composite materials. Y. Katoh (2) confirmed that Irradiation has minute effect on coefficient of thermal expansively.

Table 1. Post irradiation conductivity and diffusivity

Condition	Thermal diffusivity (HNLS) m^2/s	Thermal conductivity (HNLS) W/m-K	Thermal diffusivity (Tyranno) m^2/s	Thermal conductivity (Tyranno) W/m-K
440 °C 0.8 dpa	0.9×10^{-6}	1.3	2.3×10^{-6}	3.8
450 °C 2.0 dpa	1.0×10^{-6}	1.5	2.0×10^{-6}	3.3
500 °C 3.0 dpa	1.4×10^{-6}	2.4	2.4×10^{-6}	3.9
860 °C 5.3 dpa	1.6×10^{-6}	2.6	4.3×10^{-6}	7.3
850 °C	1.5×10^{-6}	2.4	3.3×10^{-6}	5.6

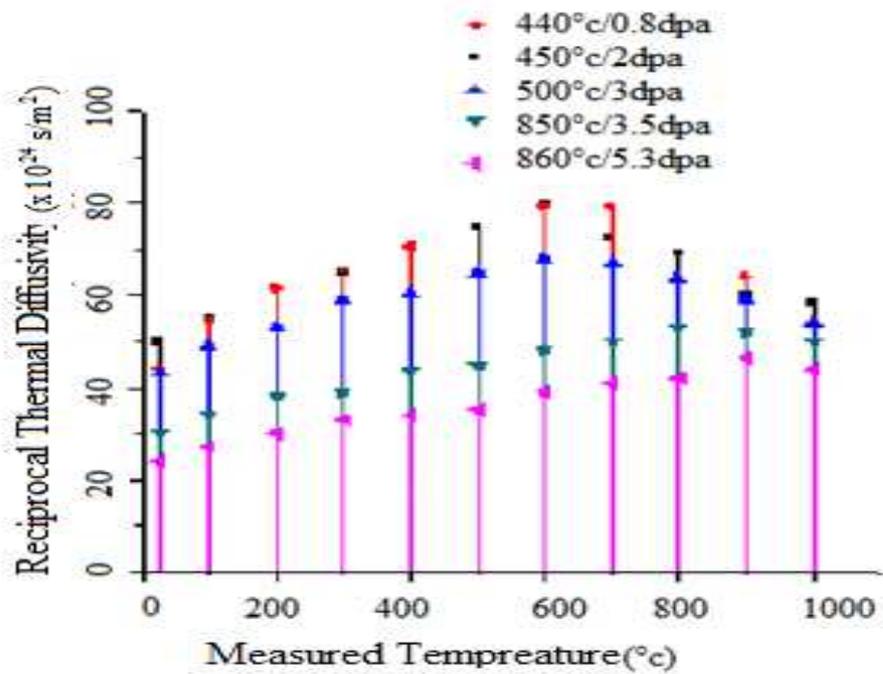


Fig: 1 Reciprocal Thermal Diffusivity of Tyranno composite

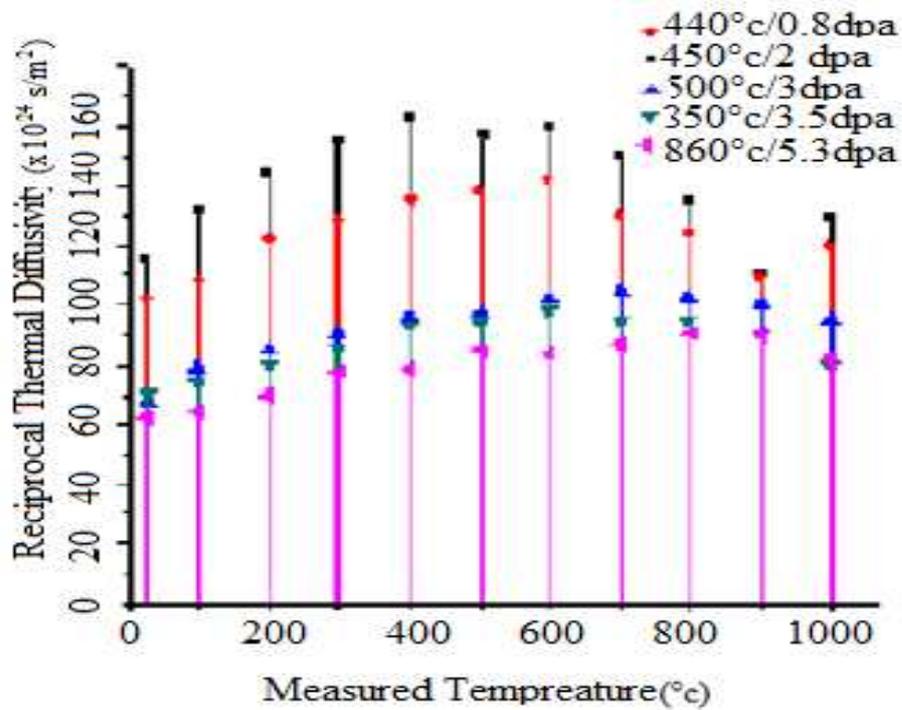


Fig:2 Reciprocal Thermal Diffusivity of Hi-Nicalon Type-S Composite

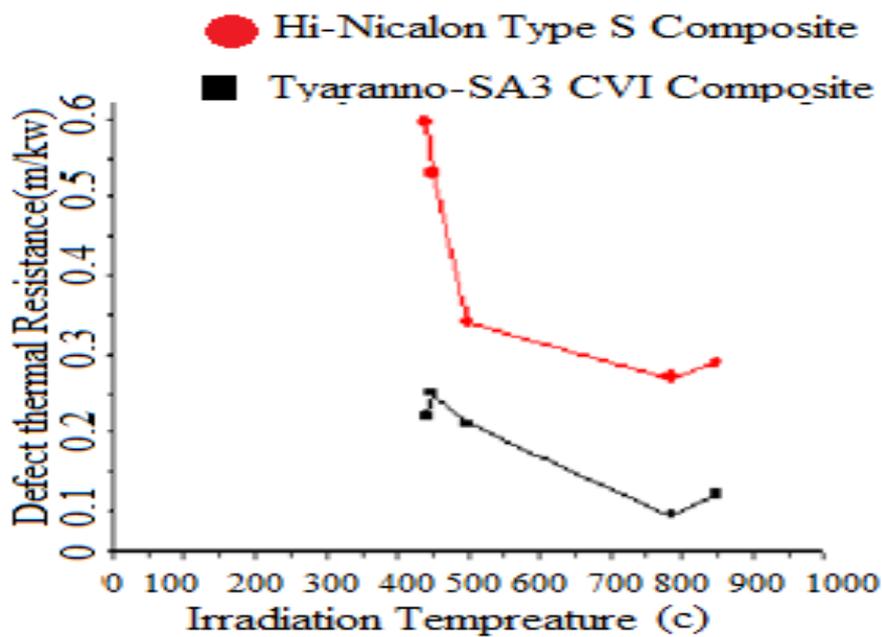


Fig:3 Defect Thermal Resistance of composites

CTE decrease over the entire temperature range after irradiation at 830°C for the composites with both fiber types, possibly indicating the effect of lattice swelling on thermal expansion. The change in thermal conductivity during irradiation saturates at relatively low fluency levels.

Conclusions:

Density of composites, fiber types it's bonding with matrix, interface in between them plays major role in deciding the thermal properties of samples at different irradiation condition. A Nicalon fiber shows the better radiation thermal resistivity as compared to other fibers. In case of both Hi-Nicalon and Tyranno composite, reciprocal thermal diffusivity shows increment upto irradiation temperature of 450°C to 550°C and then it start to decrease at high irradiation temperature. The thermal diffusivity of specimens found to decrease with irradiation temperature. Defect thermal resistance of HNLS composite decreases sharply at 400°C to 500°C irradiation temperature while that of Tyranno composites picks up. At irradiation temperature of beyond 500°C, defect thermal resistance of both composite decreases but in case of Tyranno composite decrement is steep. Self interstitial atoms generated due to high irradiation dose and high working temperature is the major defect producing cause which affects more in case of thermal properties which in turn causes the problems like generation of residual stresses volumetric swelling, crack propagation and other changes in mechanical properties. So it can be concluded that various defects causing degradation in thermal conductivity has different aspect of contribution for Nicalon and for Tyranno composite and this is due to difference in impurities. This observation indicates that the materials with the greater as-fabricated thermal resistivity develop the greater radiation defect thermal resistivity for a given irradiation condition.

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