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Radiation-induced structural changes in highly irradiated N3-1 SiC/SiC_f composite

M. Bastürk[a,*], Y. Dai[b], H. Rauch[a], M. Trinker[a]

[a] *Atomic Institute of the Austrian Universities, Stadionallee 2 A-1020, Vienna, Austria*
[b] *Paul Scherrer Institute, 5232 Villigen, Switzerland*

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Abstract

Fiber-reinforced silicon carbide ceramic composites (SiC/SiC_f) have been employed in studies of the first wall and structural material in fusion reactors due to the required high thermal efficiency. Porosity and void swelling in the fiber reinforced materials, due to the high flux of radiation, are the main problems considered. Void swelling of SiC/SiC_f composites under high radiation cause a reduction of the thermal conductivity and a limitation of the producible thickness. In order to investigate the radiation-induced changes like swelling in the fiber reinforced SiC/SiC composite, a small N3-1 SiC/SiC_f composite was irradiated under high neutron and proton radiation in the target of the SINQ spallation source. Neutron measurements of the highly irradiated N3-1 SiC/SiC_f and of non-irradiated reference samples were performed at the neutron radiography NEUTRA and small angle neutron scattering SANS facilities at PSI. The results contribute to a better understanding of pore formation and showed the porosity swelling under high neutron and proton radiation. A contrast enhancement at the edges was achieved by means of phase contrast neutron radiography and structural changes like void swelling were observed within the irradiated sample in comparison to reference samples.

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Keywords: Fusion; Phase contrast neutron radiography; SANS; SiC/SiC_f; Void swelling

1. Introduction

In our previous article, we have compared the results from different neutron imaging methods in order to determine the most efficient way for the inspection of fiber-reinforced materials [1]. In this study as a continuation of our previous study, we have focused on the investigations of radiation-induced structural changes in the highly irradiated fiber-reinforced silicon carbide composite (CERASEP® SiC/SiC_f). The SiC/SiC_f composite developed by SNECMA Propulsion Solide has been studied as a structural and an alternative first wall material for the ITER fusion reactor. Despite the increased shielding requirements (low attenuation cross section of SiC), the use of SiC/SiC is economically justified due to the high thermal efficiency, which may reduce the cost of electricity by 15%. Nicalon SiC/SiC_f consists of SiC fibers with a diameter of 14 μm, which are inserted in a SiC matrix with a carbon interface. The maximum allowable porosity for SiC/SiC fiber composites is 10% (2% porosity within the individual fibers and 8% within the fiber bundles). Its composition by weight is 56.6% Si, 11.7% O, and 31.7% C thereof 5% free carbon [2,3]. In spite of the Chemical Vapor Infiltration (CVI) method for producing low porosity materials, the porosity remains a problem in ceramic composites [1].

Under high temperature and radiation, atoms are displaced from their initial lattice positions by collisions initiated by a neutron or proton of specified energy (dpa—displacement per atom). Nuclear reactions in the target result in the transmutation of one element into a different isotope or a different element. Transmutation reactions

*Corresponding author. Tel.: +43 1 58801 14169; fax: +43 1 58801 14199.
E-mail address: bastuerk@ati.ac.at (M. Bastürk).

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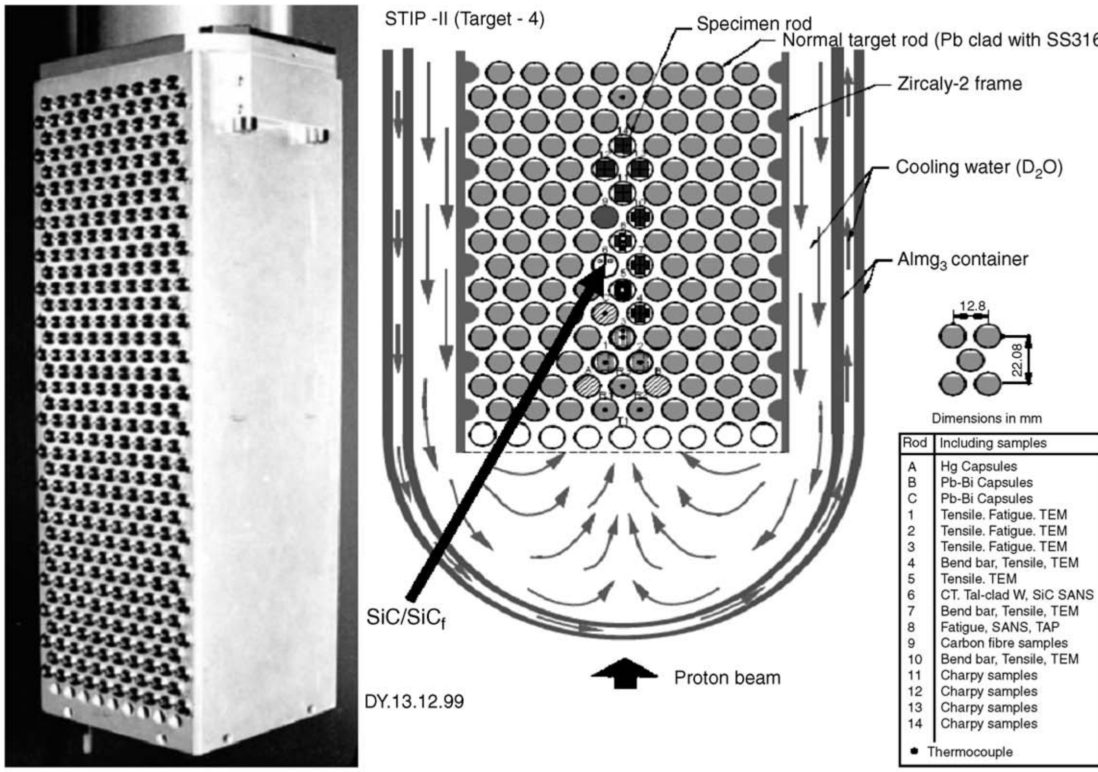
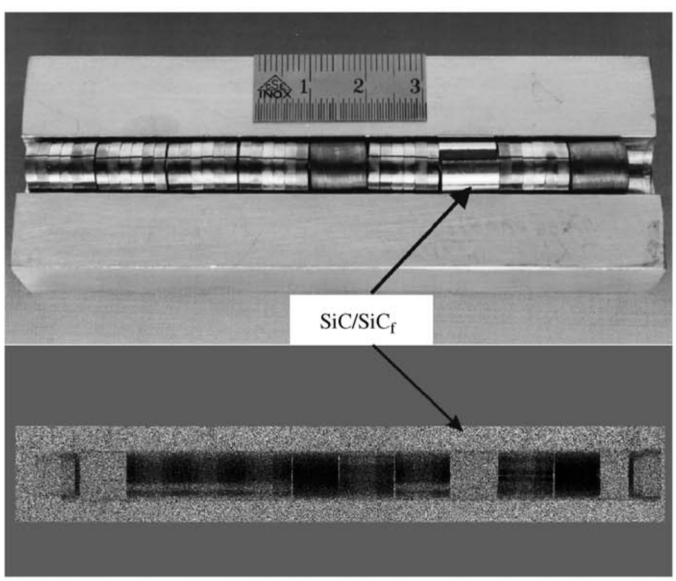


(a)



(b)

Fig. 1. (a) A photo of the Target-4 (left) and a sketch of the sample-rods positions in the lower part of the Target-4 (middle) [4], and (b) photo and neutron radiography image showing the location of the N3-1 SiC/SiC_f composite in the Rod 6: the N3-1 SiC/SiC_f composite is situated 2.5 cm away from the center of the 17 cm long Rod 6.

yield the formation of impurities (e.g. H, He atoms). The trapping of helium atoms by vacancies causes an enhanced growth rate of dislocation loops and, finally, a swelling increase. In order to investigate radiation-induced defects and structural changes like swelling, a 2 mm thick N3-1 SiC/SiC_f composite specimen was irradiated to fluencies of $8.2 \times 10^{25}\,m^{-2}$ (neutrons) and $2.5 \times 10^{25}\,m^{-2}$ (protons) in the SINQ target for 16 months in 2000 and 2001. The total proton charge in this irradiation period was 10.03 A h [4], and the irradiation temperature was measured in a number of places in the target but not in Rod 6, where the SiC/SiC_f composite was located as indicated with arrows in Fig. 1. The temperature of the SiC/SiC_f sample has been calculated to be around 200 °C.

Although, the N3-1 composite is classified as low-activity material, the gamma spectroscopy showed a total