ROOM TEMPERATURE AND HIGH TEMPERATURE MICROMECHANICAL TESTING OF SIC-SIC FIBER COMPOSITES FOR NUCLEAR FUEL CLADDING APPLICATIONS

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Silicon carbide ceramics are a candidate material for the use in nuclear power generation and are suggested to be used in novel accident tolerant fuel (ATF) cladding designs due to its favorable properties, in particular reduced (compared to Zircaloy) oxidation under accident conditions, good neutronic performance, high temperature strength and stability under irradiation. Due to its inherent brittleness, it is suggested to be used in the form of SiC-fiber reinforced SiC-matrix composite. In order to reliably model behavior of highly non-uniform and anisotropic composite materials the knowledge of the individual properties of fiber and matrix, and, crucially, the fiber-matrix interfaces, is required. In addition, nuclear fuel cladding materials are exposed to elevated temperatures during their operation, and therefore the understanding of the temperature dependences of the relevant properties is essential. Micromechanical testing techniques, such as nanoindentation and microcantilever beam fracture, allow determination of such localized properties, and can be implemented in the wide range of temperatures.

In this contribution we present the results of the nanoindentation hardness measurements and microcantilever fracture tests performed on SiC-SiC fiber composite grown by chemical vapor infiltration (CVI) method (General Atomic, US), with tests performed both at room and at different elevated temperatures (up to 600ºC) in vacuum. In the measurements performed at room temperature it was found that there is a significant difference in the values of hardness between the matrix and the fiber materials, with fiber being significantly softer and radially non-uniform in hardness (~17 GPa in the center, ~40 GPa at the periphery, comparable to the matrix). Matrix hardness is seen to drop from ~45GPa at room temperature to ~35GPa at 500ºC. This can be correlated with the results of elemental mapping using energy-dispersive X-ray spectroscopy (EDX), which indicate that within the fiber material the grain boundaries are decorated with excess carbon, abundant in the center and almost absent on the periphery of the fibers.

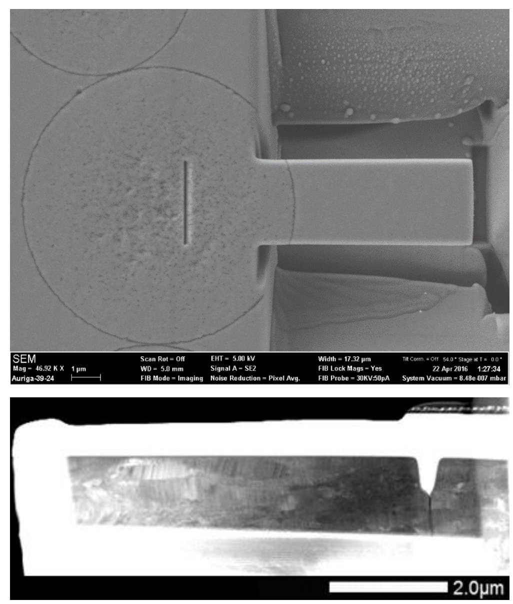

Figure 1 – Examples of pre- and post-testing microcantilevers.

Using focused ion beam (FIB) milling, microcantilevers were manufactured at the interphases, within individual fibers and in the bulk matrix. The local microstructure has been investigated using transmission electron microscopy (TEM), using FIB-machined lift-out samples, so that the local preferred direction of the grain growth could have been directly observed and cantilevers in the matrix could have been oriented differently with regard to it. It was found that interphases are weak spots (fracture stress ~2.5 GPa), matrix is the strongest (~20 GPa) and fiber intermediate (~7.5 GPa). TEM was also used on fractured cantilevers in order to determine the character of crack propagation. It was found that within the matrix fracture is transgranular, and observed fracture stress is independent on the orientation of the cantilever axis relative to the direction of the elongated grains in the matrix, within the fiber it can be both trans- and intergranular, depending on the amount of excess carbon decorating the grain boundaries, and at the interfaces it follows the interlayer-fiber boundary.

Presented results suggest a methodology enabling to better understand and predict the properties of SiC fiber composite, in advanced fission and fusion designs, as well as in non-nuclear applications.