LOCALIZED MECHANICAL PROPERTIES OF SIC-SIC FIBER COMPOSITES IN EXTREME ENVIRONMENTS – A MICROMECHANICAL STUDY

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Silicon carbide ceramics is a promising candidate material for the use in applications where a structural material able to withstand extreme environments, in particular high temperature, is required. These include applications in aero-engines (high-pressure turbine shrouds, combustor liners and turbine nozzles, among others); in recent years there is also a considerable interest in its use in nuclear applications, in particular as an accident-tolerant fuel (ATF) cladding material. The practical use of SiC is hindered by its inherent brittleness, and therefore it is usually suggested to be used in the form of a fiber composite. Mechanical properties of the composites are largely determined by the properties of their constituents, in particular interphases but also matrix and fibers; of particular practical interest is the evolution of such properties as a function of temperature and/or radiation damage. These can be measured using micromechanical testing tools, such as nanoindentation (measuring hardness and elastic modulus) and microcantilever fracture (measuring fracture strength and toughness). In this contribution we present the results of such measurements performed in the range of temperatures, including samples that were exposed to ion irradiation. Thus, the effects of temperature and radiation are investigated and rationalized.

Material used in this study was manufactured using Tyranno-SA3 fibers in plain weave geometry, coated with pyrolytic carbon, and matrix grown by chemical vapor infiltration (CVI) method. Microstructure was investigated using transmission electron microscopy (TEM), with texture information obtained with transmission Kikuchi diffraction (TKD). It was found that both matrix and fibers are nanocrystalline, with the preferred grain growth direction in the matrix being <111>, and no texture present in the fibers. Extensive twinning was found in both matrix and fiber materials.

Temperature effects were investigated using high-temperature nanoindentation performed in vacuum at the temperatures of up to 700ºC, and cantilever testing at the temperatures of up to 300ºC. Measured values of hardness had a clear trend of decease with the increase of temperature – from 45 to 20 GPa. In the same temperature range Young's modulus decreased from 450 to 300 GPa. On the other hand, fracture toughness of fibers and matrix doesn't change significantly, but that of the interphases dramatically drops from ~0.8 to ~0.15 MPa*$m^{1/2}$. At the same time, the character of fracture changes in the interphase as well – unlike fiber and matrix at the elevated temperature, it features essentially ductile behavior.

Radiation damage was introduced via Si ion irradiation, at the temperatures of 300 and 750°C, up to the damage level of 2.6 dpa. Ion irradiation didn't lead to noticeable hardening neither of matrix, nor of fiber material. This is in contrast to the behavior of simultaneously irradiated single-crystal SiC, which showed a noticeable increase in hardness. Young's modulus at the same time decreased slightly. Fracture toughness increased in all the constituents (interphase, matrix and fiber) following irradiation, with the trend towards progressive increase with the increase of irradiation dose. More significant changes of properties in the composite compared to single crystal material was explained by the nanocrystalline nature of the composite constituents, providing high density of sinks for radiation-induced defects. On the other hand, increase of toughness is attributed to the radiation-induced near-surface stresses.

These findings are discussed in relation to their impact on the further development of SiC-SiC composites for extreme environments applications, together with the perspectives of further development of implemented methodology for such studies.