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Deformation Mechanisms and Residual Stress Distributions in B_4C-TiB_2 Directionally Solidified Eutectics

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Directionally solidified eutectic (DSE) ceramic composites are investigated for potential improvement of mechanical properties over the monolithic end members. In this research, boron carbide (B_4C) - titanium diboride (TiB_2) eutectic composites are being researched for use in armor and tribological applications due to their high hardness. The microstructure of B_4C-TiB_2 eutectics consists of a B_4C matrix with TiB_2 forming a lamellar second phase, as shown in figure 1a. As the solidification rate of the materials is increased, the interlamellar spacing decreases and the Vickers indentation hardness is found to increase to ~32GPa, though traditional Hall-Petch behavior is not observed.[1] In this research quantitative 3-D microstructural analysis is conducted by focused ion beam (FIB) serial sectioning and SEM analysis, and indentation-induced deformation mechanisms are studied by transmission electron microscopy (TEM) analysis.

TEM of B_4C-TiB_2 is performed on indented material prepared via site-specific FIB liftout to directly investigate the deformation mechanisms. Fracture events are found to occur throughout the B_4C matrix, often at the ends of TiB_2 lamellae. Additionally, while as-processed eutectics display a nearly continuous single-crystal B_4C matrix, the indented material shows a transition to polycrystalline material, as indicated in figure 1a (pristine) and 1b (deformed). Indentation and scratch studies of B_4C have shown similar behavior, specifically a transition from single crystal to a combination of nanocrystalline and amorphous boron carbide.[2] Preliminary studies of the B_4C-TiB_2 eutectic indicate that materials with smaller interlamellar spacing (and hence higher interface density) tend to suppress the structural transformation in B_4C. Amorphous B_4C exhibits a π^* shoulder on the C-K energy loss peak,[2] so electron energy loss spectroscopy (EELS) is utilized to identify the spatial distribution of amorphization in deformed eutectic materials.

To understand the observed microcracking in the deformed materials, it is important to model the residual stress distributions in the composite that arise from differences in thermal expansion coefficients in the two phases. These thermal residual stresses can be very large in ceramic eutectics, on the order of a GPa in some cases [3] For the current study, 3D models of the B_4C-TiB_2 eutectic microstructure (figure 2a) were reconstructed from FIB serial sectioning data (utilizing MATLAB and COMSOL software) to serve as the basis for finite element modeling of the thermal residual stress distribution throughout the microstructure (figure 2b). The finite element models show that tensile stresses are present in the B_4C matrix between TiB_2 lamellae; these results directly correlate with the fracture behavior observed by TEM (figure 2c).

References

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[2] D. Ge, et al., Acta Materialia, **52** (2004)
[3] E.C. Dickey, et al., Journal of the European Ceramic Society, **19** (1999)

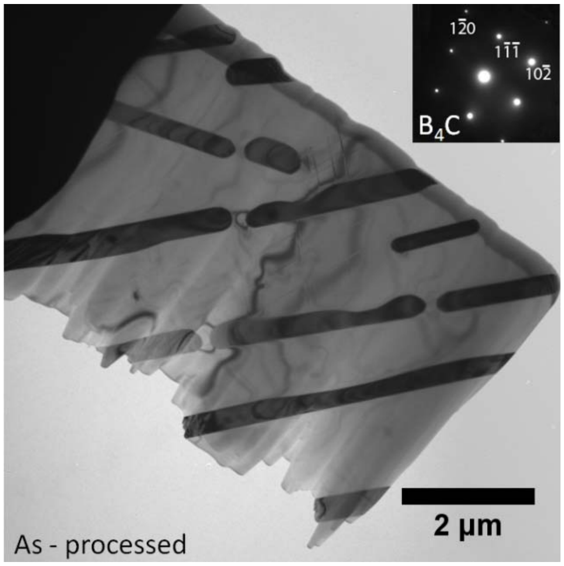

Fig. 1a – Undeformed B_4C-TiB_2 eutectic prepared by FIB-liftout. Note single-crystal diffraction pattern. TiB_2 is the dark phase.

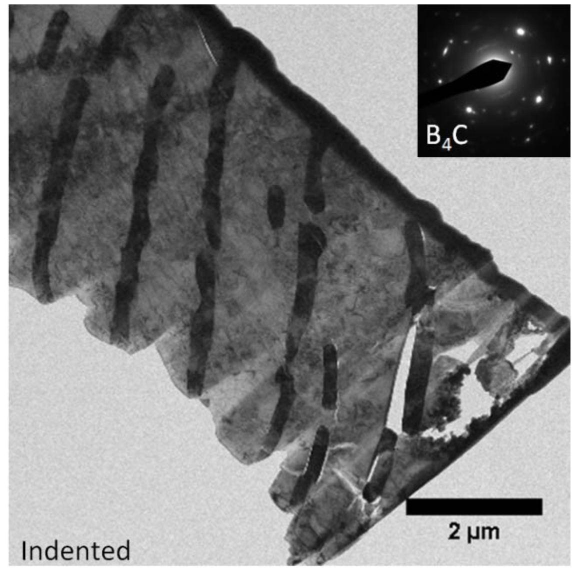

Fig. 1b – Deformed B_4C-TiB_2 eutectic FIB-extracted from Vickers indentation. Diffraction pattern indicates transition from single to polycrystal.

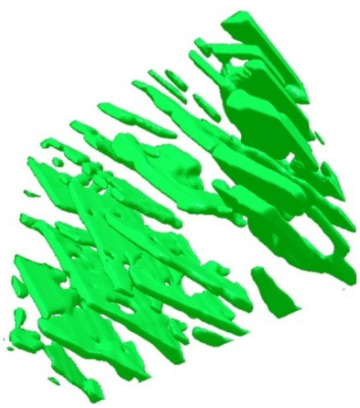

Fig. 2a – 3D reconstruction of TiB_2 lamellae from FIB serial sectioning.

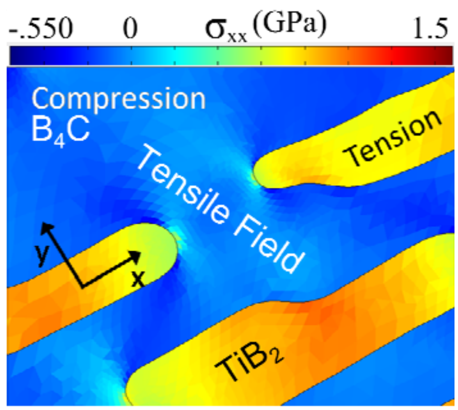

Fig. 2b – 2D finite element simulation of residual stress fields in the B_4C-TiB_2 eutectic.

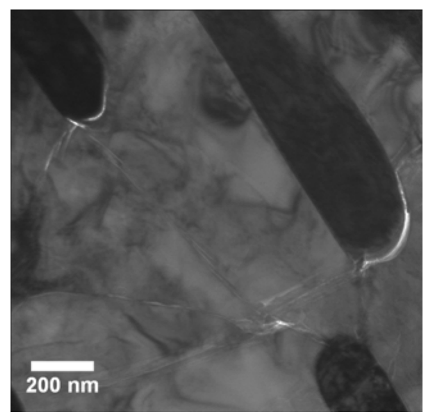

Fig. 2c – TEM image of deformed eutectic, showing cracking at lamellae tips, corresponding to residual tensile-stress regions.

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