Core-shell structural units show outstanding toughening effect for ceramics

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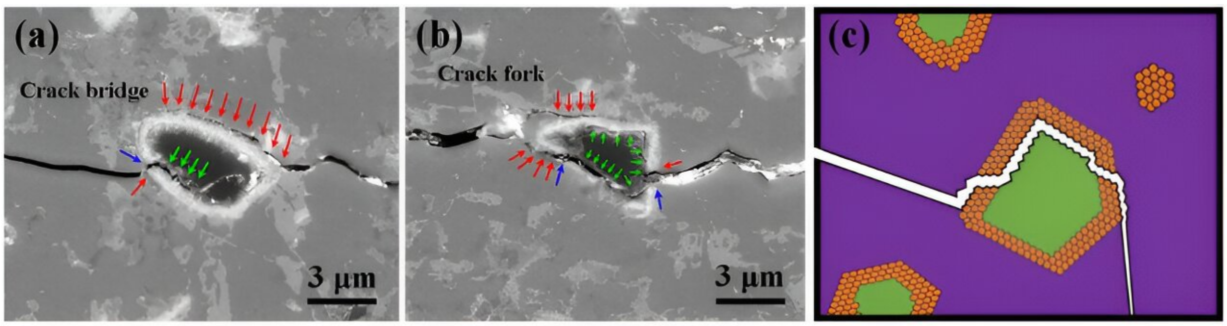

(a, b) BSE images of polished surface with cracks of Al_2O_3-B_4C@TiB_2 composite ceramics. (c) Schematic diagram for crack propagation. Credit: Journal of Advanced Ceramics, Tsinghua University Press

Toughening has always been an important research direction of structure ceramics. The addition of secondary phases to the ceramic matrix to prepare composite ceramics is an effective toughening pathway in the field of structure ceramics.

Both phase-type and microstructure of the secondary phases play a decisive role in the toughening effect of the ceramic matrix. Being different from the conventional independent phase as the secondary phase, B_4C@TiB_2 core–shell structural unit has been purposely designed as an innovative kind of secondary phase to toughen the Al_2O_3 ceramic matrix, providing a new concept for the toughening studies of structural ceramics.

A team of material scientists led by Zhixiao Zhang from the Hebei University of Engineering in Handan, China recently successfully prepared a kind of Al_2O_3 composite ceramics toughened by B_4C@TiB_2 core–shell structural units consisting of the B_4C core enclosed by the TiB_2 shell.

The core–shell structural units serving as the composite toughening phase of Al_2O_3 ceramics can break through the current toughening bottleneck of Al_2O_3 composite ceramics toughened using independent phases, and realize the further improvement for the fracture toughness of Al_2O_3 ceramics.

The team published their work in *Journal of Advanced Ceramics*.

"In this work, we prepared Al_2O_3 composite ceramics toughened by B_4C@TiB_2 core–shell structural units through a combination of molten salt methodology and spark plasma sintering. Unlike conventional setups where TiB_2 and SiC remain isolated and independently dispersed in Al_2O_3 ceramic matrix, the two secondary phases in this Al_2O_3 composites constitute core–shell composite structures which can induce multi-dimensional synergistic toughening behavior."

"The toughening effect produced by core-shell structural units is impossible to achieve by independent phases," said Dr. Zhixiao Zhang, the corresponding author of the paper, a professor in the College of Materials Science and Engineering at Hebei University of Engineering. Professor Zhang is also the Top Talent in Hebei Province of China and vice Dean of the College of Materials Science and Engineering at Hebei University of Engineering.

The B_4C@TiB_2 core–shell toughening units consist of a micron-sized

B_4C core enclosed by a shell approximately 500 nm thick, composed of numerous nanosized TiB_2 grains. The regions surrounding these core–shell units exhibit distinct geometric structures and encompass multidimensional variations in the phase composition, grain dimensions, and thermal expansion coefficients.

Consequently, intricate stress distributions emerge, thereby fostering the propagation of cracks in multiple dimensions. This behavior consumes a considerable amount of crack propagation energy, thereby enhancing the fracture toughness of the Al_2O_3 ceramic matrix. The resulting Al_2O_3 composite ceramics yield an improved fracture toughness up to 6.92 $MPa{\cdot}m^{1/2}$.

"This novel concept and the corresponding toughening mechanism of utilizing core–shell structural unit as a secondary phase to enhance ceramic matrix toughness can provide a new perspective and theoretical foundation for the toughening research of other structural ceramics." Zhixiao Zhang said.

The next step is to expand the shape and phase composition of core–shell structural units, including core–shell structural particles, whiskers, fibers, tubes, or plates, which consist of various phase types. Also, these core–shell structural units can be further extended to toughen a variety of structure ceramics, such as B_4C, TiB_2, SiC, etc.

Meanwhile, a systematical study on the toughening mechanism of core-shell structural units as composite toughening phases will be performed. The ultimate goal is to develop a new toughening theoretical system based on core–shell units toughening ceramic matrix.

More information: Yingjie Shi et al, Preparation and toughening mechanism of Al_2O_3 composite ceramics toughened by $B_4C@TiB_2$ core–shell units, *Journal of Advanced Ceramics* (2023). DOI: 10.26599/JAC.2023.9220826

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