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Ultra-High Temperature Mechanical and Thermal Properties of ZrB_2 Ceramics

Abstact

Zirconium diboride and other carbides, nitrides, and borides of early transition metals belong to a family of materials known as ultra-high temperature ceramics. Because of melting points in excess of 3000°C, these ceramics have been proposed for use in the extreme environments associated with hypersonic flight, atmospheric re-entry, rocket engines, and scramjet propulsion. Research at Missouri S&T has examined processing, densification, properties, and oxidation of these materials with recent research focused on characterizing thermal and mechanical behavior at temperatures up to at least 2000°C. For example, thermal conductivity of ZrB_2 ceramics has been characterized up to 2000°C. At room temperature, reported values of thermal conductivity range from as low as about 30 W/m•K up to as high as 130 W/m•K with no explanation for the differences. Our research has focused on the effect that impurities and processing additives have on thermal properties. Transition metals such as W and Cr reduce thermal conductivity due to decreases in electrical conductivity. In contrast, eliminating trace impurities such as Hf can increase thermal conductivity by increasing both the phonon and electron contributions to thermal transport. Reaction processing of high purity precursors has been utilized to produce ceramics with room temperature thermal conductivities in excess of 130 W/m•K. Mechanical properties of ZrB_2-based ceramics have been measured at temperatures in excess of 2000°C. Nominally pure ZrB_2 that had a room temperature strength of ~400 MPa maintained a strength of at least ~220 MPa up to 2300°C. The strength of ZrB_2-SiC was measured up to 2200°C. In air, elevated temperature strength was limited by oxidation damage to the ceramics. In inert environments, a strength of 130 MPa was maintained at 2200°C. Below 1800°C, strength was limited by the size of SiC clusters while above 1800°C strength was controlled by changes to the microstructure including growth of second phases and formation of liquids.

Biosketch

William G. (Bill) Fahrenholtz is a Curators' Distinguished Professor of Ceramic Engineering in the Department of Materials Science and Engineering at the Missouri University of Science and Technology and the Editor-in-Chief of the Journal of the American Ceramic Society. He earned B.S. and M.S. degrees in Ceramic Engineering at the University of Illinois at Urbana-Champaign in 1987 and 1989, respectively. He completed his Ph.D. in Chemical Engineering at the University of New Mexico (UNM) in 1992. He was elected a Fellow of the American Ceramic Society in 2007 and was named Editor-in-Chief of the Journal of the American Ceramic Society in January 2017. Bill teaches courses on ceramic processing, x-ray diffraction, and thermodynamics. His current research focuses on the processing, characterization, and mechanical testing of advanced structural ceramics for use in environments with extreme thermal loads, mechanical forces, and/or chemical reactivities. He has published over 135 papers in peer-reviewed journals and given over 80 invited presentations on his research.