

Deformation-resistant carbides and borides with superior hardness, toughness, and flexural strength up to 2000°C

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There is a growing need to develop new UHTCs that are multipurpose, deformation-resistant, and able to act as special protection for engines and vehicles. These ceramics are also required for segmented leading-edge components in aerospace, plasma-facing, and ceramic parts for solar towers used in gas turbine operations in combined cycle power plants (such as grids, superheaters, reheaters, evaporators, steam turbines, condensers, and chimneys). This has led to a worldwide demand for a new class of ceramic composites that exhibit incredible strength and a sufficient balance between high toughness, hardness, and high modulus.

I will discuss the resistance to ultrahigh-temperature deformation of boron, boron carbide, $Ta_{0.2}Hf_{0.8}C$, Zr-Ta multi-boride, tantalum monoboride, and tantalum diboride. The idea behind the concept of deformation-resistant ceramics (DRC) is that a novel or solid solution phase is formed that is more difficult to densify or deform during densification. As a result, creating such phases is advisable only at elevated temperatures during the densification process. In our experience, once the DRC phase is formed, it should require a temperature higher or equal to that of densification temperature to activate mass transport, thus yielding activation of plasticity at and above 2000°C.

The mechanical behavior of a bulk boron ceramic prepared by SPS of commercially- available β -boron powder will be discussed. This was the first study to show the HT flexural strength, toughness, and Young's moduli of boron up to 1400 °C. The flexural strength and fracture toughness at room temperature reached an average of 340 MPa and 4.1 MPa $m^{1/2}$, respectively. Despite showing clear signs of plastic deformation on the strain-stress curves, the yield strength of the monolithic boron ceramic exceeds 1 GPa at 1200 °C. It was determined that fracture at elevated temperatures follows a quasi-transgranular mechanism, where the sub-grains of the boron fracture as plate-like structures.

The mechanism of ultra-high temperature flexure & strain-driven amorphization in polycrystalline B_4C has been analyzed. With RT to 1800 °C mean strength of 650 MPa, boron carbide exhibits ultrahigh flexural strength far exceeding 1000 MPa, accompanied by a change in the deformation mechanism from brittle fracture to plastic at 2000 °C. The amorphization occurs inside the severely deformed grains. The results at 2000 °C suggest that the magnitude of the tensile stresses imposed on the B_4C grains during deformation in flexure and the total strain transferred to a ceramic during the deformation process play the dominant role in the crystalline-amorphous transformation. Depending on the loading rate, B_4C ceramic showed 1000 - 8400 MPa strength with a plastic stress-strain curve. Even deformation in an elastic manner at 25 mm/min resulted in a strength of 675 MPa, confirming its deformation resistivity.

Zr-Ta multiboride ceramic was formed with an artificially created hierarchical superstructure via reaction-driven consolidation of ZrB_2 , Ta, and amorphous B powders. Formation of a highly reproducible repetitive superstructure where Ta_3B_4 forms a chain-like mesh that entraps the ZrB_2 , ZrB, TaB, and (Zr, Ta) B_2 phases. Due to the formation of the (Zr, Ta) B_2 solid solution multiboride ceramic composite exhibited ultra-hardness of 28.6 ± 3.2 GPa at 98 N and 22.6 ± 0.6 GPa at 196 N, and the flexural strength 400 MPa up to 2000 °C. Deformation-resistant $Ta_{0.2}Hf_{0.8}C$ solid-solution ceramic with superior flexural strength at 2000°C showed toughness and a strength of 3.4 ± 0.4 MPa $m^{1/2}$, 500 ± 20 MPa.

TaB showed an unusually high indentation fracture toughness of 9.8 ± 0.4 MPa $m^{1/2}$, while 4.5 MPa $m^{1/2}$ was reported for TaB₂. The bending tests show that on and after 1800 °C, TaB had loading curves that exhibited nonlinear characteristics associated with flaw healing or plasticity (micro-plasticity) contribution and a tendency for the gradual increase in strength with an increase in temperature.