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 multipurpose UHTCs, able to act as special protection for vehicle engines, 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 (grids, superheaters, reheaters, evaporators, steam turbines, condensers, and chimneys). This need has led to a worldwide demand for a new ceramic composite class that exhibits 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. 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. 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 [1]. 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 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 [2].

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 [3]. 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 [4].

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 TaB_2. 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 [5].

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