Strength, deformation, and equation of state of tungsten carbide to 66 GPa

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Hard ceramics like tungsten carbide are important for their remarkable physical properties under both ambient and extreme conditions such as wear-resistance, ultra-incompressibility, and high yield stress. Although WC is widely used in industry as a strong component or protective coating, the elasticity above 16 GPa has only been studied theoretically, and quasi-static strength has not been studied at high pressure. To understand the elastic and plastic deformation behavior of WC at extreme pressure conditions, experiments were conducted up to 66 GPa in the diamond anvil cell. Synchrotron X-ray diffraction (XRD) was performed at the Advanced Photon Source beamline 16-BM-D in both axial and radial geometries. Observed unit cell volumes of WC compressed in a Ne pressure medium fit to a 3^{rd} order Birch-Murnaghan EOS yield $V_0 = 20.803 \pm 0.0436$ Å^3, $K_0 = 385.45 \pm 29.7$ GPa, and $K_0' = 3.2952 \pm 1.01$, indicating a higher stiffness than that determined by ultrasonic measurements at low pressure, but softer than XRD measurements obtained in non-hydrostatic pressure media and measurements of nano-crystalline WC. Analysis of both lattice strain and texture development was performed using full-profile Rietveld refinement of radial diffraction patterns obtained with no pressure medium. Texture was fit using E-WIMV model with imposed fiber symmetry. Strength and plasticity were determined with complementary lattice strain and texture analysis of radial patterns, and Elasto-ViscoPlastic Self-Consistent (EVPSC) simulations of experimental lattice strain and texture evolution. Plastic deformation/development of preferred crystallite orientation is observed to begin at ~30 GPa. The differential stress (difference between maximum and minimum stresses) sustained by WC at yielding is ~13 GPa. Differential stress increases to a maximum of 23-28 GPa at a pressure of 66 GPa, depending on whether the shear modulus was extrapolated from lower-pressure ultrasonic experiments or obtained from theoretical predictions, respectively. Above yielding, the measured non-hydrostatic elastic strain is similar to other hard materials TiB_2 and B_6O. Texture evolution is characterized by the development of a maximum near 2-1-10 in inverse pole figures of the compression direction. Plastic deformation above 30 GPa and is primarily accommodated by prismatic slip on {10-10}<-12-10> and {10-10}<0001>, with a third pyramidal slip system {10-11}<-2113> becoming activated at ~40 GPa, neither of which mechanism is similar to basal slip in metallic W.