Solving the strength-toughness dilemma in superhard ceramics with a chemically tuned solid solution approach

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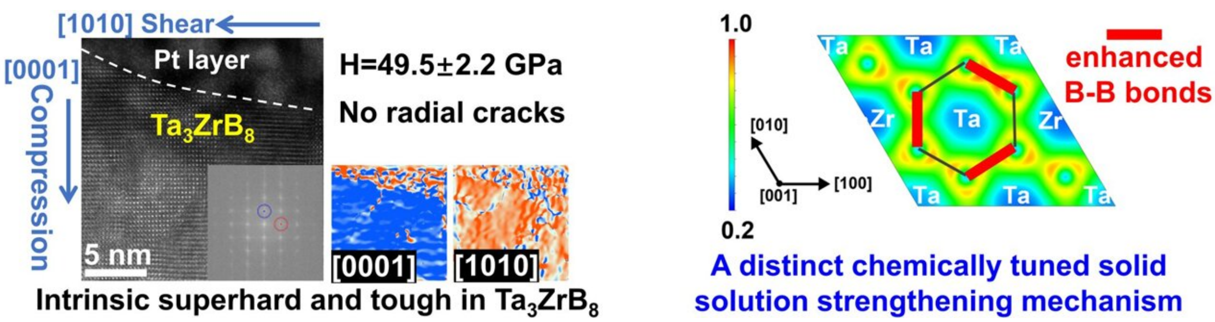

The strengthening-toughening of Ta_3ZrB_8 solid solution based on superhard TaB_2. Credit: *Research* (2023). DOI: 10.34133/research.0035

Materials with superior mechanical strengths are crucial to many areas of modern industries and the scientific enterprise by providing cutting and drilling tools, structural components, protective coatings, and abrasives that find wide applications. Solid solution strengthening is a well-established method to enhance hardness of metals by introducing solute atoms to create local distortions in the crystal lattice, which impedes dislocation motion and plastic deformation, leading to increased strength but reduced ductility and toughness.

In sharp contrast, superhard materials with Vickers hardness HV > 40

GPa exhibit high strength but low toughness via a distinct mechanism dictated by brittle bond deformation, showcasing another prominent scenario of classic strength-toughness tradeoff dilemma. Solving this less-explored and poorly understood problem presents a formidable challenge that requires a viable strategy of tuning main load-bearing bonds in these strong but brittle materials to achieve concurrent enhancement of the peak stress and related strain range.

By leveraging a combination of experimental and theoretical methods, professor Kan Zhang's team from Jilin University demonstrated a chemically tuned solid solution approach that achieves simultaneously enhanced hardness and toughness in ternary $Ta_{1-x}Zr_xB_2$ based on the superhard transition-metal diboride TaB_2. This striking phenomenon is achieved by introducing solute atom Zr that has lower electronegativity than solvent atom Ta to reduce the charge depletion on the main load-bearing B-B bonds during indentation, leading to prolonged deformation that gives rise to notably higher strain range and the corresponding peak stress.

"This finding highlights the crucial role of properly matched contrasting relative electronegativity of solute and solvent atoms in creating concurrent strengthening and toughening, and opens a promising avenue for rational design of enhanced mechanical properties in a large class of transition-metal borides," Zhang said. "This strategy of concurrent strength-toughness optimization via solute-atom induced chemical tuning of the main load-bearing bonding charge is expected to work in broader classes of materials, such as nitrides and carbides."

The research is published in the journal *Research*.

More information: Xinlei Gu et al, Solving Strength–Toughness Dilemma in Superhard Transition-Metal Diborides via a Distinct Chemically Tuned Solid Solution Approach, *Research* (2023). DOI:

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