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Controlling Fracture in Complex Engineered Materials

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In the design of high-performance materials, there is often a trade-off in the strength of a material and its ability to resist crack growth. High strengths at high temperatures, desirable for many energy-efficient applications of advanced materials, can be achieved with various materials systems but such systems are not sufficiently tough (a measure of crack growth resistance) to be used. In addition to the chemistry of the material, however, materials scientists can control the material structure at the scale of the grains of material packed together to form a polycrystal. A major design question is that of how to arrange the grains in a microstructure to increase the resistance of the material to crack growth, and how much resistance can be achieved through this strategy.

Work at Brown is addressing one fundamental feature of the broader problem: how does a crack grow across a boundary between two grains of material as a function of the misorientation of the underlying crystal structures of the two grains. The research studies Zn bicrystals with controlled grain boundary misorientation as model material because Zn has a very strongly preferred plane of crack growth similar to that found in technologically-important alloys like Titanium-Aluminides. Crack growth experiments are performed in-situ in a Scanning Electron Microscope to observe the growth of a crack as it approaches and crosses the boundary. Our experimental results show that when the preferred fracture plane experiences a twist misorientation across the grain boundary, there is significant resistance to further crack growth, with important energy-dissipating mechanisms of multiple cracking, bridging ligaments, slip and twinning all contributing to increase the resistance to fracture (Figure 1). Complementary computational models of the process, using advanced mechanics models for the material deformation and fracture, capture the behavior observed experimentally, including multiple internal cracking events at the grain boundary (Figure 2).

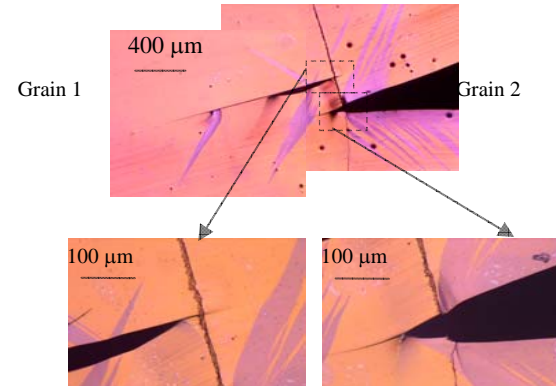


Figure 1: Crack interaction with a twist-misoriented grain boundary in a Zn bicrystal accompanied by multiple cracking, slip and twinning.

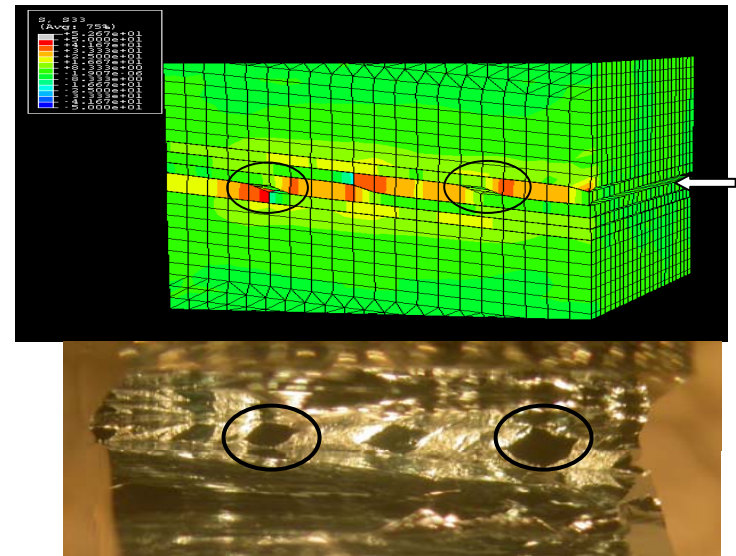


Figure 2: Internal “diamond-shaped” micro-cracks (circled) looking down inside a crack that has been arrested at the grain boundary, as found computationally and observed in the experiments.