Microstructure matters: why smaller is often (but not always) stronger

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Abstract

Size effects in plasticity have received much attention in recent years, due to increased resolution in experimental capabilities, and the development of materials at small geometric and microstructural length scales. In particular, the hardness of many materials have been shown to decrease with increasing depth of indentation, the so-called indentation size effect (ISE). In order to circumvent the coupled effects of extrinsic strain gradients, as are encountered in nanoindentation, microcompression testing has become a widely used method to understand the effect of geometric length scale on deformation behavior. In these experiments, a columnar structure is fabricated, typically using Focused Ion Beam (FIB) machining from a thin film or bulk specimen, with diameters on the order of tens of microns down to 100 nanometers. The columns are then compressed using a nanoindenter outfitted with a flat punch indenter. As in the indentation experiments, results for many materials show a general trend of increasing strength with decreasing deformation volume. However, the result is not ubiquitous. It is demonstrated here that the critical parameter which dictates the presence of a size effect is not the sample size or deformation volume alone, but rather the relative deformation length-scale relative to the representative microstructural length-scale. This observation holds for both microcompression and conventional nanoindentation experiments, and can be used to model size effects in terms of classical laws. The talk will focus on single crystalline, high purity Mg and the Mg alloy AZ31 of two orientations associated with dislocation plasticity (i.e., no twinning), where the active slip systems for the two orientations have significantly different Peierls barriers. In this way, the influence of intrinsic lattice strength and alloying content can be differentiated. Additional results from other “microstructurally rich” materials will also be drawn upon to support a picture of size effects in plasticity as dependent on the interplay between microstructural and geometric length-scales.