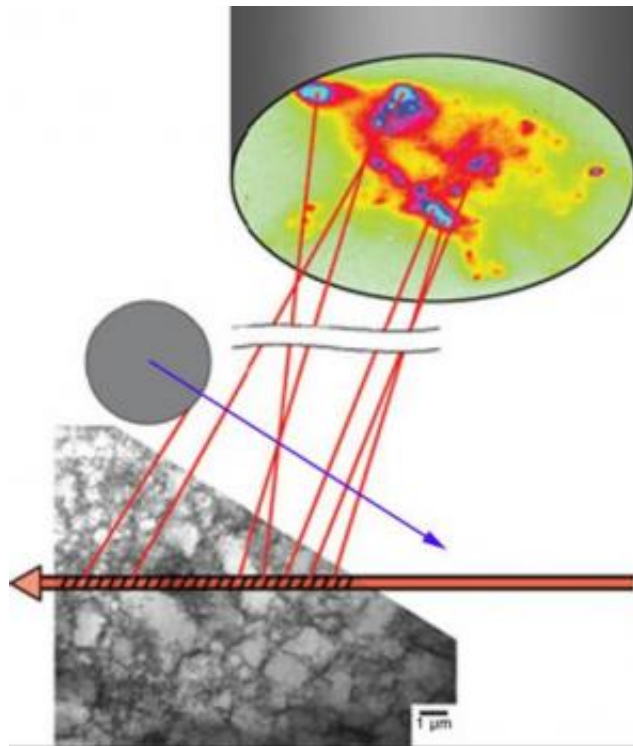


New X-Ray microbeam answers 20-year-old metals question

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Novel 3-D microbeam experiment enables direct proof of the Mughrabi model of metal stress. Submicron X-ray beam (broad arrow) penetrates a deformed copper single crystal and is diffracted onto a CCD detector. Platinum wire profiler (circle) traverses the sample and successively intercepts diffracted X-rays, providing depth measurement and allowing strains to be measured from individual dislocation cells. Credit: NIST

What happens to metals when you bend them? The question isn't as easy

as you may think. A research team from the National Institute of Standards and Technology, Oak Ridge National Laboratory, and the University of Southern California, using a unique X-ray probe, has gathered the first direct evidence showing that, on average, a 20-year-old model is a useful predictor of stresses and strains in deformed metal.

But the measurements also show that averages can be deceiving. They mask extremely large variations in stresses that, until now, had gone on undetected. The experiments have implications for important practical problems in sheet metal forming and control of metal fatigue, which is responsible for many structural materials failures.

When metals deform, the neat crystal structure breaks into a complex three-dimensional web of crystal defects called "dislocation walls" that enclose cells of dislocation-free material. The effect is like micron-sized bubbles in foam. These complex dislocation structures are directly responsible for the mechanical properties of virtually all metals, and yet they remain very poorly understood in spite of decades of research. Twenty years ago, the German researcher Helmut Mughrabi theorized that the stresses in the dislocation walls and the cell interiors would be different and have opposite signs--an important result for modeling the effects of shaping and working metal on its properties. Until now there has only been indirect evidence for Mughrabi's model because of the problem of precisely measuring stress at the micron level in individual cells in the dislocation structure.

At that level, in fact, stresses can vary greatly. "Scientifically, these stress fluctuations are probably the single most significant finding of the work since no previous measurements even hinted at their existence," explains NIST physicist and lead author Lyle Levine. "A few researchers had speculated that such variations might exist but they had no clue about their size and distribution."

The NIST/ORNL/USC team used intense X-ray microbeams--100 times thinner than a human hair--generated at the Advanced Photon Source at Argonne National Laboratory to scan samples of single-crystal copper that had been deliberately stressed. The diffracted X-rays revealed the local crystal lattice spacing, a measure of stress, at each point. As this happens, a thin platinum wire is moved across the face of the crystal. By noting which diffracted rays are blocked by the wire at which point, the team calculated the depth of the region diffracting the beam. They determined cell positions in three dimensions to within half a micron.

The experiments on both compressed and tensioned copper crystals agreed with Mughrabi's model. "One big advantage to this method is that the results are completely definitive. We can make unambiguous, quantitative measurements from the submicron sample volumes most pertinent to metals deformation," Levine says.

The new technique opens a detailed window into the microstructure of stress in metals and provides quantitative data to support computer models of mechanical stress. The research was supported by NIST and the Department of Energy.

Citation: L.E. Levine, B.C. Larson, W. Yang, M.E. Kassner, J.Z. Tischler, M.A. Delos-Reyes, R.J. Fields, and W. Liu. X-ray microbeam measurements of individual dislocation cell elastic strains in deformed single-crystal copper. *Nature Materials*, 5, 619-622 (2006)

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