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Development of microscale mechanical testing methods for assessing radiation damage in cladding steels

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This paper describes efforts to develop microscale methods for mechanical testing of radiation damaged metals. The objective of this program is to simulate fast neutron damage in cladding steels using high energy, heavy ions. While these ion beams can create large levels of radiation damage, e.g. 100 displacements per atom, they do so over a limited depth from the surface of the sample, on the order of several microns.

Recent work by Hosemann et al. introduced the concept of applying the micropillar compression approach to irradiated metals to assess their mechanical properties. This paper examines the fundamental issues of accuracy and precision of the micropillar apporach by using copper single crystals with several levels of irradiation damage and many pillars per condition. The result is that we can accurately model and assess the changes in the mechanical behavior of the copper as a function of radiation damage.

Copper single crystals of <110> and <111> orientations were irradiated using 20MeV copper ions at nominally room temperature until a damage level of 50dpa and 100dpa had been achieved. Micropillars were fabricated from these samples using a 30keV gallium ion beam on a FEI dual-beam focused ion beam (FIB) machine. Mechanical testing was performed using a Hysitron nanoindentation machine with a diamond, flat punch of 25μm in diameter.

As shown in Figure 1, there are two distinct bands of stress strain curves; distinguishing the control samples (no irradiation) from the irradiated samples. Even, so there is no distinct difference in initial yield point between the two populations with many, visible displacement jumps discernable for both conditions. There is a marked increase in the work hardening rate for the irradiated material. The level of scatter in the data appears to be greater for the irradiated material.

The SEM micrographs in Figure 2 explain these observations and underscore the need for careful development of the micropillar approach prior to application to complex microstructures. In Figure 2A, slip bands are observed throughout the volume of the micropillar as would be expected. These distinct slip bands mostly likely correspond to the observed jumps in strain (displacement) in Figure 1. In Figure 2B, slip bands are only observed in the lower half of the micropillar. The upper half of the pillar has been hardened by irradiation until no slip is possible under the current loading conditions. The lower half, however, has several, discrete slip bands as observed in the control pillar.

We are currently performing micropillar compression tests on a series of pillars of different sizes to force the deformation into the irradiated zone nearer to the surface. We will discuss the optimization of this approach and its application on steels.

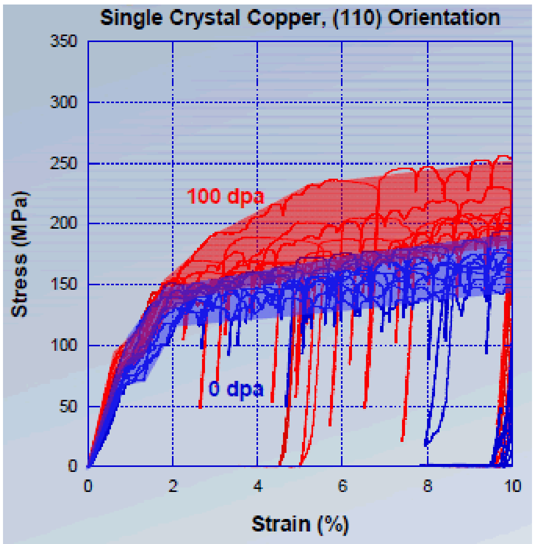

FIG1. Stress-strain curves measured by micropillar compression. The solid lines are from individual curves, while the solid shading shows the extent of the data for a given damage level, (red=100dpa, blue=0dpa).

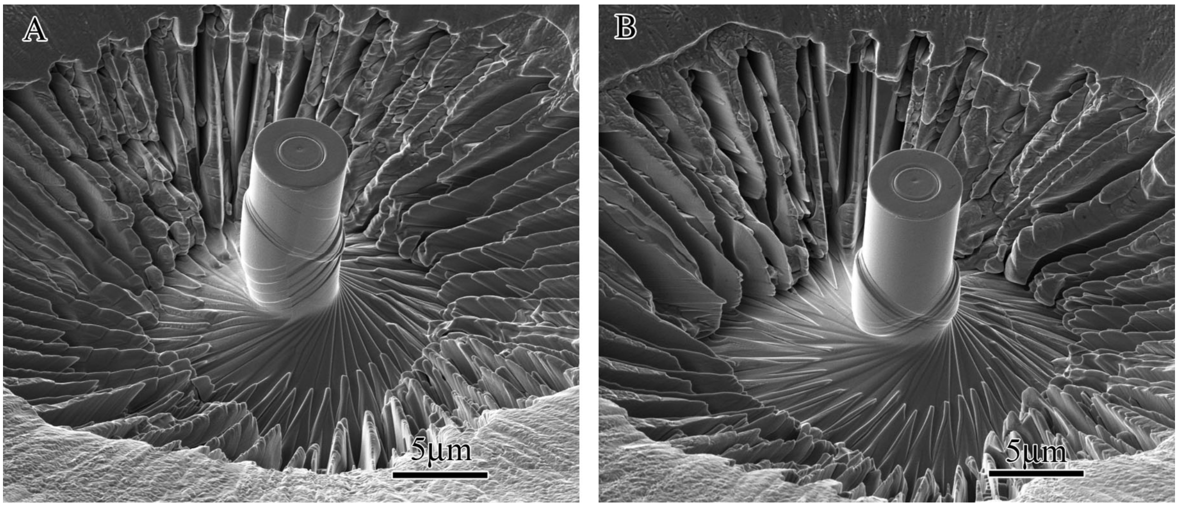

FIG 2. SEM micrographs from two, tested micropillars. A.) from control and B.) from material irradiated to 100dpa.