Combined Effect of Stacking Fault Energy and Specimen Size on the Mechanical Behaviors of Single Crystalline Face-Centered Cubic Metals

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Size effects on the mechanical behaviors of small-sized materials have drawn significant attention due to the substantial applications of small-sized materials in MEMS/NEMS devices. It is clear that the dimensions of small-sized materials affect their mechanical properties through the effects of their defect behaviors and deformation mechanisms. Other than materials dimensions, it is well known that the stacking fault energy (SFE) of materials is also critical in determining the deformation mechanism and consequently the mechanical properties of the materials. For example, reducing SFE leads to the transformation of slip mode from wavy slip to planar slip and increases the propensity of deformation twinning. However, there has been no systematic investigation on how SFE affects the size effect on the deformation behavior and mechanical properties of small-sized materials. In this research, we applied state-of-the-art in-situ deformation transmission electron microscopy (TEM) to quantify the combined effect of SFE and materials dimensions on the flow stress and work hardening behavior of submicron-sized materials.

Pure Cu, Cu-7at.%Al and Cu-15at.%Al single-crystals having face-centered cubic structures and SFE of ~45, ~17 and ~6 mJ/ m^2, respectively, were selected as the model materials. Pillar specimens with diameters ranging from 70 to 800 nm and aspect ratio of diameter to length of ~1:3 were fabricated with the axial direction along <100> using the focused ion-beam technique. In-situ compression tests were conducted in a JEOL 2100 TEM under displacement control using a Hysitron PI 95 PicoIndenter. TEM characterization was also performed on the compressed samples to investigate microstructural evolution and deformation mechanism.

SFE affects significantly the size effect of submicron-sized single-crystal pillars on their mechanical behaviors. High SFE results in a high power law exponent in the size effect of flow stress as shown in Figure 1. This is attributed to the deformation mode transition caused by SFE. Figure 2 shows snapshot TEM images of in-situ compression tests of Cu, Cu-7%Al and Cu-15%Al pillars with a diameter of 200 nm. Post-mortem TEM studies confirmed that (i) plastic deformation in pure Cu was induced mainly by full dislocation activities, (ii) thick twins with a low number density also contributed to the plastic deformation of Cu-7% pillars and (iii) a high density of nano-twins and stacking faults played a crucial role on the plastic deformation of Cu-15%Al samples. Comparisons of various submicron scales among the three model materials suggest that the competition between slip and twinning is the key for the observed impact of SFE on the size effect of flow stress. In addition to the impact on flow stress, details of our research results will be presented to clarify the combined impact of SFE and sample size on the mechanical properties of small sized metallic materials from the aspect of strain-hardening behavior. Detailed mechanical behaviors and microstructural images will also be presented to explain the observed results.

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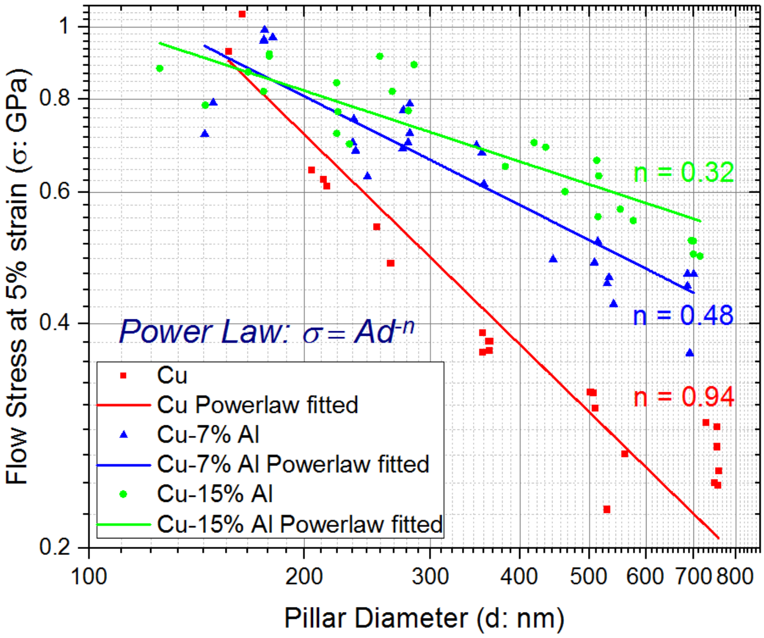

Fig. 1. Flow stress at 5% strain vs pillar diameter for three materials obtained by in-situ compression tests.

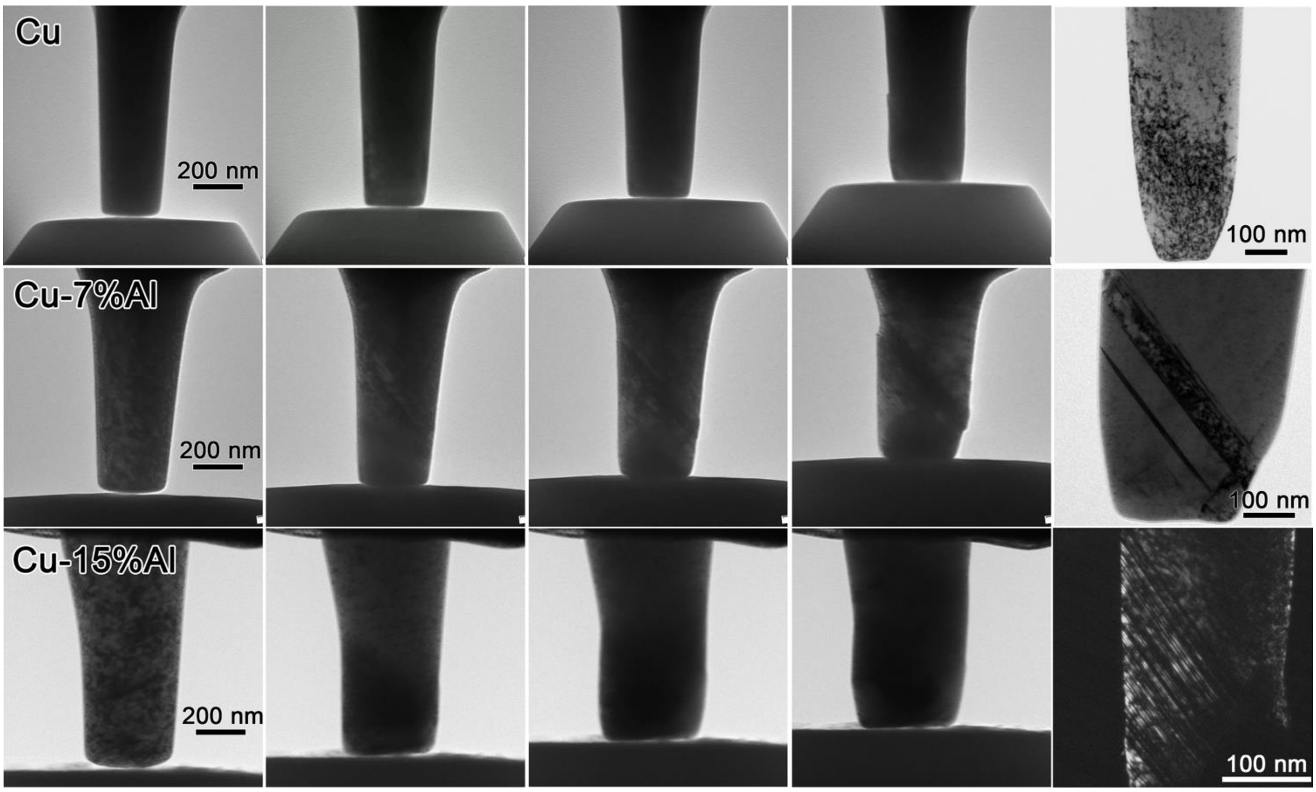

Fig. 2. Snapshot TEM images of in-situ compression processes and corresponding post-mortem TEM images for Cu, Cu-7%Al and Cu-15%Al pillars.