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Discrete Dislocation Simulations of Compression of Tapered Micropillars

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Abstract

The effect of taper on the plastic response of micropillars with a relatively high density of dislocation sources (1.5×10^{14} m^{-2}) is analyzed. The large number of dislocation sources and dislocations in the simulations rule out many of the mechanisms that govern size effects in pillars with a low dislocation source density. The mechanical response of compressed pillars with mean widths of $W = 0.4$, 0.8, 1.6, 3.2 μm and taper angles of 0°, 2° and 5° is analyzed using 2.5D discrete dislocation plasticity. For all taper angles, large scatter is found in the stress strain response for the submicron, $W = 0.4$ and 0.8 μm pillars, and relatively little scatter for the larger pillars. Taper leads to an increased average hardening rate for the submicron pillars, although this increase is within the scatter band of the stress strain response. Little sensitivity of the plastic response to taper is found for the larger pillars. The effect of size and taper on the stress strain response stems from the build up of geometrically necessary dislocations (GNDs). The reduced number of dislocation sources in the submicron pillars is identified as the origin of the large scatter in the predicted mechanical response.

Keywords: Dislocation plasticity; geometrically necessary dislocations; stress strain response; size effects; taper effects

1. Introduction

Micropillar compression experiments have shown that there can be a size effect in the flow strength of crystalline metals in the absence of strain gradients, with smaller being harder (Uchic et al., 2004; Greer et al., 2005; Volkert and Lilleodden, 2006; Kiener et al., 2006; Frick et al., 2008; Uchic et al., 2009; Aitken et al., 2015). Mechanisms that can lead to this size dependence include: dislocation starvation (Greer et al., 2005), exhaustion hardening (Dimiduk et al., 2005), a stress dependent source distribution (Parthasarathy et al., 2007), dislocation nucleation by single arm sources (Rao et al., 2007), and single-ended dislocation pile-ups (Pan et al., 2015). A variety of such mechanisms have been seen in experiments (Shan et al., 2008; Oh et al., 2009; Ng and Ngan, 2009; Kiener and Minor, 2011; Kiener

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