Effects of size on the strength and deformation mechanism in Zr-based metallic glasses

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We report results of uniaxial compression tests on Zr35Ti30Co6Be29 metallic glass nanopillars with diameters ranging from ~1.6 μm to ~100 nm. The tested pillars have nearly vertical sidewalls, with the tapering angle lower than ~1° (diameter >200 nm) or ~2° (diameter ~100 nm), and with a flat pillar top to minimize the artifacts due to imperfect geometry. We report that highly-localized-to-homogeneous deformation mode change occurs at 100 nm diameter, without any change in the yield strength. We also find that yield strength depends on size only down to 800 nm, below which it remains at its maximum value of 2.6 GPa. Quantitative Weibull analysis suggests that the increase in strength cannot be solely attributed to the lower probability of having weak flaws in small samples – most likely there is an additional influence of the sample size on the plastic deformation mechanism.

1. Introduction

Emergence of size effects in mechanical properties is an intriguing phenomenon: reduction of material size to the order of its microstructure has been found to give rise to unique properties due to the engagement of fundamentally different physical processes at nano-scale (Arzt, 1998). For example, when the extrinsic sample dimensions are reduced below the minimum distance for dislocation multiplication in face centered cubic (fcc) metals, the conventional dislocation multiplication mechanism ceases and the materials are left in a dislocation-starved state, leading to fundamentally different from bulk mechanical response such as size-dependent strength and discrete plastic flow (Greer et al., 2005; Uchic et al., 2004). In the absence of well-defined plasticity carriers like dislocations in crystalline metals, metallic glasses show significantly different mechanical behavior from their crystalline counterparts such as high ceramic-like strength, increased elastic limit, and catastrophic failure under uniaxial loads at room temperature (Schuh et al., 2007). The plastic deformation of metallic glasses is generally known to occur through collective atomic rearrangements called shear transformation zones (STZ) (Argon, 1979; Falk and Langer, 1998), and their temporal and spatial correlation determines the deformation mode (Schuh et al., 2007). At elevated temperatures, the STZs are uniformly distributed under an applied stress, and the plastic deformation is homogeneous. At low temperatures, however, the STZs are densely populated within a narrow region, and the deformation quickly localizes into what is usually called a shear band (Schuh et al., 2007). Even though the specific mechanism of shear banding process remains controversial, the general consensus is that an embryonic shear band forms when the secondary STZs are activated near the primary STZs by the assistance of the free-volume, and catastrophic failure occurs when this embryonic shear band instantaneously propagates across the sample at the yield stress.

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