11th International Conference on Advanced Materials
ICAM 2009
Rio de Janeiro Brazil
September 20 - 25

Deformations in nanosized metallic glass systems

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Abstract –To unravel possible size effects in pillars made of metallic glasses (MGs) it is shown that in situ deformation tests offer particular advantages. With quantitative in-situ Transmission Electron Microscopy size-effects were observed in MGs and grouped in three different regimes. Depending on the pillar diameter, the deformation is dominated by shear banding at large diameter (*d* >~570 nm), by fully homogeneous flow at smaller size (*d* <220 nm) and cleavage fracture in the intermediate range 220 nm < *d* < 570 nm . The fundamentals of these observations are intrinsic size effects initiated by extrinsic loading conditions.

Size effect, or the lack thereof, during deformation of metallic glasses (MGs) has recently drawn great attention It is not only of fundamental interest when scrutinizing shear localization processes in MGs, but also of practical significance for the incorporation of small size MG components in micro-/nano-electromechanical systems, as well as in composites or multilayers as an attempt to enhance ductility without compromising strength.

Despite the number of recent publications dealing with compression of FIB (focused ion beam) fabricated micropillars, consensus does not seem to exist on size effects in either strength or deformation mode of MGs. The rise of these significant controversies is largely related to the test method itself. Although, FIB damage can be minimized particularly in MGs by carefully designing the milling procedure, the tapering, which is inevitable for submicron-diameter pillars, causes considerable complexities specifically for the compression of MGs, as during compression, highly localized SBs may nucleate preferentially at the corner of sample-plunger contact. This affects not only SB nucleation but also makes stress analysis rather difficult. This is especially so for the ex-situ experiments when the events in a stress-strain curve cannot be correlated to particular individual SBs. These effects become more serious with smaller pillars. Another obstacle to access intrinsic size effects by microcompression is the incapability of the FIB method in fabricating small enough pillars, e.g. tens of nanometers or smaller, which may be essential for the size effect, if any, to be noticeable.

Significant progress has been made in recent years in the understanding of the associated deformation and crack propagation in amorphous metals, together with possible control of shear band propagation by virtue of (nano-)crystalline additions in order to suppress the tendency for instantaneous catastrophic failure. An intriguing question is why and how nucleation and propagation of these shear bands are affected by the size of the system, and would it be possible to suppress brittleness and enhance ductility just by changing the size of the samples?

We have carried out quantitative in-situ TEM deformations of metallic glass pillars with diameters ranging from 50 nm to 500 nm reveals that the deformation is controlled by nucleation of shear bands in larger pillars but becomes propagation controlled in smaller pillars. Upon decreasing diameter the in-situ experiments show a gradual transition from heterogeneous to homogeneous type of deformation, keeping the yield stress essentially size-independent. A micromechanical model based on quantitative description of shear banding events explains the size-dependent deformation behavior and a statistical analysis of strength reveals the physical picture defined by the interactions between stress fields of flow defects. Implications of our findings for applications in nanosized systems will be illustrated.