Superelastic behaviour at the nanoscale in shape memory alloys

Jose M. San Juan*[1], José F. Gómez-Cortés[1], and Maria L. Nó[1]

[1]University of the Basque Country (UPV/EHU) – Spain

Abstract

Shape memory alloys (SMA) are functional materials exhibiting the shape memory and superelastic effects. These phenomena were also observed at mico/nano scale, particularly in Cu-Al-based SMA (1-3), where ultrahigh mechanical damping was discovered during nano-compression tests in micro and nano pillars. The reproducibility of the superelastic behaviour along thousands of nano-compression cycles was also tested in micro and nano pillars, which undergo a long-term stable behaviour during years (4,5).
In the present work we approach a study of the stress-induced martensitic transformation in a series of micro and nano features, for potential damping applications in MEMS technology. Different kind of micro/nano pillars, specific dog-bone nano-samples and micro-bridges were milled by focused ion beam in a FEI Helios Nanolab 650, on (001) oriented single crystal slides of Cu-Al-Ni SMA. Then, the samples were tested in compression and bending at the Hysitron 950 nanoindenter, as well as in tension during in-situ experiments with the Hysitron Picoindenter PI-85 mounted inside the JEOL 7000F field emission scanning electron microscope, and using a flat diamond indenter of 20 micrometres in diameter. An experimental difficulty was to evaluate the required load to induce the stress-induced transformation avoiding an overload that could scratch the sample in the first test. This is a particularly critical aspect because of the size effect on the critical stress for superelasticity observed in these SMA (6,7), but the predicted model in such works allowed a successful estimation of the stress required for each sample.

In this work a complete study of the superelastic behaviour at the nanoscale in compression and tension, which was approached in several Cu-Al-based shape memory alloys, will be presented. Exceptional superelastic strain above 8%, with a complete recovery when withdrawing the stress, will be reported. These results exhibit a relevant potential interest for its application in Micro-Electro-Mechanical Systems (MEMS). In addition, during superelastic tests, the Cu-Al-based SMA exhibit an exceptionally high mechanical damping (2, 5, 8, 9) that can be used to damp noisy vibrations in MEMS technology. Then, we also report a comparative study of the superelastic damping at the nanoscale in several Cu-Al-based SMAs and in different sollicitation modes, compression, tension and bending.

These results pave the way for designing micro/nano actuators and micro-dampers of Cu-Al-based SMA, which can work in different mechanical modes of compression, bending, and torsion, opening the way for many applications on micro/nano mechanics at the nanoscale.
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*Speaker

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