Experimental Report for Experiment 2017B0102, 15.3.-22.3.2018

Søren Schmidt, Senior Scientist (Principal Investigator)
Technical University of Denmark, Fysikvej, Building 307, room 258, 2800 Kgs. Lyngby

1. Introduction

Polycrystalline Cu-Al-Mn-Zn shape memory alloys (SMA) show reversible pseudoelastic strain in tensile and compressive loading experiments of ca. 2 %. [1] Pseudoelasticity is a property of SMA which effects large reversible strain attributed to a martensitic phase transformation upon mechanical stress: in the Cu-Al-Mn-Zn system a cubic austenite phase, $L1_2$-type β_1 phase, is transforming to monoclinic stress induced martensite (SIM), R18 type β'_1. [2] Up to a load of 200 MPa austenite grains deform elastically, from 200 to 280 MPa SIM is forming locally wherever the transformation stress of 'softer' crystallographic directions in austenite is reached and for stress higher than 280 MPa the rest of the polycrystal gradually transforms to martensite. [3] After loading over 280 MPa, residual macroscopic strain is persisting due to large localized microstresses caused by large elastic anisotropy of the austenite phase and transformation anisotropy of the martensitic transformation. [3] Residual stress significantly builds during the first loading cycle and assists the martensitic phase transformation in subsequent cycles. [3,4] Compared to the initial austenite texture the SIM texture upon loading is sharper and shows distinct maxima evidencing anisotropy in the martensitic transformation where favorably oriented martensite grains transform first. [5] Owed to the elastic anisotropy the Young's modulus is lowest along austenitic [100] directions and highest along austenitic [111] directions. [3] In CuAlBe polycrystals austenite grains have shown to 'rotate' between transformed martensitic grains. [4]

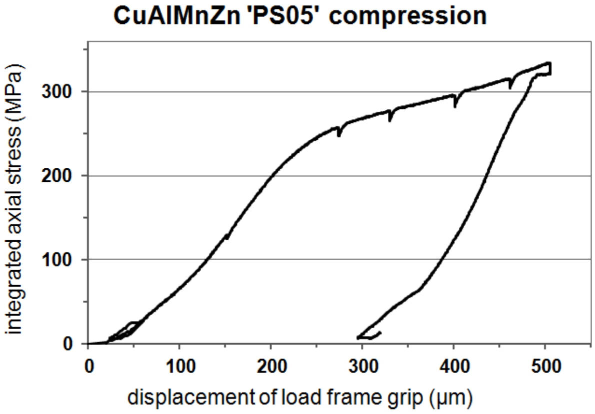

Fig.1: *in situ* loading curve of the $CuAl_{10}Mn_5Zn_5$ compression sample.

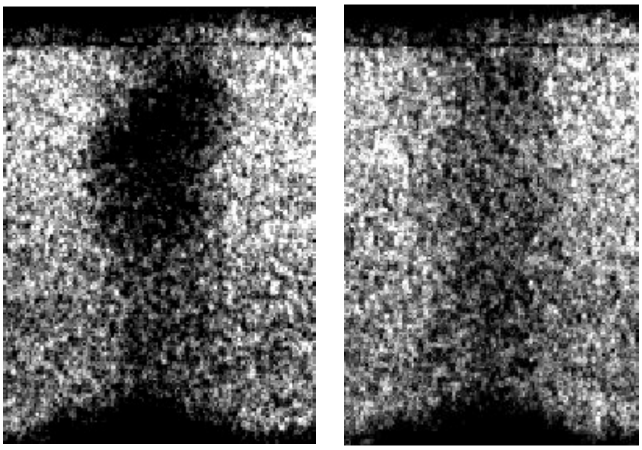

Fig.2: Left image shows the unloaded $CuAl_{10}Mn_5Zn_5$ sample (3x3x10 mm^3). Right image shows the sample after plastic deformation.

In ferromagnetic SMA the shape memory effect (SME) can be induced by a change of temperature, a stress field or a magnetic field (demonstrated for NiMnGa in [6]). CoNiAl ferromagnetic SMA have shown reversible superelastic response of 4 % [7] and are interesting materials for applications of ferromagnetic actuation [8].

2. Experiment

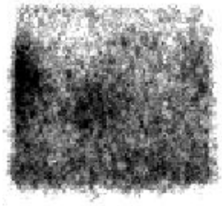

Fig.3: CoNiAl sample (5x5x5 mm^3).

Every measurement was performed using the SENJU detector banks plus an additional near field imaging (MCP) detector positioned downstream directly behind the sample. For compressive *in situ* loading a load frame with a rotatable load axis was installed on and synchronized with SENJU. We aim to study the microstructure of CuAlMnZn in a stress field with the goal of finding how neighboring grains affect each other during the martensitic transformation and elucidating mechanisms of the martensitic transformation and martensite-austenite coherence within grains. An undeformed, multicrystalline $CuAl_{10}Mn_5Zn_5$ (wt.%) sample was exposed to compressive loading to 320 MPa for one cycle (fig. 1) where a residual stress state has been established. We performed a full tomographic scan in its unloaded state and after compression to 320 MPa and subsequent unloading.

For CoNiAl multi crystals the magnetic domain structure is investigated without applied load and without an external magnetic field. Employing a new fitting algorithm we intend to map the orientation of austenitic magnetic domains (RADEN data) with respect to austenite grains (SENJU data) in the sample.

3. Results

Figure 2 compares the near field detector image before and after loading: a large extinction spot (large austenite grain) in its unloaded state is replaced by a variety of smaller features after loading. Large compressive deformation probably lead to stabilization of martensitic domains. After further data processing [9] a 3-dimensional reconstruction of the of CuAlMnZn austenite/martensite microstructure will be obtained. The CoNiAl sample in figure 3 shows large extinction spots throughout the sample indicating large austenite grains. CoNiAl samples will be evaluated together with magnetic imaging data taken at RADEN: a newly developed evaluation method will shed light on the distribution of magnetic domains within austenite grains of CoNiAl SMA.

4. Conclusion

The measuring campaign of the experiment was successfully concluded. Further data analysis will give insight in austenite-martensite relations across and within grains of CuAlMnZn SMA. The magnetic microstructure of CoNiAl SMA will be mapped in combination with RADEN data which will help to understand magnetic and austenitic domain relations and presents a feasibility study for a new analysis method for imaging of multiferroic (ferromagnetic + ferroelastic) materials.

[1] Šittner, P.; Hara, Y. & Tokuda, M. Metall. Mater. Trans. A, 1995, 26, 2923-2935.

[2] Otsuka, K. & Ren, X. Prog. Mater Sci., 2005, 50, 511 - 678.

[3] Šittner, P.; Lukáš, P.; Daymond, M. R.; Novak, V. & Swallowe, G. M. J. Phys. IV France, 2001, 11, 159-166.

[4] Malard, B.; Šittner, P.; Berveiller, S. & Patoor, E. C. R. Physique, 2012, 13, 280 - 292.

[5] Neov, D.; Lukáš, P.; Šittner, P. & Černík, M. Appl. Phys. A, 2002, 74, 1095-1097.

[6] Ullakko, K.; Huang, J.; Kokorin, V. & O'Handley, R. Scr. Mater., 1997, 36, 1133 - 1138.

[7] Meyer, D.; Maier, H.; Dadda, J.; Karaman, I. & Karaca, H. Mater. Sci. Eng. A, 2006, 438–440, 875 - 878.

[8] Liu, Z.; Yu, S.; Yang, H.; Wu, G. & Liu, Y. Intermetallics, 2008, 16, 447 - 452.

[9] Cereser, A.; …; Schmidt, S. Sci. Rep., 2017, 7, 9561.