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Nanoscale Characterization of Shape Reversibility and Structural Transformations in Shape Memory Alloys

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Abstract

Metals and many alloy systems have different phases at different conditions and these phases are described in phase diagrams as alloy composition-temperature, or composition-pressure dependent. Shape memory alloys are also at different phases depending the alloy compositions and exhibit a peculiar property called shape memory effect in β-phase region. These alloys are very sensitive to external conditions, and crystal structures turn into other crystal structures by lowering temperature and stressing material, by means of crystallographic transformation, thermal and stress induced martensitic transformations. Thermal induced martensitic transformation occurs in atomic scale in the material on cooling from parent phase region, and interatomic interactions govern this transition. Shape memory is characterized by the recoverability of two certain shapes of material at different temperatures. These alloys possess two unique abilities: the capacity to recover large strains and to generate internal forces during their activation. The basis of this phenomenon is the stimulus-induced phase transformations, martensitic transitions, which govern the remarkable changes in internal crystalline structure and properties of the materials. Thermal induced martensitic transformations are first order lattice-distorting phase transformation and occurs along with lattice twinning on cooling from parent β-phase region and ordered parent phase structures turn into twinned martensite structures. The twinned structures turn into detwinned martensite structures by means of stress induced transformation by stressing the material in the martensitic condition. Thermal induced transformation occurs as martensite variants with cooperative movements of atoms in <110 > -type directions on the {110} - type planes of austenite matrix, by means of lattice invariant shear. These alloys exhibit another property called superelasticity, which is performed in only mechanical manner by deforming and releasing the material in parent phase region just over austenite finish temperature. Superelasticity exhibits ordinary elastic material behaviour and recover the original shape after releasing. Additionally, superelasticity exhibit nonlinearity, stressing and releasing paths are different at stress-strain diagram and hysteresis loops refers to the energy dissipation.

Copper based alloys exhibit this property in metastable β-phase region, which has bcc-based structures at high temperature parent phase field. Lattice invariant shear is not uniform in these alloys and give rise to the formation of layered structures, like 3R, 9R or 18R depending on the stacking sequences on the close-packed planes of the ordered lattice. The unit cell and periodicity is completed through 18 layers thorough z-axis in 18R martensite.

In the present contribution, x-ray diffraction and transmission electron microscopy (TEM) and differential scanning calorimetry (DSC) studies were carried out on two copper based CuZnAl and CuAlMn alloys. X-ray diffractograms taken in a long-time interval show that locations and intensities of diffraction peaks change with the aging time at room temperature. Especially, some of the successive peak pairs providing a special relation between Miller indices come close each other, and this result refers to the redistribution of atoms in diffusive manner.

Keywords: Shape memory effect, martensitic transformation, superelasticity, twinning, detwinning, and lattice invariant shear.