Shape Reversibility and Nanoscale Design of Diffusionless Phase Transformations in Shape Memory Alloys

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Abstract

Shape memory alloys take place in a class of advanced smart materials with adaptive properties and stimulus response to the external conditions and changes, by exhibiting a peculiar property called shape memory effect. This phenomenon is initiated with thermomechanical processes on cooling and deformation processes and performed thermally on heating and cooling, with which shape of materials cycles between original and deformed shapes in reversible way in bulk level. Therefore, this behavior can be called thermal memory or thermoelasticity. This is plastic deformation, with which strain energy is stored and releases on heating by recovering the original shape. Thermoelasticity is governed by the crystallographic transformations in nanoscale and atomic level, thermal and stress induced martensitic transformations. Thermal induced martensitic transformation occurs on cooling, with cooperative movement of atoms in <110 > -type directions on the {110} - type planes of austenite matrix, along with lattice twinning and ordered parent phase structures turn into twinned martensite structures. The twinned structures turn into detwinned structures by means of stress induced transformation with deformation. Martensitic transformations are diffusionless transformations, and movements of atoms are confined into the neighbour atom distances.

These alloys exhibit another property called superelasticity. This behavior is performed in mechanical manner with stressing and releasing the material in elasticity limit at a constant temperature in parent phase region, and shape recovery occurs instantly and simultaneously upon releasing, by exhibiting elastic material behavior. Superelasticity is performed in non-linear way; stressing and releasing paths are different in the stress-strain diagram, and hysteresis loop refers to energy dissipation. Superelasticity is also result of the stress induced martensitic transformation and ordered parent phase structures turn into the detwinned martensitic structure with stressing in parent phase region.

Copper based alloys exhibit this property in metastable β-phase region, which has bcc-based structures. Lattice invariant shears are not uniform in copper-based shape memory alloys, and the ordered parent phase structures undergo the non-conventional complex layered structures with martensitic transformation. The long-period layered structures can be described by different unit cells as 3R, 9R or 18R depending on the stacking sequences on the close-packed planes of the ordered lattice.

In the present contribution, x-ray diffraction and transmission electron microscopy studies were carried out on copper based CuZnAl and CuAlMn alloys. X-ray diffraction profiles and electron diffraction patterns exhibit super lattice reflections inherited from parent phase due to the displacive character of martensitic transformation. X-ray diffractograms taken in a long-time interval show that diffraction angles and intensities of diffraction peaks change with the aging time at room temperature. This result refers to a new transformation in diffusive manner.

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