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Physical basis of shape memory effect and reversibility in shape memory alloys

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A series of alloy system take place in a class of smart materials due to stimulus response to external effect. Shape memory alloys take place in this class by exhibiting a peculiar property called shape memory effect. This phenomenon is characterized by the recoverability of two certain shapes of material at different temperatures. Shape memory materials are used as shape memory devices in many interdisciplinary fields such as medicine, metallurgy, building industry and many engineering fields. Shape memory effect is performed thermally by heating and cooling after first cooling and stressing treatments. Shape memory effect is result of successive crystallographic transformations; thermal and stress induced martensitic transformations. Shape memory alloys exhibit another property called superelasticity, which is performed by stressing material at high temperature parent phase region. This effect exhibit classical elastic material behavior and it is performed by stressing and releasing the material in parent phase region. Loading and unloading paths are different in stress strain diagram, and cycling loop reveals energy dissipation. The strain energy is stored after releasing, and these alloys are mainly used as deformation absorbent materials in control of civil structures subjected to seismic events, due to the absorbance of strain energy during any disaster or earthquake.

Thermal induced martensitic transformation is first order lattice-distorting phase transformations, and thermally occurs on cooling, by which ordered parent phase structures turn into twinned martensitic structures. This transformation occurs with cooperative movements of atoms by means of lattice invariant shear. Lattice invariant shears occur in two opposite directions, <110 > -type directions on the {110} - type planes of austenite matrix which is basal plane of martensite. Thermal induced martensite occurs as twinned martensite, and the twinned structures turn into the detwinned structures by means of stress induced martensitic transformation by stressing the material in the martensitic condition.

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 and twinning is not uniform in copper based ternary alloys and gives rise to the formation of complex layered structures, depending on the stacking sequences on the close-packed planes of the ordered parent phase lattice, like 3R, 9R or 18R depending on the stacking sequences on the close-packed planes of the ordered lattice. Crystal structure of martensite of these alloys is orthorhombic and basal plane is hexagonal.

In the present contribution, x-ray diffraction and transmission electron microscopy (TEM) studies were carried out on two copper based CuAlMn and CuZnAl alloys. X-ray diffraction profiles and electron diffraction patterns reveal that both alloys 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 duration at room temperature. In particular, some of the successive peak pairs providing a special relation between Miller indices come close each other. This result refers to the rearrangement of atoms in diffusive manner.

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