World Academy of Science, Engineering and Technology
International Journal of Physical and Mathematical Sciences
Vol:16, No:02, 2022

Physical Aspects of Shape Memory and Reversibility in Shape Memory Alloys

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Abstract : Shape memory alloys take place in a class of smart materials by exhibiting a peculiar property called the shape memory effect. This property is characterized by the recoverability of two certain shapes of material at different temperatures. These materials are often called smart materials due to their functionality and their capacity of responding to changes in the environment. Shape memory materials are used as shape memory devices in many interdisciplinary fields such as medicine, bioengineering, metallurgy, building industry and many engineering fields. The shape memory effect is performed thermally by heating and cooling after first cooling and stressing treatments, and this behavior is called thermoelasticity. This effect is based on martensitic transformations characterized by changes in the crystal structure of the material. The shape memory effect is the result of successive thermally and stress-induced martensitic transformations. Shape memory alloys exhibit thermoelasticity and superelasticity by means of deformation in the low-temperature product phase and high-temperature parent phase region, respectively. Superelasticity is performed by stressing and releasing the material in the parent phase region. Loading and unloading paths are different in the stress-strain diagram, and the 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 occurs thermally on cooling, along with lattice twinning with cooperative movements of atoms by means of lattice invariant shears, and ordered parent phase structures turn into twinned martensite structures, and twinned structures turn into the detwinned structures by means of stress-induced martensitic transformation by stressing the material in the martensitic condition. Thermal induced transformation occurs with the cooperative movements of atoms in two opposite directions, <110 > -type directions on the {110} - type planes of austenite matrix which is the basal plane of martensite. Copper-based alloys exhibit this property in the 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. 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 superlattice reflections inherited from the 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 to each other. This result refers to the rearrangement of atoms in a diffusive manner.

Keywords : shape memory effect, martensitic transformation, reversibility, superelasticity, twinning, detwinning
Conference Title : ICECMP 2022 : International Conference on Experimental Condensed Matter Physics
Conference Location : Jeddah, Saudi Arabia
Conference Dates : February 17-18, 2022