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Crystallographic studies on phase transition in copper based shape memory alloys

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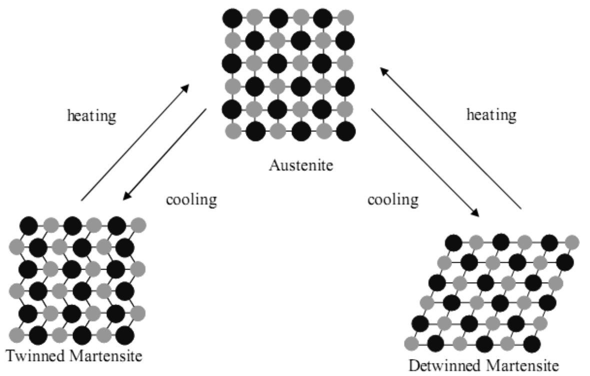
Abstract

Shape memory alloys take place in a class of smart materials by exhibiting a peculiar property called shape memory effect. This property is characterized by the recoverability of the desired shape on the material at different conditions. Shape memory effect is based on a solid state phase transition, martensitic transformation, and this transformation is characterized by a change in the crystal structure of the material. Martensitic transformations are first order diffusionless transitions and occur in thermal manner in the materials on cooling from high temperature. Thermal induced martensite occurs as multivariant martensite in self-accommodating manner on cooling from high temperature parent phase region, and this martensite is called self-accommodated martensite or multivariant martensite. Deformation of shape memory alloys in martensitic state proceeds through a martensite variant reorientation. Martensitic transformations occur with cooperative movement of atoms by means of lattice invariant shears on a {110} -type plane of austenite matrix which is basal plane of martensite. The lattice invariant shears occurs, in two opposite directions, <110>-type directions on the {110}-type basal plane. This kind of shear can be called as {110}<110>-type mode, and possible 24 martensite variants occur. Copper based alloys exhibit this property in metastable β–phase region, which has bcc-based structures at high temperature parent phase field and these structures martensiticaly turn into layered complex structures with lattice twinning following two ordered reactions on cooling. Copper based alloys exhibit this property in metastable β–phase region, which has bcc-based structures at high temperature parent phase field and these structures martensiticaly turn into layered complex structures with lattice twinning following two ordered reactions on cooling.

Introduction

Shape memory alloys take place in a class of functional materials exhibiting a peculiar property called shape memory effect. This property is characterized by the recoverability of desired shape on the material at different conditions. Shape memory phenomena are based on a solid state phase transformation, martensitic transition, which occurs on cooling from high temperatures. These alloys are plastically deformed in martensitic condition, and the material spontaneously returns to the original phase on heating over the austenite finish temperature. Shape memory effect is facilitated by martensitic transformation governed by changes in the crystalline structure of the material, and shape memory properties are intimately related to the microstructures of the alloy. Thermal induced martensite occurs as multivariant martensite in self-accommodating manner on cooling from high temperature parent phase region. Deformation of shape memory alloys in martensitic state proceeds through a martensite variant reorientation, and twinned martensite turns into the detwinned martensite. These processes are schematically illustrated in Figure 1 The first cycle proceeds as follow: cooling, deformation and heating. The oriented martensite turns into the ordered austenite structure through heating in both reversible and irreversible shape memory effect.[1]. The ordered parent phase structure turns into the twinned martensite on cooling after first cycle in irreversible case, and it turns into the oriented martensite in case of reversible shape memory effect [1,2].



(a) (b)

Figure 1. Schematic illustration of structural changes with phase transformation; (a) formation of twinned martensite structure on cooling, (b) formation of oriented martensite structure with deformation in low temperature martensitic state[1].

Martensitic transformations occur usually by two or more lattice invariant shears on a {110}-type plane of austenite matrix. Therefore, thermal induced martensites have 24 variants[3].

Copper based alloys exhibit this property in metastable β-phase field, and high temperature bcc-structures martensiticaly undergo non-conventional layered structures following two ordered reactions on cooling. The product phases have the unusual complex structures called long period layered structures such as 3R, 9R or 18R depending on the stacking sequences on the close-packed planes of the ordered lattice[3].

Experimental

In the present contribution, a CuZnAl alloy was selected for investigation: CuZnAl alloy with a nominal composition by weight of 26.1 %zinc, 4 % aluminium, and the balance copper. X-ray powder specimens were prepared by filling the alloy samples. Specimens for TEM examination were also prepared from 3 mm diameter discs and thinned down mechanically to 0.3 mm thickness. These specimens were heated in evacuated quartz tubes in the β-phase field (15 minutes at 830°C for homogenization and quenched in iced-brine.

These specimens were also given different post-quench heat treatments and aged at room temperature.

TEM and X-ray diffraction studies carried out on these specimens. TEM specimens were examined in a JEOL 200CX electron microscope, and X-ray diffraction profiles were taken from the specimens using Cu-K_{α} radiation with wavelength 1.5418 Å.

Results and Discussion

An x-ray powder diffractogram taken from the aged CuZnAl alloy samples is shown in Figure 2. An electron diffraction pattern taken from CuZnAl alloy sample is also shown in Figure 3. X-ray powder diffractograms and electron diffraction patterns reveal that this alloy has an ordered structure in martensitic condition, and exhibit superlattice reflections. X-ray powder diffractograms and electron diffraction patterns were taken from the specimens in a large time interval and compared with each other. It has been observed that electron diffraction patterns exhibit similar characteristics, but some changes occur at the peak locations and intensities on the x-ray diffractograms with aging duration. These changes occur as rearrangement or redistribution of atoms in the material, and attribute to new transitions in diffusive manner [3]. The ordered structure or super lattice structure is essential for the shape memory quality of the material.

In the shape memory alloys, homogenization and releasing the external effect is obtained by ageing at β–phase field for adequate duration.

Crystallization is essential for shape memory quality, and crystallization and formation of the ordered structure is also obtained by the quenching process in the suitable media. The quenching rate is also important for the formation of homogenous ordered structures and shape memory optimization.

On the other hand, post-quench ageing and service processes in devices affect the shape memory quality, and give rise shape memory losses. These kinds of results lead to the martensite stabilization in the reordering or disordering manner [3, 4].

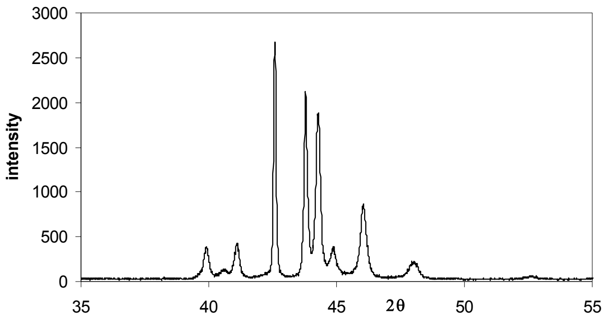


Figure 2. An x-ray diffractogram taken from the CuZnAl alloy sample.

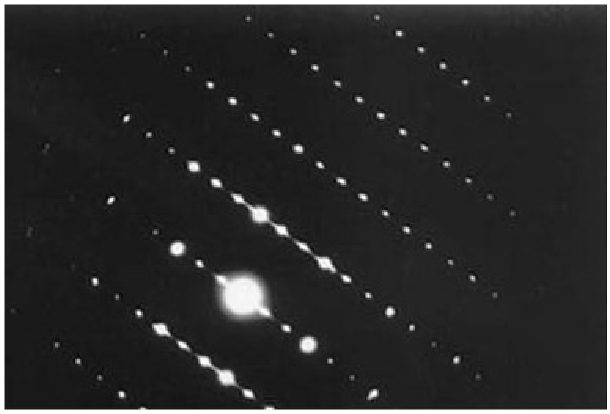


Figure 3. An electron diffraction patterns taken from CuZnAl alloy sample.

In order to make the material satisfactorily ordered and to delay the martensite stabilization, copper-based shape memory alloys are usually treated by step-quenching after homogenization.

Although martensitic transformation has displacive character, martensite stabilization is a diffusion controlled phenomena, and leads to redistribution of atoms on the lattices sites. Stabilization is important factor and causes to memory losses, and changes in main characteristics of the material; such as, transformation temperatures, and x-ray diffraction peak location and peak intensities.

It can be concluded from the above results that the copper-based shape memory alloys are very sensitive to the ageing treatments, and heat treatments can change the relative stability and the configurational order of crystal planes. This result attributes to a rearrangement of atoms.

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