The effect of nanoparticles on magnetic behavior of aged Cu-Al-Mn-Fe alloys

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Abstract

The paper highlights changes in the magnetic and mechanical properties of Cu–Al–Mn-Fe alloys under annealing in magnetic field as the result of change in a critical size of forming precipitated ferromagnetic phase and determines correlation in the behavior of magnetic and mechanical properties of the alloy, depending on a critical nucleus size of forming precipitated ferromagnetic phase.

Introduction

Phase transformations of **martensitic type** are inherent to a wide class of materials and alloys, which are characterized by structural features, that determine peculiarities of their formation and physical properties.

A mechanism of the behavior of martensitic transformation (MT), occurring in alloy after decomposition of solid solutions with precipitation of ferromagnetic nanoparticles in the nonferromagnetic matrix, is very attractive. In ternary Cu-Mn-Al Heusler alloy, MT can take place and an appearance of longrange ferromagnetic order in a system of superparamagnetic nanoparticles, dissolved in the nonmagnetic matrix, is caused by the cooperative ordering of their magnetic moments. Alloys of this system demonstrate high values of characteristics of shape memory effects and superelasticity, they also exhibit a giant magnetoresistance. Thus, by varying regimes of aging of high-temperature phase (austenite), it is possible to considerably affect the process of its decomposition, that can result in significant changes of characteristic temperatures and a hysteresis of MT in Cu-Mn-Al alloys. To develop a concept of the nature and character of MT behavior and to directly control the process of MT induction it is of great interest to study the morphology of MT behavior in Cu-Al-Mn alloy after an aging of high-temperature phase as a result of annealing in a constant magnetic field depending on sample orientation relative to the field. For this purpose, in order to select the best regime of thermal or thermal-magnetic treatment, the Cu-Al-Mn alloy with a chemical composition which provides the lowest value of MT temperature hysteresis was chosen for the investigations.



Materials and methods

The Cu-Al-Mn alloys were smelted in an induction furnace in an argon atmosphere. According to energy dispersive X-ray fluorescent analysis data, the chemical composition of the alloys (in mass%) are as follows with error $\pm 0.5\%$:

Alloy1 - Cu(84.7), Al(11.1), Mn(3.4)-Fe(0.8) Alloy2 - Cu(84.7), Al(11.4), Mn(3.4)-Fe(0.5)

After homogenizing annealing at 1123K for 10 hours, the samples were quenched in water, then were annealed at a constant temperature of 498 K for 3 hours. The permanent magnetic field with a strength of 1.5 kOe was created by the selection of ferromagnetic plates which were spaced by a distance, required for a placement of an electrical heater with a sample in their gap.



Scheme of placement of Cu-Al-Mn alloy samples at annealing: a) without a field; b) in the magnetic field perpendicular to the main axis of sample; c) in the magnetic field parallel to the main axis of sample, where 1 is an electrical heater, 2 is a sample, 3 is a thermocouple, 4 is a magnetic pole.

Temperature dependence of low-field magnetic susceptibility of Alloy1 samples after aging: a) without field; b) in perpendicular magnetic field; c) in parallel magnetic field; an arrow indicates heatingcooling.

Alloy1 samples after aging: 1) without magnetic field; 2) in perpendicular magnetic field; 3) in parallel magnetic field; a) in martensite state (-40°C); b) in austenite state (+ 40 °C); where σ is a saturation magnetization.

Annealing	Average microhardness, $H\mu$ (GPa)
without a field	4.4
in perpendicular field	4.6
in parallel field	4.8

Conclusions

Characteristic temperatures and MT hysteresis were determined from the curves of temperature dependences of electrical resistance (p/pmax) and magnetic susceptibility $(\chi/\chi max)$ according to a standard technique. A size of precipitated nanoparticles was estimated by the two-pass method of atomic force microscopy (AFM) using a scanning probe microscope (SPM) Solver PRO-M

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Annealing in a magnetic field effects on the process of phase formation at the aging of high-temperature phase and promotes the increasing of ferromagnetic nanoparticles number in the nonferromagnetic matrix in order to optimize the parameters of martensite transformation behavior in Cu-Al-Mn alloy.

A number of precipitated nanoparticles are maximal in the case of annealing in the parallel magnetic field. In turn, an increase in a number of precipitated nanoparticles stimulates the growth of start temperature of direct MT and the reduction of MT hysteresis.

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