The effect of Fe-dopant on magnetic and structural features of aged Cu-Al-Mn(Fe) alloys

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Abstract

The paper highlights changes in magnetic and mechanical properties of Cu–Al–Mn(Fe) alloys under annealing in magnetic field as a result of change in a critical size of forming precipitated ferromagnetic phase and determines correlation in behavior of magnetic and mechanical properties of alloys, 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 long-range 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.

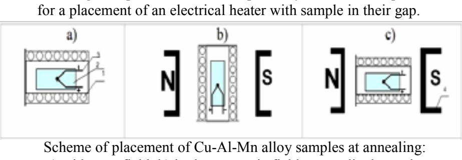
To develop **a concept of the nature and character of MT** behavior and to directly control the process of MT induction it is of great interest to study the morphology of MT behavior in Cu-Al-Mn alloy after an aging of high-temperature phase as a result of annealing in a constant magnetic field depending 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(Fe) 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 are as follows, in wt/% with error ±0.005%:

Alloy1 – Cu – 11.1%Al – 4.2%Mn
Alloy2 – Cu – 11.4%Al - 3.9% Mn
Alloy3 – Cu - 11.2%Al – 6.4% Mn - 0.9%Fe

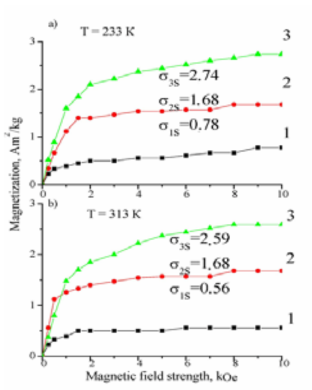
After homogenizing annealing at **1123K for 10 hours**, the samples were **quenched in water**, then were annealed at a constant temperature of **423, 473 and 498 K for 10, 20, 40, 80, 120 min and 3 hrs**. The **permanent magnetic field** with a strength of **1.5 kOe** was created by the selection of ferromagnetic plates which were spaced by a distance, required for a placement of an electrical heater with sample in their gap.



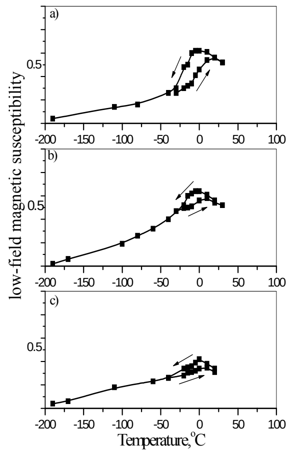
Scheme of placement of Cu-Al-Mn alloy samples at annealing: a) without a field; b) in the magnetic field perpendicular to the main axis of sample; c) in the magnetic field parallel to the main axis of sample, where 1 is an electrical heater, 2 is a sample, 3 is a thermocouple, 4 is a magnetic pole.

Characteristic temperatures and MT hysteresis were determined from the curves of temperature dependences of electrical resistance (ρ/ρ max) and magnetic susceptibility (χ/χ 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.

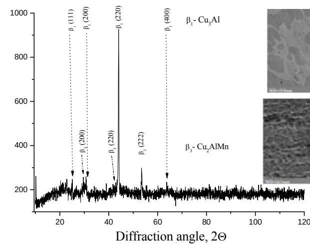
Results

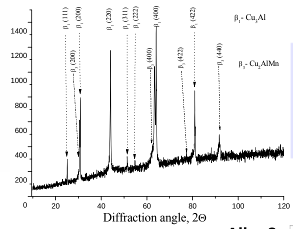


Field dependences of magnetization of **Alloy1** samples after aging: 1) without magnetic field; 2) in perpendicular magnetic field; 3) in parallel magnetic field; a) in martensite state (-40ºC); b) in austenite state (+ 40 ºC); where σ is a saturation magnetization.

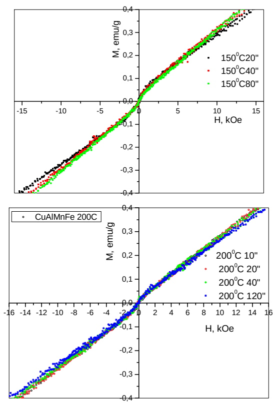


Temperature dependence of low-field magnetic susceptibility of **Alloy1** samples after aging: a) without field; b) in perpendicular magnetic field; c) in parallel magnetic field; an arrow indicates heating-cooling.

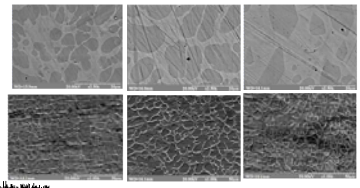




X-ray diffraction patterns of **Alloy2** samples in monochromatic Kα-radiation of Cu-anode: a) after annealing without magnetic field; c) after annealing in magnetic field perpendicular to the main axis of a sample.

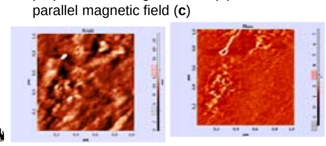


Hysteresis curves of specific magnetization of **Alloy3** after annealing at 423 and 473K depending on aging. The alloy in magnetic field behaves like a superparamagnetic. Due to the fact that particles are single-domain, magnetization is accompanied by their rotation.

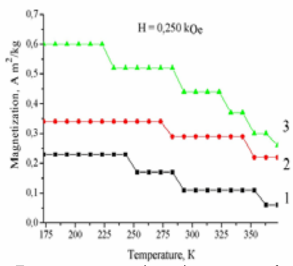


a) b) c)

Microstructures of **Alloy2** samples annealed at 200C for 3 h: without magnetic field (**a**); in perpendicular magnetic field (**b**); and in parallel magnetic field (**c**)



Microstructures of **Alloy2** surface: a surface image in micron scale (**a**); and the same image in phase contrast (**b**)



Temperature dependences of magnetization of **Alloy1** samples after aging: 1) without magnetic field; 2) in perpendicular magnetic field; 3) in parallel magnetic field.

Microhardness of Alloy2 after thermomagnetic treatment

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

Conclusions

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.

A small addition of Fe (~1%) to CuAlMn alloy prevents martensite transformation and limits ferromagnetic contribution to paramagnetic matrix at certain heat treatment regimes at 100, 150, 200, and 225°C.

References

[1] A. Titenko, L. Demchenko. **Nanoscale Res Lett** (**2016**) 11: 237.

[2] Titenko, A.N., Demchenko, L.D., Perekos, A.O., Gerasimov O. Yu. **Nanoscale Res Lett** (**2017**) 12: **285**.

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