Nanodimension and magnetic state of copper-based Heusler alloys

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Abstract

The changes in the magnetic properties of Cu-Al-Mn and Cu–Al–Mn-Fe alloys under annealing as the result of changes in a critical size of forming precipitated ferromagnetic phase are highlighted. The difference in magnetic behavior is a consequence of the formation of Heusler ferromagnetic phases Cu_2AlMn, or Fe_3Al and $(Fe,Mn)_2Al$ during isothermal aging and the transformation of the alloys to a superparamagnetic state. The doping with Fe contributes to non-monotonic changes in **martensite transformation (MT) temperatures**.

Introduction

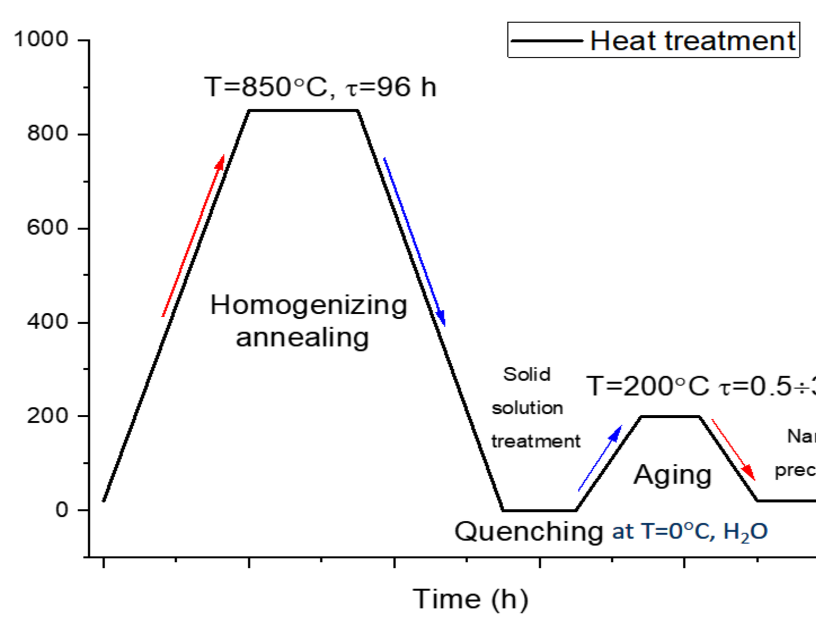
Cu-based shape memory (SM) alloys can exhibit unusual magnetic properties depending on heat treatment, additionally to their functional properties. In this system, ferromagnetic nanosized particles of Heusler compound Cu_2MnAl are precipitated due to aging, which contributes to an increase in SM effect and superelastisity SE [1]. Depending on the size and distribution of nanoparticles, the alloys of this system can exhibit superparamagnetic, ferromagnetic and antiferromagnetic ordering [2].

A mechanism of the behavior of martensite 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.

Materials and methods

The complex alloys of different chemical compositions of **Cu-23%Al-7%Mn-xFe (x=0; 0.5; 1; 2; 3 at%)** alloys were manufactured by electric arc melting in inert protective (**Ar**) atmosphere using Edmund Burler Mini Arc Melting System MAM-1 and controlled thermal treatment.

Obtained alloys were annealed at 850°C for 95 hours for homogenization. To get nanocomposite structure the alloys were thermally treated with quenching followed by aging. **Quenching for supersaturated solid solution** obtaining was performed **from 850° C in water at 0° C.** As **an aging, low-temperature annealing** was performed **at 200° C for 0.5, 1, and 3 hrs**.



References

[1] *Titenko A., Demchenko L., Perekos A., Gerasimov O.* Effect of Thermomagnetic Treatment on Structure and Properties of Cu–Al–Mn Alloy // Nanoscale Res Lett.-2017.-**12**.-P. 285.

[2] *Titenko A., Demchenko L., Perekos A., Babanli M., Huseynov S., Ren T.-Z.* Deformational and magnetic effects in Cu–Al–Mn alloys // Appl Nanosci.- 2020.- **10**.-P. 5037–5043

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The purpose of this work

to establish the dynamics of changes in the structural transformation and their relationship with the magnetic and mechanical parameters of alloys of the Cu-Al-Mn-Fe system as a result of alloying and heat treatment.

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.

Results

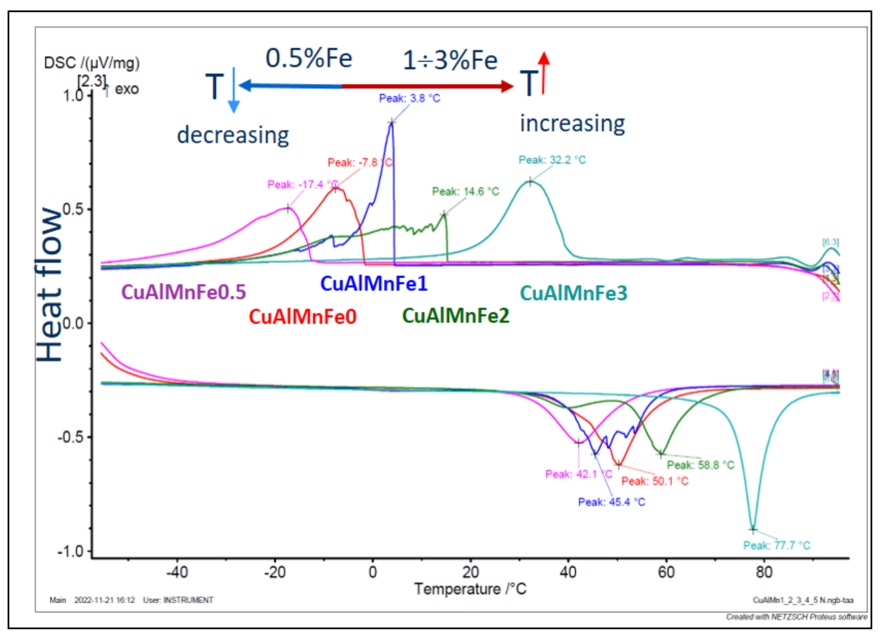
A. The Martensite Phase Transitions

The characteristic temperatures of MT depending on doping with the fourth element (Fe) derived from the result of DSC measurement:

Alloy Designation	Fe, at%	Ms, °C	Mf, °C	As, °C	Af, °C	ΔT, °C
CuAlMnFe0	-	-1.7	-21.1	41.4	57.3	57.9
CuAlMnFe0.5	0.5	-12.5	-36.2	33.2	55.7	59.5
CuAlMnFe1	1	4.4	-10.9	42.9	70.6	50.0
CuAlMnFe2	2	15.3	-3.0	53.3	66.2	44.2
CuAlMnFe3	3	39.6	21.9	67.7	80.8	41.4

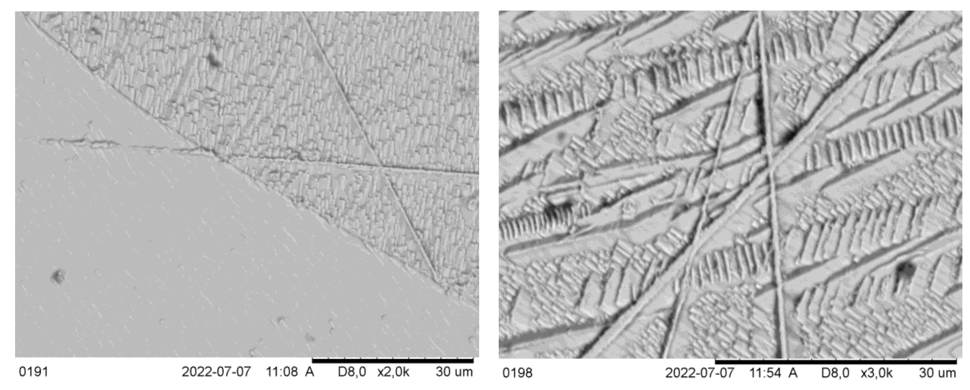
[a] **Ms** and **Mf** are the start and finish temperature of direct MT, respectively; **As** and **Af** are the start and finish temperature of reverse MT, respectively; **ΔT** is a thermal hysteresis width of M

DSC curves in MT interval of the different Cu-Al-Mn-Fe alloys in the quenched state depending on Fe concentration (at%):

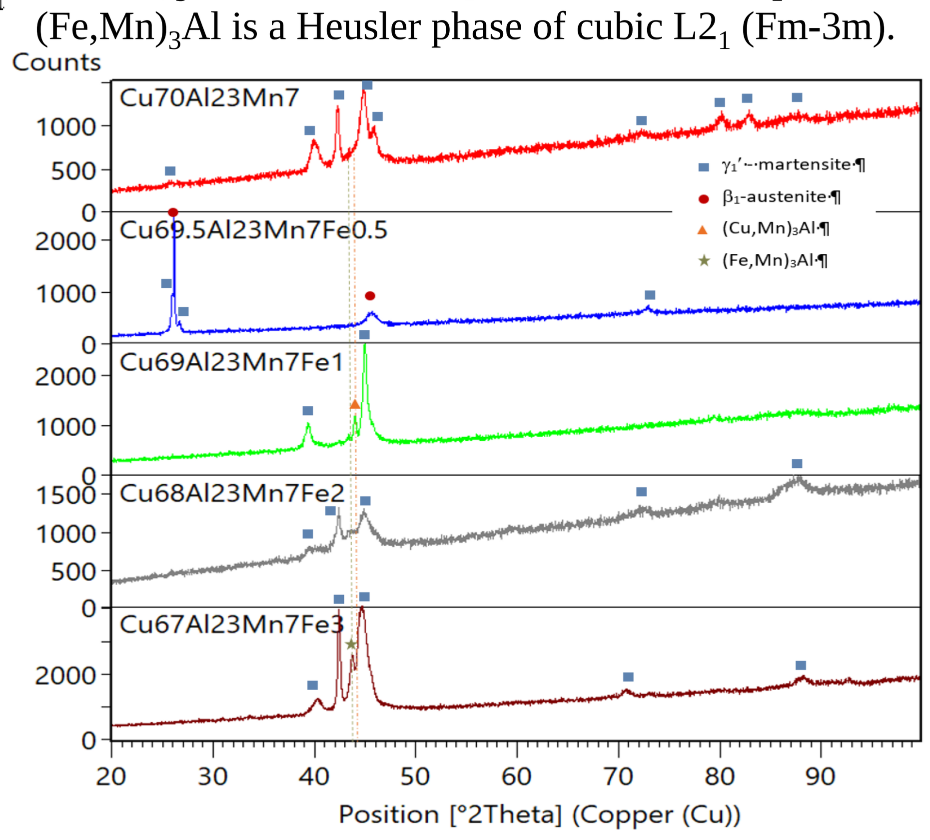


B. Microstructure and phase composition

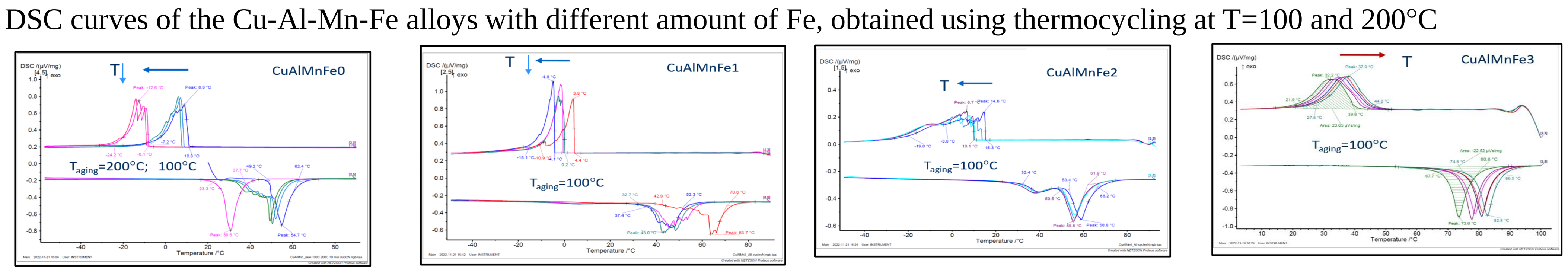
The microstructure of CuAlMnFe alloy (without Fe) in austenite+martensite (left) and martensite (right) state:



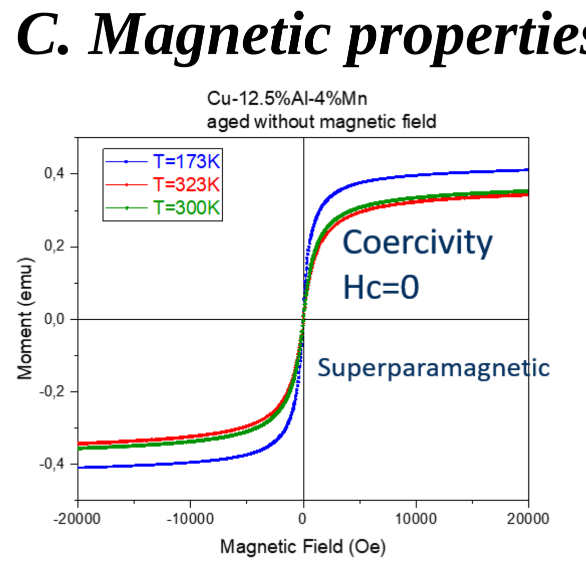
XRD of the studied alloys in the quenched state, where: γ_1' is a martensite orthorhombic (P2mm); β_1 is an austenite with cubic DO_3 structure (Fm-3m); $(Cu,Mn)_3Al$ is a Heusler phase of cubic $L2_1$ (Fm-3m); $(Fe,Mn)_3Al$ is a Heusler phase of cubic $L2_1$ (Fm-3m).



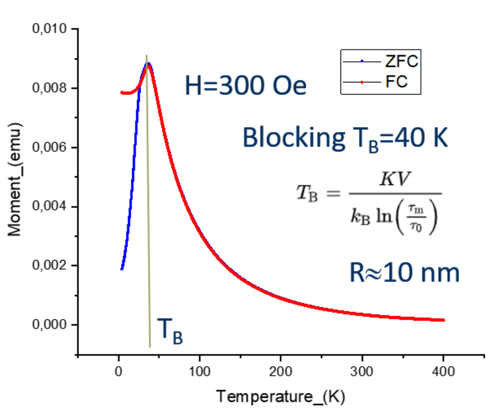
DSC curves of the Cu-Al-Mn-Fe alloys with different amount of Fe, obtained using thermocycling at T=100 and 200°C

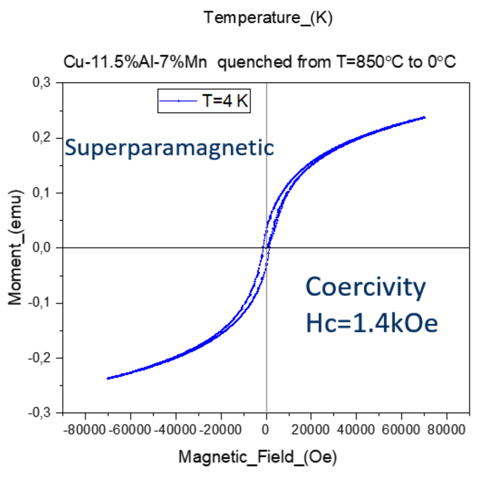


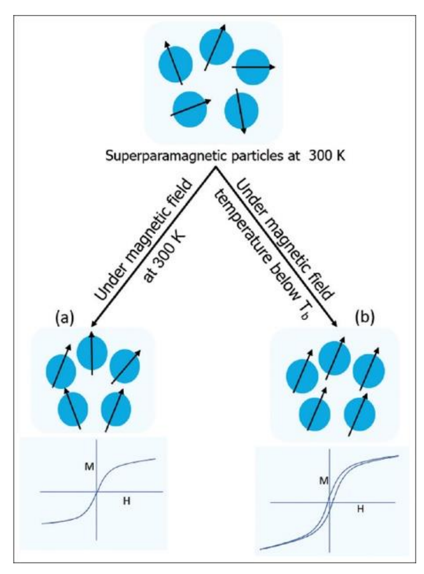
C. Magnetic properties



Specific magnetization curves (hysteresis loops) of Cu-Al-Mn (without Fe) as quenched and as aged and Cu-Al-Mn-Fe alloy with 1%Fe after annealing at 150 and 200°C for 0.1÷2 hours.

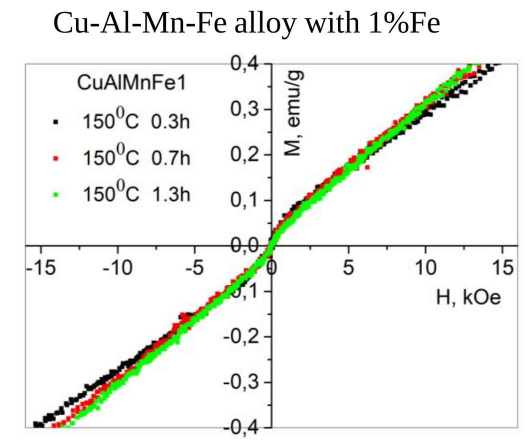


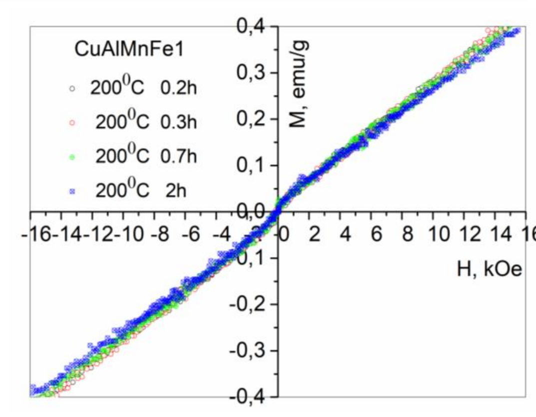




The alloy in magnetic field behaves like a superparamagnetic. Due to the fact that particles are single-domain, magnetization is accompanied by their rotation.

Cu-Al-Mn-Fe alloy with 1%Fe





Conclusions

The structural state and the magnetic subsystem change strongly as a result of the precipitation of a secondary phase: $(Cu,Mn)_3Al$ or $(Fe,Mn)_3Al$ of Heusler compound, essentially depending on Fe concentration in alloy.

It has been established that with an increase in content of iron, a nonmonotonic increase in the start temperature of martensitic transformation and a decrease in hysteresis occur. In this case, the morphology and kinetics of the transformation change significantly, which is associated with variations in the compositions and precipitation of another nanostructured phases.

In magnetic properties, the ternary Cu-Al-Mn alloys behave like typical superparamagnets. Thermal treatment (aging) in ternary alloys leads to a more rectangular course of hysteresis curves and facilitates their magnetization, and reduces the anisotropy field.