Special issue of the 2nd International Conference on Computational and Experimental Science and Engineering (ICCESEN 2015)

Electromagnetic Properties in Nanostructured Alloy $Cu_{70}Co_{30}$ Obtained by a Non-Equilibrium Method

W. Laslouni[a,b,*] and M. Azzaz[b]

[a]Département de Physique, Faculté des Sciences, Université de Blida, Route de P270 Blida 09000, Algeria,
[b]Laboratoire de Science et Génie des Matériaux, u.s.t.h.b., BP 32 El-Alia, Babezzouar 16311, Alger, Algeria

The $Cu_{70}Co_{30}$ alloy was developed by a non-equilibrium method of "mechanical alloying", from a mixture of copper powder and pure cobalt. The nanostructured alloy Cu-Co with grains with a size of about 12 nm, has different electromagnetic properties which are often superior to those of conventional solid alloy, because of the critical size effect. In this work we are interested in the electromagnetic properties of the synthesized material. Resistivity, eddy current and the magnetization evolution were studied. The frequencies selected for plotting the diagram vary from 100 Hz to 100 kHz. To satisfy the Weiss condition, the excitation field must be of the same order of magnitude as the field that characterizes the area of Weiss. For all prepared series, the evolution of the magnetization as a function of milling time was analyzed. The influence of milling time on the resistivity variation is shown.

DOI: 10.12693/APhysPolA.130.112

PACS/topics: 13.40.–f

1. Introduction

The nanostructured materials continue to receive a great attention in different fields of material engineering because of their outstanding physical, mechanical, magnetic and chemical properties, which are different from those of the coarse-grained counterparts [1–3]. Significant progress has been made in developing several processing techniques to prepare nanostructured materials. Mechanical alloying (MA) is one of these techniques. MA is a solid state synthesis method to prepare nanocrystalline alloy/compound powders by milling the elemental powders in an appropriate ball mill. Extreme local pressures and temperatures, engendered for a small milling time during repeated ball-powder-ball collisions, lead to the powdered materials transfer by diffusion and eventually, to the formation of new phases which cannot be obtained by other techniques of preparation [4–6]. In this study, the chosen composition is $Cu_{70}Co_{30}$, which is quite different from all previous alloys in this system.

2. Experimental procedure

The $Cu_{70}Co_{30}$ alloy was prepared by MA from Cu and Co elemental powders. A mixture of appropriate amounts of Cu and Co powders was mechanically alloyed, using a RETSCH PM400 ball mill with stainless balls, under an Ar atmosphere, with the balls to powder weight ratio of 20:1. Mechanical alloying was performed for several processing times: 4, 8, 12, 24, 36 and 54 h, respectively. The produced powders have been characterized by the following techniques: eddy current measurements, measurements of the electrical resistivity and magnetic measurements. Eddy current measurement consists in placing a conductive sample in a variable magnetic field. It is then traversed by induced currents, called "eddy currents" [7]. Measurements of the electrical resistivity were made using the four-point method. Magnetic measurement allowed us to trace the hysteresis loops.

3. Results and discussion

3.1. Eddy current measurement

The impedance diagrams are shown in Fig. 1. According to this figure, one can classify the sample impedance diagrams into two kinds:

- The first kind of impedance diagram is observed in the first eight hours of milling. Such curve has the same form as the impedance curve of pure copper (the curve has a half-circle shape). We can conclude that in this time interval the solid solution Cu-Co is not yet formed and the mixture is inhomogeneous.
- In the samples milled longer then 12 hours, the impedance curves are not close again due to the increase of the resistive part, which is due to the reduction of the crystallite size along with the increase in number of joints in the grains.

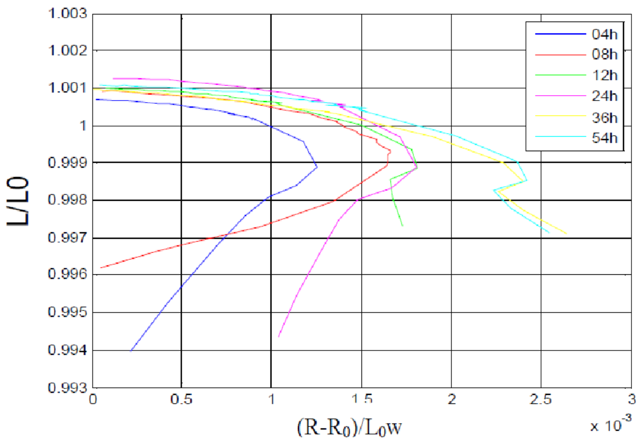

Fig. 1. The impedance diagrams of Cu_{70} CO_{30} for different milling times.

In general, the variation in the impedance of the ferromagnetic particles is proportional to the reduction of the crystallite size, but as is well illustrated in Fig. 2 it is not the case in this alloy. This unexpected change can be attributed to different changes due to mechanical milling (agglomeration, particle morphology, internal defects, etc.).

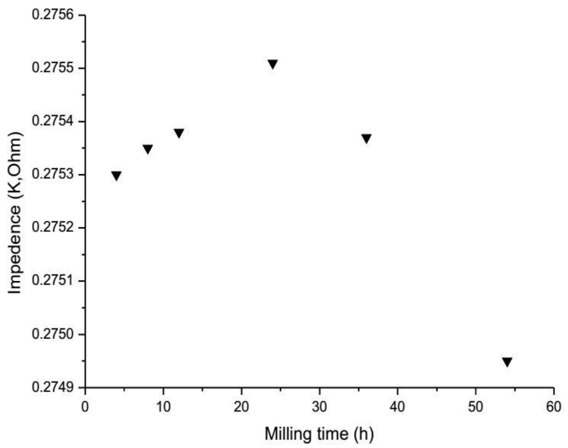

Fig. 2. Variation of the impedance as a function of milling time in $Cu_{70}Co_{30}$.

3.2. Resistivity measurements

In this kind of alloy $Cu_{70}Co_{30}$, the majority of studies have investigated the influence of milling on the measurement of the magnetoresistance (measurement of the resistivity in the magnetic field) [8–11]. The results of measurement of the resistivity for $Cu_{70}Co_{30}$ alloy (which take into account the sample thickness) are given in Table I. The starting of milling causes an increase in electrical resistivity. The evolution of the electrical resistivity and grain size are shown in Fig. 3. The evolution of the resistivity is inversely proportional to the grain size evolution.

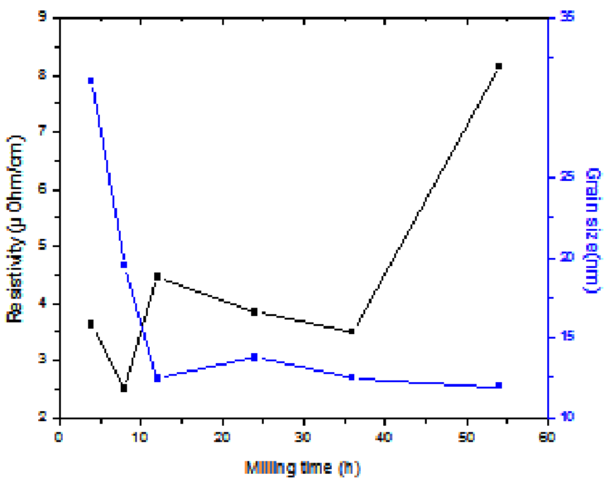

Fig. 3. Crystallite size and resistivity evolution as a function of milling time for $Cu_{70}Co_{30}$.

The milling leads to the dispersion of magnetic element (cobalt) in a non magnetic matrix (copper), which slows the movement of the electron flow. The prolongation of milling time generates structural defects that have a proportional effect on the electrical resistivity.

TABLE I

The results of measurements of the resistivity.

Milling time [h]	0	4	8	12	24	36	54
Resistivity [$\mu\Omega$ cm]	1.5	3.63	2.5	4.46	3.85	3.5	8.16

3.3. Magnetic measurements

At the time of acquisition of the magnetic measurements, it was noted that saturation is achieved more quickly for the samples milled for longer time, compared to the samples milled for shorter duration. The hysteresis loop shown in Fig. 4 was expanded to obtain the values of the coercive field. The hysteresis curves produced at room temperature for the powders milled up to 54 hours clearly have a ferromagnetic behavior. The magnetization increases with the magnetic field and the saturation is reached. The only plausible explanation is that the alloy is a "homogeneous" ferromagnetic, because of the importance of the fraction of cobalt present. A study of each curve shows the presence of low coercivity in each studied sample.

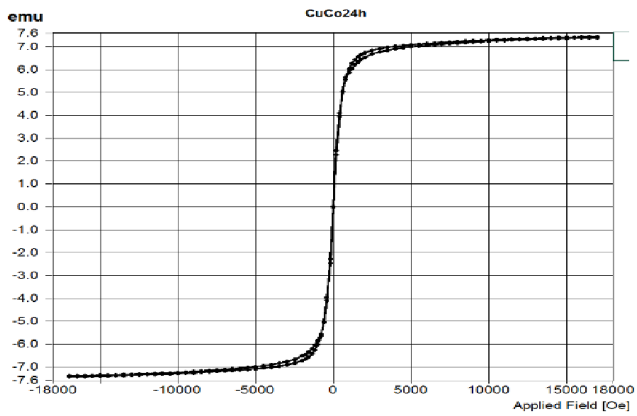

Fig. 4. The shape of the hysteresis curves recorded for the sample milled for 24 h.

4. Conclusions

The impedance diagram has a curve shape which is very different from that of solid materials. The impedance curve of the nanostructured $Cu_{70}Co_{30}$ alloy does not close because of the increase of the resistive part, which is due to the decrease in crystallite size along with the increase in number of grain junctions. Milling permits the homogeneous distribution of the magnetic elements in the copper matrix, which slows the movement of the electron flow. The prolongation of milling time generates structural defects that have a proportional effect on the electric resistivity. The magnetic measurements show that the hysteresis curves obtained at room temperature on the powders milled up to 54 hours clearly exhibit ferromagnetic behavior. The magnetization increases with the magnetic field and saturation of magnetization is reached. The only plausible explanation is that the alloys are ferromagnetic and globally "homogeneous", because of the size of the fraction of these magnetic elements.

References

[1] C.C. Koch, *Nanostruct. Mater.* **9**, 13 (1997).

[2] C. Suryanarayana, *Prog. Mater. Sci.* **46**, 1 (2001).

[3] D.L. Zhang, *Prog. Mater. Sci.* **49**, 537 (2004).

[4] S. Alleg, M. Ibrir, N.E. Fenineche, S. Azzaza, R. Bensalem, J.J. Suñol, *J. Alloys Compd.* **494**, 109 (2010).

[5] M.S. El-Eskandarany, *Mechanical Alloying for Fabrication of Advanced Engineering Materials*, Noyes Publication, New York 2001.

[6] W. Tebib, S. Alleg, J.M. Greneche, *Int. J. Nanoparticles* **3**, 237 (2010).

[7] R. Grimberg, L. Udpa, A. Savin, R. Steigmann, V. Palihovici, S. Udpa, *NDT & E Int.* **39**, 264 (2006).

[8] Y.G. Yoo, D.S. Yang, S.C. Yu, W.T. Kim, J.M. Lee, *J. Magnet. Magnet. Mater.* **203**, 193 (1999).

[9] J. Jiang, D.G. Zeng, H. Ryu, K.W. Chung, S. Bae, *J. Magnet. Magnet. Mater.* **322**, 1834 (2010).

[10] E.H.C.P. Sinnecker, I.S. Oliveira, P. Tiberto, A.P. Guimaraes, *J. Magnet. Magnet. Mater.* **218**, L132 (2000).

[11] G. Martinez, M.N. Baibich, M.G.M. Miranda, E. Vargas, *J. Magnet. Magnet. Mater.* **272–276**, 1716 (2004).