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ResearchArticle

Theory of Magnetic Anisotropy in Nanostructured Alloy Cu_{70} Fe_{30}[#]

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Anisotropy theory

Abstract: The intermetallic based on transition metal compounds present interesting magnetic properties for the technological applications (permanent magnets, magnetic recording,. . .).

$Cu_{70}Fe_{30}$ nanostructured with crystallite size vary from 10 a 12 nanometers ha been developed by a mechanical milling method. The iron and copper distribution was clear. The distribution showed a homogeneous distribution of iron and copper in a Cu-Fe obtained after 36 h milling.The structural properties have been performed with X-ray diffraction. With in- creasing milling times, Fe diffuse into the Cu matrix, which accelerates the formation of the magnetic nanostructure Cu- Fe alloys. The magnetic behavior is investigated using Vibrating Sample Magnetometer (VSM). The binary alloys nanocrystals possess ferromagnetic character at room temperature.

1. Introduction

The technical development of nanomaterials are becoming more diverse, most of annealing are used to tape [1] - [6] and thin films [7] - [10]. Recently, the nanocrystalline state is often obtained by high energy milling followed by recrystallization controlled by various heat treatments [11] - [17]. The latter technique is adapted to meet the required standards and coercive remanent magnetization. In effect, as mentioned in the literature, this method has enabled many studies to show its efficiency [15,18,20]. The influence of structural disorder on the magnetic properties has been evidenced, in CuFeCo, in different types of microstructures such as cold worked single crystals quenched or ball milled and mechanically alloyed nanoparticles. In general, some magnetic properties can be improved when the grain size is reduced to the nanoscale, while the presence of stresses and defects introduced by MA impairs the magnetic behavior; the overall magnetic property is a competition between decreasing grain size and increasing strain. Extrinsic magnetic properties such as the remnant magnetization (Mr) and coercivity (Hc) can be tailored by modifying the structure and composition . Hc is dependent on how the sample has been processed and therefore will be affected by any change in microstructure. The saturation magnetization is regarded as independent of the microstructure and strongly depends on the chemical composition. In this paper, we present structural and magnetic properties of nanocrystalline Cu-Fe alloy prepared by mechanosynthesis.

2 Magnetic properties of nanostructured metal alloys (random anisotropy)

Experience has shown that a reduction in grain size leads firstly an increase in the coercive field, until a diameter of about 100 nm, then a decrease thereafter (Figure 1). For sizes smaller grains (up to the amorphous state), the coercive force is extremely low. The contributions of the magnetocrystalline anisotropy strongly differ from those of microcrystalline system. In addition, the concept of domain wall disappears because the grains are monodomain. However magnetocrystalline anisotropy of an assembly of crystalline nanograins randomly distributed can be modeled by the random anisotropy model [21,22,23, 24]. This approach was originally developed by R. Alben et al [25] to explain the magnetic properties of amorphous ferromagnetic materials. This model has subsequently been extended by G.Herzer et al [24] to explain the magnetic behavior of nanocrystalline alloys. The model predicts the sharp variation of the effective anisotropy and coercive force depending on the grain size. This is supported by experimental observations. To better explain this theory, we will introduce the mathematical model proposed by G.Herzer [24].

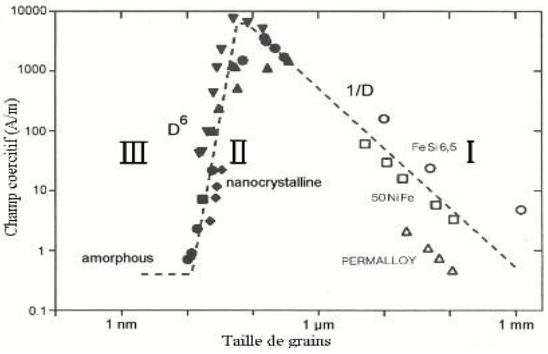

Figure1. *Coercive field of metal alloys; depending on the grain size.*

The model shows a variation of the anisotropy constant averaged with the sixth power of the particle size, which gives to the coercive force:

$$H_c = P_C \frac{K}{J_S} = P_C \frac{V^2 D^6 K_1^4}{A^3 j_s} \qquad (1)$$

Pc is a dimensional factor, and Jc is the average saturation magnetization of the material.

The coercive force is therefore proportional to the sixth power of the particle diameter, which has been verified experimentally for nanocrystalline materials (Figure 1.).This model uses only the magnetocrystalline anisotropy, but we can also take into account the magnetoelastic anisotropy and shape anisotropy. It is considered in this case that the total anisotropy in the material is the sum of all the anisotropies.The model proposed by Herzer [24] is strictly applicable to single phase systems, but subsequent developments have shown the possibility of using the anisotropy averaged model for two-phase systems. These models are reduced to a model proposed by Herzer, when the number of phases is equal to a [25 - 28].

3 Experimental

Using highly pure fine powder (≥99.90%) of Cu and Fe, sample of the system $Cu_{70}Fe_{70}$ was prepared by mechanical alloying. The structural and microstructural properties of powder were investigated by X-ray diffraction. XRD was performed using a Panalytical X' Pert Pro MPD X-ray diffraction system with Cu K_α radiation (($\lambda K_{\alpha 1}$=1.540598 Å and $\lambda K_{\alpha 2}$ = 1.544426 Å) in the range from 20° to 105°. The step size and step time were 0.02° and 1 s/step, respectively.

Magnetic measurements were obtained at room temperature by means of a vibrating sample magnetometer (VSM, EV9) with the external magnetic field H in the 0–25 kOe range.

4 Results

4.1 Structural Analysis

At the early stage of the MA process (less than 12 h of milling), the intensity of the fcc Cu and Fe diffraction peaks decreases progressively with respect to that of the fcc Cu ones. Simultaneously the Cu diffraction peak profiles become asymmetric, and their low-angle shoulders are broadened. Due to the appearance of broad and low intensive peaks on the left side of the Fe peaks. These peaks can be attributed to new phases Cu-Fe solid solution which possess the same structure type as the fcc Cu but are characterized by slightly larger unit of cell parameters.

The crystallite size is positively one of the most important parameters in the mechanical alloyed powders. The change in breadth of diffraction peaks observed is due to the changes in crystallite size and in lattice strain. The average crystallite size decreased rapidly up to 8 h of milling and then attained 9.5 nm after 24h of milling for CuFe.

Hysteresis biorehav

Saturation magnetization (Ms) and coercivity (Hc) were obtained from the hysteresis curves (Fig 2). The grain refinement diminishes the magneto-crystalline anisotropy due to averaging the effect of magnetization over randomly oriented nanosized grains.

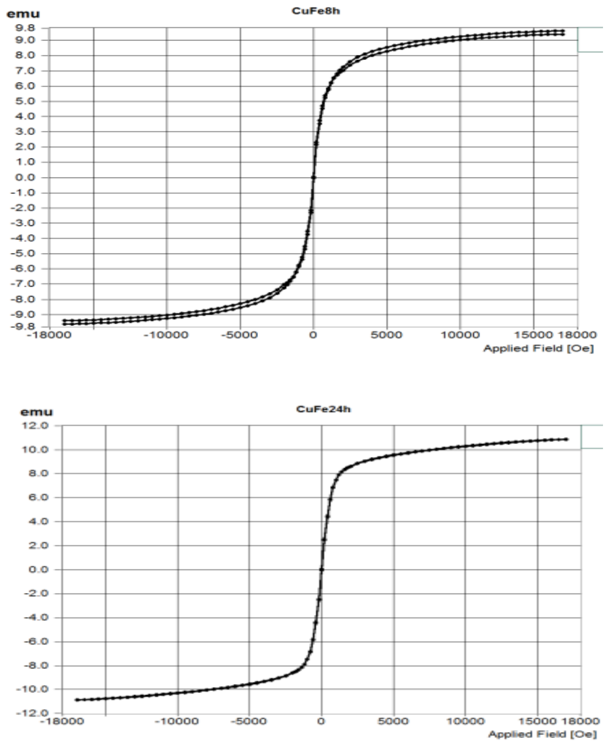

Figure . 2 *Hystérésis curves CuFe alloys (8h and 24h).*

Table .1 *The values of H_C, Br and M_s*

	$Cu_{70}Fe_{30}$		
Milling time (h)	**Hc (Oe)**	**Ms (emu)**	**Mr/ Ms**
4h	5.71	10.87	0.007
8h	2.8	9.51	0.003
24h	43.7	16.25	0.032

The saturation magnetization is very sensitive to the composition changes during MA. The increment of saturation magnetization aggregates during milling can be ascribed to the completion of alloying and the diminishing of magneto- crystalline anisotropy due to the grain refinement, which leads to an easier rotation of the magnetic vector. Table 1 shows the variation of coercivity, Mr and Ms against milling time. The Hc increases, it can be related to the grain size and plastic deformation effect in the introduction of internal strain due to different types of defects. The coercivity of crystalline alloys depends strongly on grain size because the magnetic domain walls interact with the grain boundaries. The behavior of the coercive force depending on the grain size, shown in Figure 3, appears to illustrate a difference from the model of the averaged anisotropy, because an increase in coercivity is observed with decreasing grain size. For both alloys, there are two points that do not follow the general trend of the variation of coercive field size grains. This increase in coercive field with decreasing grain size, for our ground powders, can be explained by:

- Firstly, by the presence of stresses introduced during the extended grinding (to the ground powder to 36 hours).

- Second, by defects introduced during the compacting, because the magnetic measurements are performed on the pellets. it should be mentioned that the coercive force of a powdered material depends on how the sample is

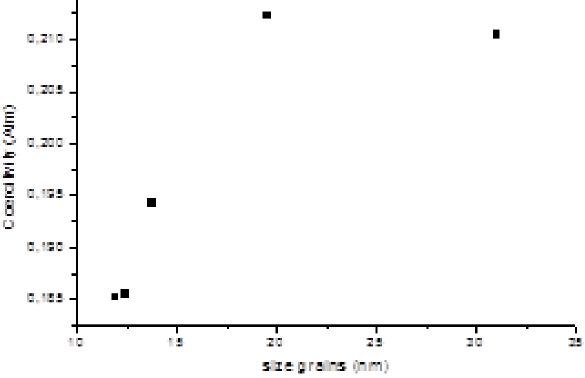

Figure. 3. *Evolution of the coercive field with the grain size for the Cu_{70} Fe_{30} alloy.*

prepared; more poorly compacted powder is, the higher the coercive force is large as the particles are far apart.

5 Conclusion

The crystallite size decreased from 26 nm to9.56nm after 24 h of milling for both alloys.

These results were expected with the high levels of iron. Concerning physical quantities characterizing the hysteresis loop (coercivity, remanent induction and saturation magnetization), a small difference value is stored between these two alloys. This difference depends on the nature of the magnetic elements and their distribution in the copper matrix. The variation of HC with the grain size shows a difference from the model of the average anisotropy, because an increase in coercivity is observed with decreasing grain size for grinding time. The increase in coercive field with decreasing grain size, can be explained by the presence of stresses introduced during grinding.

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