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In-plane magnetic anisotropy along the width in amorphous magnetic ribbons

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Abstract

A study about the variation of the in-plane magnetic anisotropy along the width of the ribbon is carried out in Co- and Fe-based amorphous magnetic ribbons. From the measurements of the anisotropy in as-quenched, mechanical polished and annealed samples the origin of the lack of homogeneity of the in-plane magnetic anisotropy in wide amorphous ribbons is determined. In addition a shape magnetic anisotropy that we think is originated by the edge effect was found.

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The improvement of the manufacturing process of amorphous ribbons during the last years allows the production of wide, thick, and long amorphous magnetic ribbons nowadays. But a lack of homogeneity of their magnetic properties has been observed in these kinds of materials [1,2]. Investigation of the variation of the magnetic properties along the width, length and thickness provides information necessary to improve the homogeneity of the magnetic behaviour of these materials and then, it will allow to produce high-quality magnetic materials [3].

One of the most important magnetic parameters of a magnetic material is its magnetic anisotropy, which results in the anisotropy character of a number of material parameters such as induction and core loss [4]. In the wide amorphous ribbons it has been observed that the in-plane magnetic anisotropy takes different values in the centre and at the edges of the ribbons [5,6]. Then, in order to improve the use of these materials in transformer cores it would be necessary to study the origin of this lack of homogeneity of the in-plane magnetic anisotropy.

In this paper, we are going to study the origin of the variation of the in-plane magnetic anisotropy along the width in Co- and Fe-based amorphous magnetic ribbons.

The materials used in this article were amorphous ribbons from the British firm Goodfellow of composition $Fe_{78}B_{13}Si_9$ and $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$. Both ribbons are 50 mm wide and 25 μm thick. Discs of 1 cm diameter were cut from different parts along the ribbon width. We used circular samples to measure the in-plane magnetic anisotropy in order to avoid any shape effect.

The in-plane magnetic anisotropy was obtained by torque magnetometry using an automatic torque magnetometer "DMS-1660" from Digital Measurements Systems and a very sensitive magnetometer developed by some of the authors [7].

Curves (1) of Figs. 1a and b show the variation of the in-plane magnetic anisotropy along the width in the as-quenched state of $Fe_{78}B_{13}Si_9$ and $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$. As can be observed there is a lack of homogeneity in the in-plane magnetic anisotropy, which shows a random variation along the width. This random

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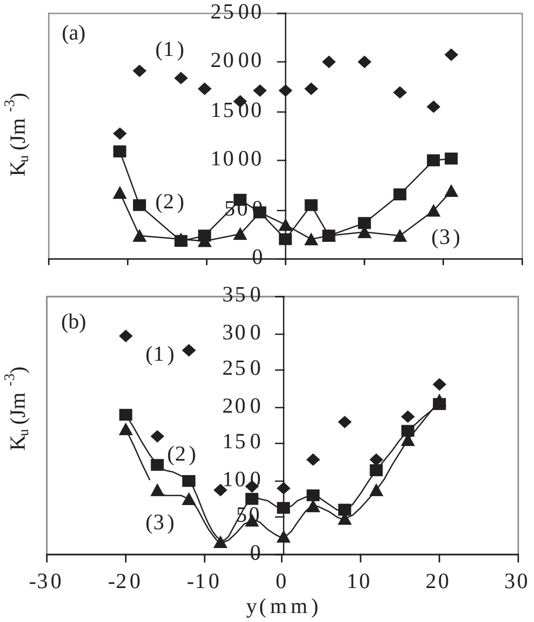

Fig. 1. Variation of the in-plane magnetic anisotropy constant along the width in (a) $Fe_{78}B_{13}Si_9$ and (b) $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$ amorphous ribbons; (1) as-quenched samples, (2) after mechanical polishing, and (3) after mechanical polishing and annealing.

variation can be explained as due to the surface roughness that varies in a random way from point to point of the ribbon (the arithmetic mean deviation of the roughness profile, Ra, in the studied samples varies from 0.49 to 1.51 μm in the air-surfaces of the ribbons and from 0.22 to 0.84 μm in the wheel-surfaces).

We performed a random mechanical polishing with 0.1 μm grain size alumina to remove the surface roughness of the samples. In this way practically all the surface roughness was removed as checked with a commercial prophilograph with a maximum sensitivity of 0.1 μm. The variation of the in-plane magnetic anisotropy along the width in the polished samples is shown in curves (2) of Figs. 1a and b. The results show that in the case of $Fe_{78}B_{13}Si_9$ the magnetic anisotropy decreases dramatically and it has a value of about 400 Jm^{-3} in the central part of the ribbon, but there are two zones of about 3 mm near both edges in which the anisotropy is much greater (1250 $J\,m^{-3}$). This drastic reduction of the anisotropy after the mechanical polishing could be explained because the surface roughness originates a great anisotropy due to the saturation magnetization (1.56 T) of this material. In the $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$ polished samples the in-plane magnetic anisotropy has also been reduced, but it shows the same behaviour as before the mechanical polishing. The central part presents lower anisotropy than the zones near both edges (about 6 mm) in which the anisotropy is much greater. In this case there is a gradual increase of the anisotropy from the central part to the edges. Taking into account that the saturation magnetization of this material is only 0.7 T the magnetic anisotropy originated by surface roughness is small.

Other sources of in-plane magnetic anisotropy could be internal stresses and directional order originated during the quenching process, so an annealing of 2 h at 480°C (above the Curie temperature of both materials) in a controlled furnace with an inert Ar atmosphere was performed to remove the internal stresses and the directional order. The results are shown in curves (3) of Figs. 1a and b. It can be seen that the magnetic anisotropy practically does not vary except in the previously mentioned areas near the edges in which it has been a reduction of the magnetic anisotropy from 1250 to 600 $J\,m^{-3}$ in $Fe_{78}B_{13}Si_9$ and there has not been any appreciable variation in $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$.

The above-mentioned results suggest that in addition to the surface roughness and directional order as sources of in-plane magnetic anisotropy in amorphous magnetic ribbons, there is an effect associated with the edges of the ribbons.

In the $Fe_{78}B_{13}Si_9$ polished samples the in-plane magnetic anisotropy in the edges, which is removed after the annealing, could be explained in the following way: in amorphous magnetic ribbons the anisotropy follows the magnetization direction present during quenching and also the magnetization stays parallel to the edges on every point along an edge normal to avoid the magnetic poles formation [8,9]. Then, in the edges of ribbons with high Curie temperature a magnetic anisotropy parallel to the edges will be developed [10]. But there is a remainder anisotropy that it is not removed by the annealing. In the $Co_{69}Fe_4Mo_2Ni_1B_{12}Si_{12}$ polished samples there is not a variation of the edge anisotropy after annealing. This fact seems to indicate that directional order cannot be the origin of this anisotropy.

The same edge effect has been observed by Kolano et al. [11] when they induced a transverse magnetic anisotropy in samples of $Co_{71.5}Fe_{2.5}Mn_2Mo_1Si_9B_{14}$ by magnetic field annealing. They also explain the results as due to a demagnetization field near the edges.

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