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MAGNETISATION AND MAGNETOSTRICTIOn OF RAPIDLY QUENCHED RARE EARTH-IRON-BORON ALLOYS

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Abstract. - Tb-Fe-B alloys have been melt spun and data obtained for the room temperature magnetisation and magnetostriction as functions of applied field and composition. Small additions of La (~5 at. %) leave the magnetisation unchanged but substantially reduce the magnetostriction. Results are compared with sputtered binary metallic Tb/Fe alloys.

Introduction

Although large magnetomechanical coupling coefficients (>0.9) have been observed in rapidly quenched, magnetically annealed iron-boron alloys [1], they only generate small magnetostrictive strains (~30×10^-6). If these strains could be raised by introducing rare earths, a combination of an extremely high coupling efficiency with large magnetostriction would be an attractive material for transducers. Unfortunately the Fe-RE phase diagram indicates that compositions of the form RE-Fe2, with Curie points above room temperature, are not easily quenched by melting. Furthermore, if such an alloy can be quenched into an amorphous phase with a totally random structure, there could be zero magnetostriction if each RE ion resides in a locally isotropic environment.

The present work was undertaken to investigate

(a) possible ways of overcoming the practical problems in melt spinning binary RE-Fe2 metallic alloys and

(b) the changes in magnetostriction arising from the introduction of RE ions into an amorphous matrix.

Experimental techniques

Alloys based on Fe30B70 are easily melt-spun due to a deep eutectic at this composition. The appropriate addition of boron to RE-Fe2 lowers the melt temperature and two systems were chosen as candidates for melt spinning, TbFe2 (Fe0.82B0.18)1-x and TbFe2 (Fe0.82B0.18)0.96-xLa0.04 in the range 0.05 < x < 0.30. Polycrystalline samples were pre-cast with 3N pure materials and all compositions spun with wheel velocities of ~35 ms^-1 in an inert gas atmosphere. Ribbons ~30 μm thick, 1.5 mm wide and 1-3 cm in length were examined by XRD using Cu Kα radiation. There was little or no evidence of crystallinity on ribbon faces that had been adjacent to or remote from the wheel surface, the common result being an amorphous “hump” centred around a diffraction angle 2θ ~ 45 deg. Magnetisation measurements were made with a VSM capable of resolving ±0.1 emu with an accuracy of ±3 % and strain gauges (Micromeasurements Type SK) used to measure the magnetostriction. The “clamping” effect of a gauge on a single thickness of ribbon was investigated by applying a single gauge to one face of a Metglas 2605 SC ribbon, measuring the magnetostriction, and then repeating the measurement after bonding an additional gauge to the opposite face. The two measurements gave the same result (to within ±1 %) and agreed with previous data [2].

Results

Room temperature magnetisation curves for samples taken from the extremes of the compositional range (x = 0.05 and x = 0.30) show that the materials are magnetically soft and saturate in small applied fields (~10 kA m^-1). The hysteresis is almost negligible with typical coercive fields ~0.4 kA m^-1 and apart from the saturation magnetisation being dependent on the Tb/Fe ratio, there are very few differences between the behaviours of these samples. One slight change is that the addition of La for x = 0.30 does increase the permeability. The variations of saturation magnetisation with terbium content (i.e. Tb/(Tb+Fe)) are shown in figure 1 for samples in the range 0 < x < 0.3 with or without La, and at this particular temperature there is a compensation point (M_s ~ 0) when x ~ 0.25.

Unlike the magnetisation, the magnetostriction in the series with and without lanthanum are quite different (Fig. 1). The alloys without La at first show a small decrease in λ_s as the terbium content is increased, followed by a maximum (λ_s ~ 170×10^-6) for Tb/(Tb+Fe) ~ 30 at. %. The strains in alloys with La at first show little change as the Tb content is increased but begin to decrease once the Tb content exceeds ~18 at. %.
Fig. 1. - Magnetisation and magnetostriction in alloys with ( ) and without (0) La for increasing Tb content, i.e. Tb: (Tb+Fe) ratio.

The field dependences of the magnetostrictive strains in materials with and without La are very different. With lanthanum, the strains are mostly due to a volume effect whereas without lanthanum relatively large anisotropic strains are developed.

Discussion

Compared with binary metallic alloys with similar Tb:Fe ratios, the presence of boron in the present alloys has little effect on the intrinsic magnetisation. After compensating atomic compositions for the boron content, the minima in the magnetisations as a function of the Tb:Fe ratio are almost identical to that seen in sputtered Tb-Fe films [3], regardless of the La content. The boron seems merely to act as a simple diluent without participating in the magnetic interactions. An explanation for a zero net magnetisation is similar to that proposed by Alperin et al. [4] for the behaviour of sputtered films, namely that the iron and terbium moments are antiparallel. Hence at the iron rich end of the compositional range, the net magnetisation is attributed to the iron moments but as the terbium content is increased there is a particular composition (at room temperature) at which the iron and terbium moments are completely opposed. For further additions of terbium, the terbium magnetisation exceeds that of the iron.

It is speculative at this stage to try and identify the detailed magnetic structure. If these rapidly quenched materials are wholly amorphous then the observed effects could be attributed to a spin glass structure [5] or instead of a collinear antiferromagnet it may be that a sperimagnetic system exists. Further analysis of the magnetic and metallurgical structures must be conducted in order to identify these precisely.

Finally, the additions of lanthanum are not expected to form any stable intermetallic compounds with iron. It has been suggested previously that the lanthanum assists the glass forming process [6]. Although the present XRD results show no significant differences between samples with and without lanthanum, the magnetostrictive behaviours are markedly different. The magnetostrictive strains in alloys without lanthanum compare more favourably with previous results from deposited films and as may indicate their structures are not wholly amorphous. The reasons for such small additions of lanthanum causing the reduction in magnetostriction, are not yet understood. It is possible that the lanthanum preferentially occupies positions near terbium sites, thereby reducing the magnetic coherence length.

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