JORNADAS ACADÉMICAS 2019

CIMAV · CONACYT · 25 ANIVERSARIO

Magnetostrictive effect of $Fe_{81}Al_{19}$ alloys doped with Terbium

J. S. Uribe-Chavira[1], M. C. Grijalva-Castillo[2], C. R. Santillán-Rodríguez[1], R. J. Sáenz-Hernández[1], J. A. Matutes-Aquino[1]

[1.] Centro de Investigación en Materiales Avanzados, S.C., Materials Physics Department, Chihuahua, México.

[2.] CONACYT – Centro de Investigación en Materiales Avanzados, S.C., Materials Physics Department, Chihuahua, México.

1. Introduction

In recent years, there has been strong interest in producing low-cost magnetostrictive materials for various industrial applications, such as stress and torque sensing, energy harvesting, structural health analysis, among others. Among the materials that exhibits a moderate magnetostriction value at low-cost there is two systems of interest: Fe-Ga and Fe-Al. The Galfenol shows moderate magnetostriction in polycrystalline form and recently has been reported a drastically improvement in the magnetostriction coefficient of polycrystalline Galfenol doped with rare earths such as Tb [1-3] and Dy [4]. This raises the question if using similar technique with Fe-Al alloys should produce similar results. Therefore, in this work we have studied the magnetostrictive coefficient in Fe-Al alloys doped with Tb.

2. Experimental

Raw material preparation

- $Fe_{81}Al_{19}$
- $Fe_{81}Al_{19}Tb_{0.05}$
- $Fe_{81}Al_{19}Tb_{0.1}$
- $Fe_{81}Al_{19}Tb_{0.15}$
- $Fe_{81}Al_{19}Tb_{0.20}$
- $Fe_{81}Al_{19}Tb_{0.25}$

Arc-melting

4 times under Ar atmosphere in a water cooled copper mold.

Structural characterization

- Composition was determined by ICP-OES, for digestion: HCl y HF (relation 1:1).
- Crystalline structure analysis by X-ray diffraction (Cu Kα) and Rietveld refinement.
- Grain size was observed by optical microscopy.
- Composition homogenization was verified by EDS.

Magnetic characterization

- Hysteresis loops measured at room temperature
- Longitudinal ($\lambda_{\parallel}$) and transversal ($\lambda_{\perp}$) magnetostriction measured at room temperature.

3. Results

3.1. XRD & ICP-OES

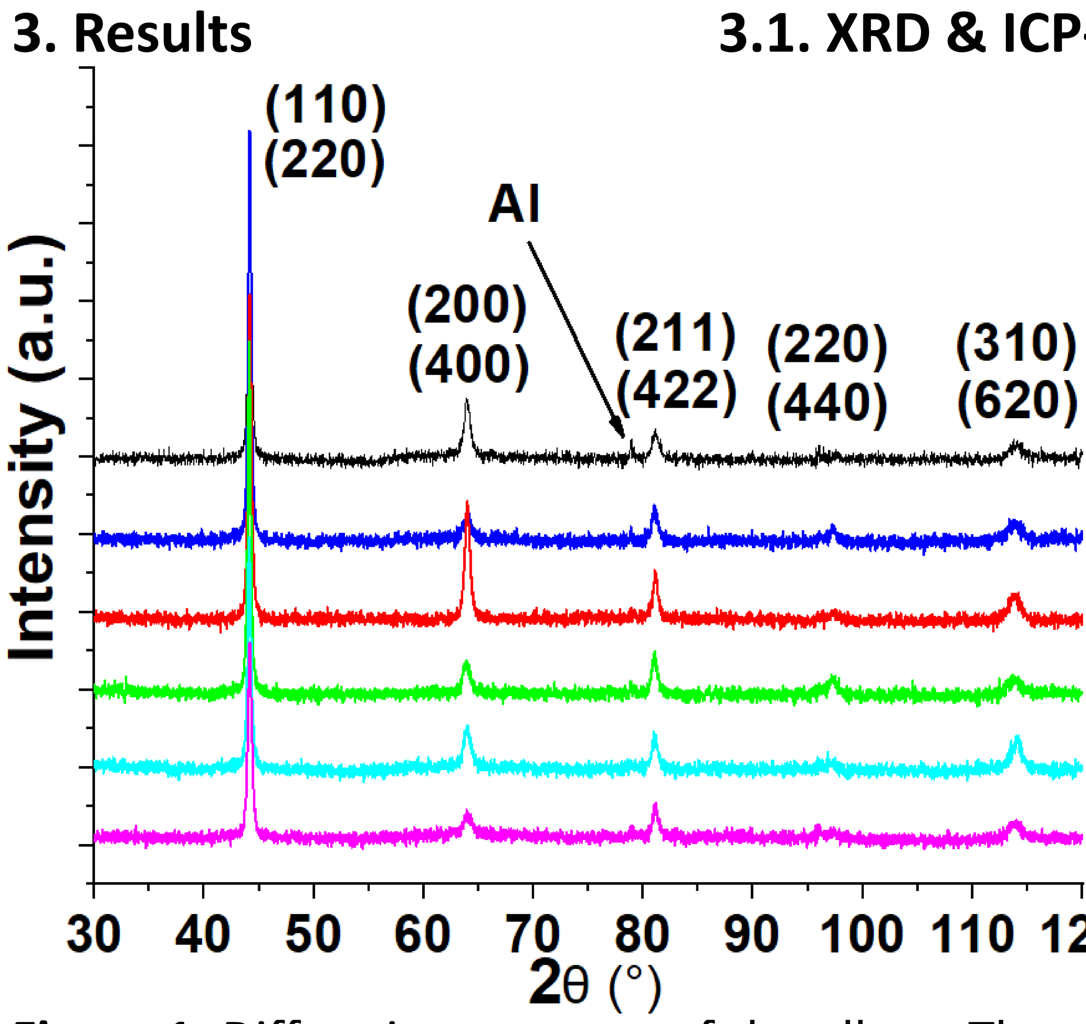

Figure 1. Diffraction patterns of the alloys. The upper directions correspond to the BCC A2 phase (α –FeAl) and lower directions for cubic D03 phase (Fe_3Al).

Table 1. Compositions obtained by ICP-OES analysis.

	Fe at. %	Al at. %	Tb at. %
←	82.571	17.429	0
←	81.530	18.452	0.018
←	81.289	18.692	0.019
←	81.418	18.557	0.025
←	81.938	18.036	0.026
←	81.671	18.294	0.035

3.2. Rietveld refinement

FullProf Suite [5]. Pseudo-Voigt function was used. Data used: 2.911 Å (α − FeAl) [6] and 5.791 Å (Fe_3Al) [7].

x	Rwp	Rexp	χ^2	% α-FeAl	% Fe_3Al
0	37	34.6	1.14	88.04	11.96
0.018	28.3	27.4	1.06	91.63	8.37
0.019	34.4	28.8	1.41	86.81	13.19
0.025	29.6	29.3	1.02	93.37	6.63
0.026	36.9	34.8	1.12	93.67	6.33
0.035	39.2	38.7	1.05	93.70	6.30

Table 2. Weighted profile factor (Rwp), Expected factor (Rexp), Goodness of fit and phase proportion for each Rietveld refinement.

	Lattice parameter (Å)		V		G1
x	α-FeAl	Fe_3Al	α-FeAl	Fe_3 Al	Texture (200)
0	2.914	5.811	0.267	0.151	-1.83
0.018	2.910	5.839	0.143	0.265	0.69
0.019	2.915	5.818	0.176	0.389	-2.36
0.026	2.911	5.841	0.167	0.335	0.04
0.027	2.911	5.800	0.204	0.381	-1.39
0.035	2.909	5.794	0.259	0.143	-0.67

Table 3. Refined parameters for each Rietveld refinement.

3.3. Microstructure evolution

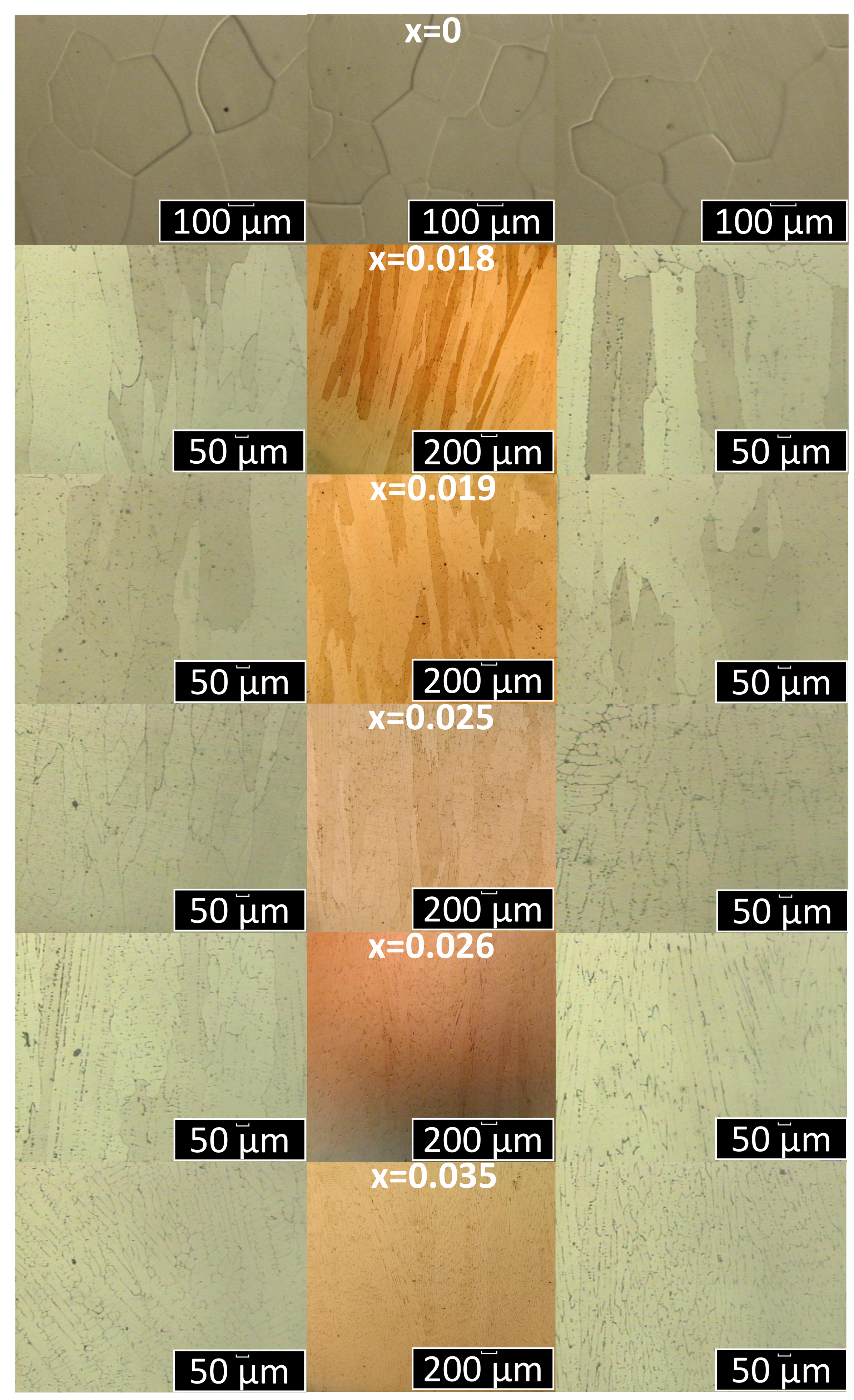

Figure 2. Optical micrographs of the samples of $Fe_{81}Al_{19}Tb_x$ alloys.

3.4. EDS

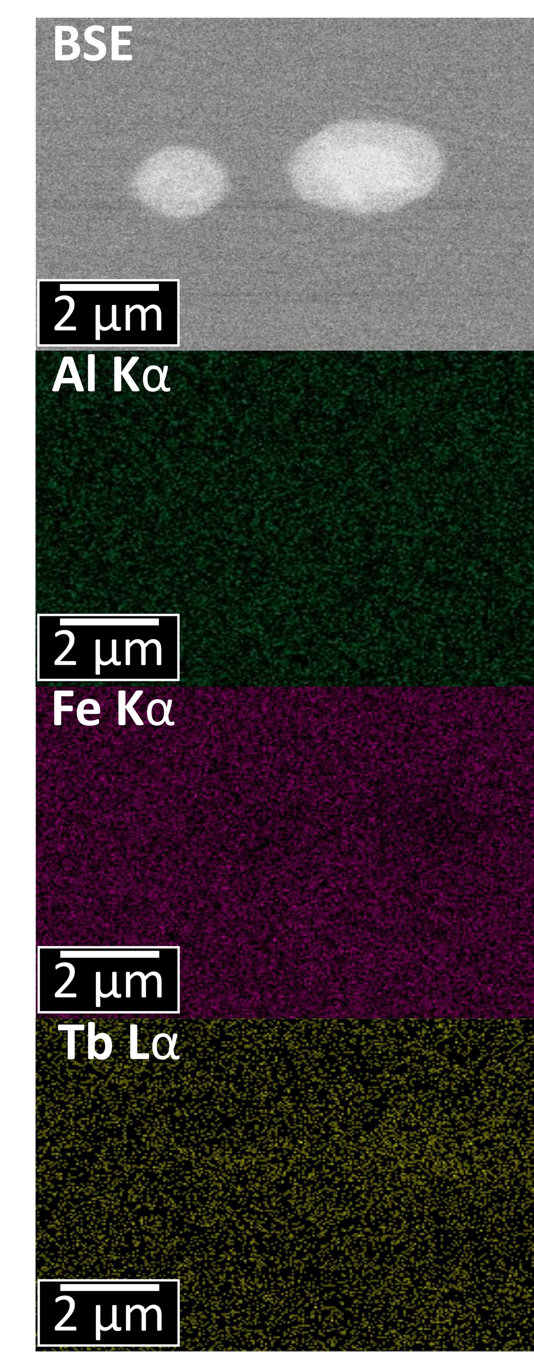

Figure 3. EDS Mapping of $Fe_{81}Al_{19}Tb_{0.035}$ alloy.

Alloy	Grain Class
x=0	EG
x=0.018	EG+CG
x=0.019	CG
x=0.025	EG+CG
x=0.026	CG
x=0.035	EG+CG

Table 4. Grain class of each alloy: Equiaxial and Columnar.

3.4. Magnetization and Magnetostriction

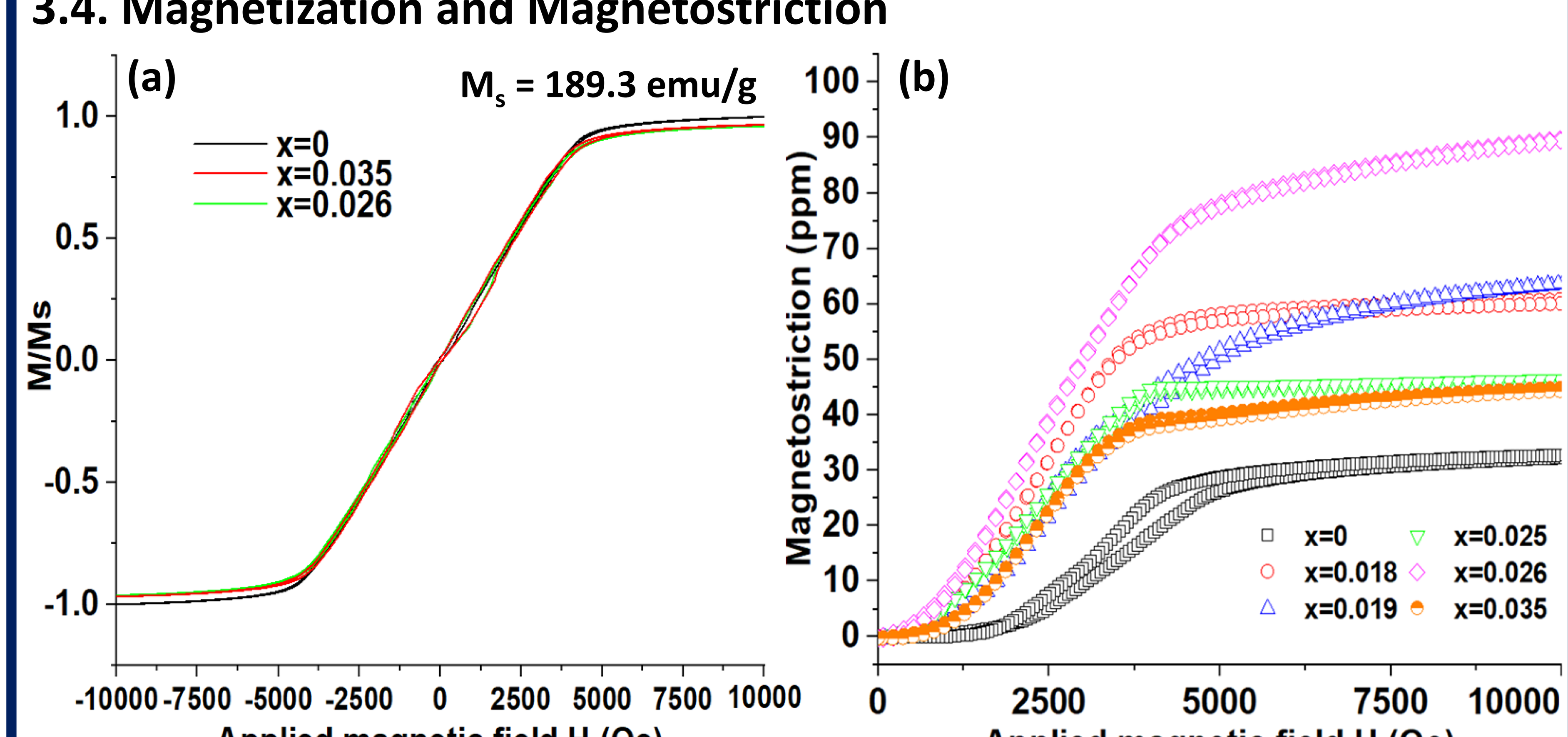

Figure 4. (a) Hysteresis Loops of samples of the $Fe_{81}Al_{19}Tb_x$ (x=0, 0.026 and 0.035) alloys, and (b) total magnetostriction curves of the alloys ($\lambda_T = \lambda_{\parallel} - \lambda_{\perp}$).

4. Conclusions

Doping the base system $Fe_{81}Al_{19}$ with minimal amounts of terbium produces an increase in magnetostriction. In the best case, from 33 ppm for the alloy without terbium to 84 ppm for $Fe_{81}Al_{19}Tb_{0.026}$.

Two important aspects that helps in the improvement of magnetostriction in this type of systems are; the simultaneous existence of the phases A2 and D03, as well as the presence of columnar and equiaxal grains or only columnar grains favors, to a lesser or greater extent, respectively, to the texture formation.

The texture was formed in direction (200) as reflected in the Rietveld refinements, which, was obtained directly through the process of melting by electric arc furnace without the need of a thermal treatment.

5. References

[1] L. Jiang, et al, (2013) Applied Physics Letters. 102, 222409.
[2] T.I. Fitchorov, et al, (2014) Acta Materialia 73, 19.
[3] W. Wei, et al, (2015) Journal of Alloys and Compounds 622, 379.
[4] T. Jin, et al, (2014). Scripta Materialia 74, 100.
[5] Rodríguez-Carvajal, J. (1993). Physica B: Condensed Matter, 192(1-2), 55-69.
[6] Buschow, K. J., & Engen, P. G. (1983). Journal of Magnetism and Magnetic Materials, 38(1), 1-22.
[7] Popiel, E., et al, (1989). Journal of the Less Common Metals, 146, 127-135.