Eddy Current and Microwave Characterization Of Fe- Based Alloy Synthesized By Mechanical Alloying

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ABSTRACT

In the present study mechanical alloying has been used to obtain bulk nanocrystalline FeAl intermetallic compound. Nanocrystalline powder of Fe(Al) solid solution was the product of ball milling. The structural effects of mechanical alloying of powders were investigated by X- Ray diffraction analysis, microwaves and eddy current technique. The complete formation of bcc-FeAl solid solution was observed after 4 h of milling. Crystallite size of 10nm was obtained after 24 hours of milling. Experimental results showed that fine nanocrystalline alloy powders prepared by mechanical milling were very promising for microwave applications.

Keywords: Mechanical alloying, Nanostructured materials, Fe-Al, Eddy current, Microwave absorption.

1 INTRODUCTION

The FeAl intermetallic compound possesses advantageous properties, in particular a high specific strength (strength-todensity ratio) [1], good strength at intermediate temperatures and an excellent corrosion resistance at elevated temperatures under oxidizing, carburizing and sulfidizing atmospheres [2,3]. These features make the FeAl intermetallic compound a very attractive material for structural and coatings applications at elevated temperatures in hostile environments [4].

In the present study, we formed FeAl based alloys by MA and investigated their physical properties; especially the eddy current dependence at low frequency and the coefficient of reflection studied at high a frequency.

Eddy current nondestructive testing of conductive materials is important in many domains of industry: energy production (nuclear plants), transportation (aeronautic) [5] workpiece manufacturing etc. This technique, based on the analysis of impedance of one or more coils placed near the sample, is used to detect and characterize possible flaw or anomalies in the workpiece [6] Microwave absorption material is an essential part of a stealth defence system for all military platforms and wireless communication tools such as mobile telephones and computer local area networks (LAN) [7]. Wave absorbing materials are required to have a large electric and magnetic loss in the frequency range of interest. The usual method for designing wave-absorbing materials is to find a zero reflection condition [8]. Magnetic powder materials with low values of the coefficient of reflection have been promising in the application of microwave absorption. The effective microwave of the composite depends on both intrinsic characteristics of the particles and their microstructural, electrical and magnetic parameters: such as particle size, saturation magnetization and magnetic anisotropy field [9].

2 EXPERIMENTS

The mechanical alloying process was performed in a high-energy planetary ball mill (Retsch PM400). The mixed powder was sealed in a cylindrical vial under an argon atmosphere with stainless steel balls to prevent oxidation phenomena. The ball-to-powder weight ratio was 50:1, while the vial rotation speed was set to 380 rpm. Different milling times ranging from 2 to 24 h were used. X-ray diffraction experiments were performed with Philips X-Pert Pro diffractometer in continuous scanning mode using Cu $K\alpha$ radiation. The X-ray patterns were analysed using Philips X-Pert Plus software [10]. Each peak was fitted by the pseudo-Voigt (PV) function, a linear combination of Lorentzian (L) and Gaussian (G) functions described by $PV(2\theta) = \gamma L(2\theta) + (1-\gamma) G(2\theta)$ where γ was a refinable "mixing" parameter called the shape parameter. This parameter described the amount of Gaussian profile versus the amount of Lorentzian profile; and thus described the overall profile shape. The shape parameter of the Pseudo-Voigt profile function determined the profile. It could vary between 0 (= Gaussian profile) and 1 (=Lorentzian profile). After removing the Cu $K\alpha_2$ radiation from the profiles using the Rachinger method and removing the instrumental broadening using a high purity silicon sample, the physical breadths (β) of the spectral lines were determined for each peak of the pattern [11]. The eddy current impedance was carried out with Hp 4192ALF impedance analyzers were used in the test, which can supply a sinusoidal signal variable frequency output to the coil in a frequency scanning manner. The voltage and current across the coil give the real and imaginary parts of the coil impedance. Reflection loss (R_L) was measured in metallic wave-guide (PM 7001X).

3 RESULTS AND DISCUSSION

3.1 Structure

The X-ray diffraction spectrum for the starting powder (labelled 0 h in Fig. 1) shows reflections corresponding to distinct bcc Fe and FCC Al metals. It can be clearly seen that the diffraction peaks are broadened as the milling time increases, indicating a continuous decrease in grain sizes. This broadening was due to the second-order internal stress which acted at the macroscopic level in the crystallites [12]. After 4 h of milling, the reflection peaks corresponding to FCC Al disappeared and the Fe peaks slightly shifted towards lower angles. This proved that Al atoms dissolved in the Fe lattice leading to the formation of Fe (Al) solid solution. The slight angular shift could be attributed to the formation of the new bcc phase, and the first-order internal stress induced by milling. The first-order angular stress acted at the macroscopic level by modifying the lattice parameter, and consequently produced an angular shift of X-ray diffraction peaks. It is worth noting that for $Fe_{72}Al_{28}$ obtained by mechanical alloying, the formation of bcc solid solution (Fe-Al) was confirmed by Wolski et al. [13], Fan et al. [14] and Oleszak et al. [15] after 10 h of milling.

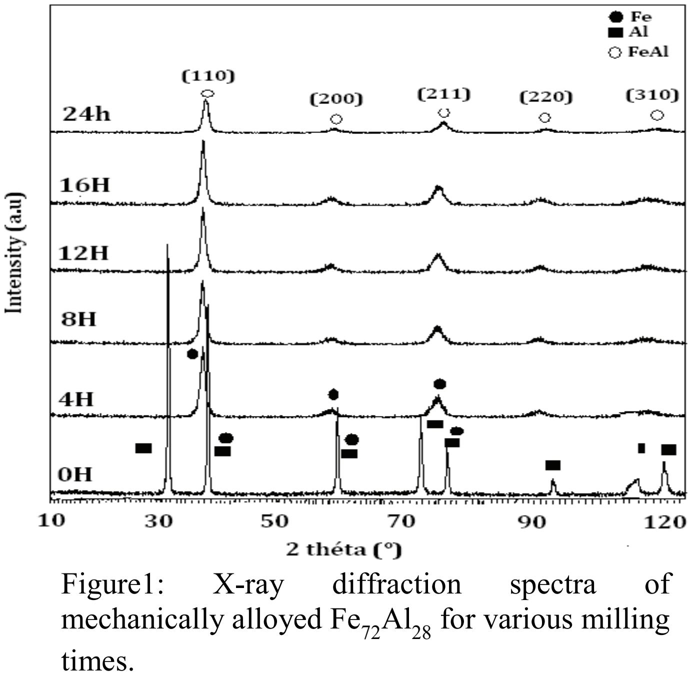

Figure1: X-ray diffraction spectra of mechanically alloyed $Fe_{72}Al_{28}$ for various milling times.

3.2 Variation of impedance

The measured impedance curves of the samples ranging 50Hz to 500 KHz, figure 2. As can be seen from this curve, their imaginary parts virtually increase but a signeficatif decreasing at 12h of milling time, due to a relative permeability of sample [5]. However, the real parts decrease with the milling time and frequencies variation. We can see that curve for the samples milling more than 2hours. The normalizes impedance does not close again, is due to the diminutions of ratio grains size to boundaries.

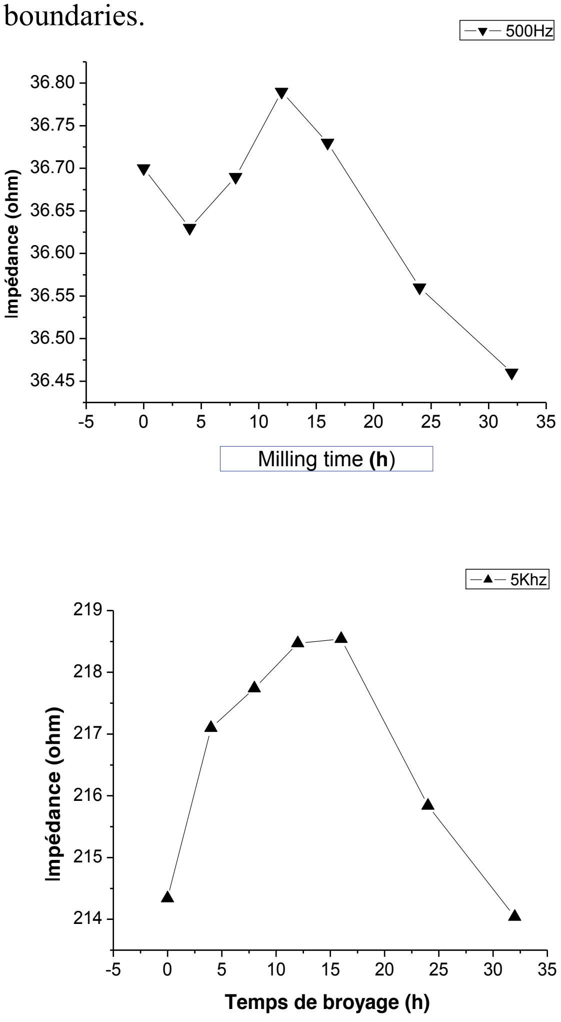

Figure 2: Variation of impédance as a fonction of milling time, at 500Hz and 5 KHz.

3.3 Microwave absorbing property

According to transmission line theory, the reflection loss of electromagnetic radiation RL [dB] under normal incidence of the electromagnetic field on the surface of a single-layer material backed by a perfect conductor is expressed as [16]:

$$R_L = 20log10\left(\frac{Z_{in} - Z_0}{Z_{in} + Z_0}\right) \text{ [dB]} \qquad (10)$$

where Z_0 is the characteristic impedance of free space and Z_{in} is the input impedance of the sample, it depends on the complex relative dielectric permittivity er, magnetic permeability lr, thickness of the sample and the frequency of microwave in free space. Reflection depends on the difference between Z_{in} and Z_0. In this work, reflection loss has been measured using metallic wave guide (PM 7001X) in the X-band frequency (9 and 9.5 GHz). Fig. 5 shows that reduction in crystallites size causes decreasing reflection losses (R_L). This evolution of R_L is due to the presence of defects generated during intensive milling; these defects can create multiple reflections and interfacial polarizations making possible to improve the absorbing property of microwaves [17].

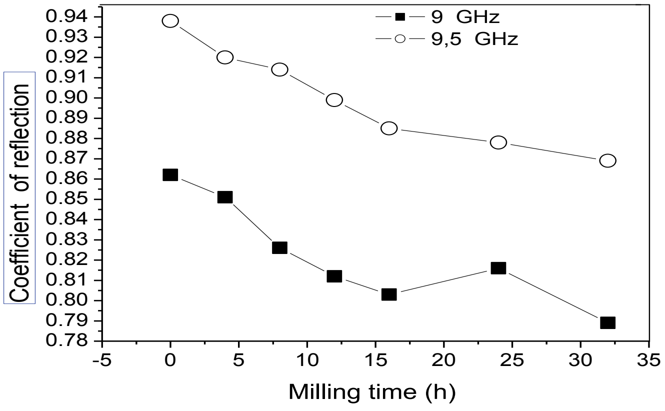

Figure 3: Milling time dependence of measured coefficient reflection for 9 GHz and 9.5 GHz.

4 SUMMARY

The Fe-Al alloys powders have been prepared by a mechanical alloying process using high energy ball milling. is formed by substitution the solution of Al into bcc Fe. This paper has presented the capability to apply the eddy current nondestructive testing to characterize nanostructure FeAl alloy. Our microwave measurements have shown that small particle size leads to a low reflection coefficients.

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