THE EFFECT OF HEAT TREATMENT ON MAGNETIC PROPERTIES OF RAPIDLY SOLIDIFIED MNAL ALLOY RIBBONS

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Abstract: The effect of heat treatment on magnetic properties of rapidly solidified $Mn_{54}Al_{46}$ alloy ribbons was studied. Melt spun $Mn_{54}Al_{46}$ alloy ribbons were heat treated at temperatures 500 ^{o}C for 8, 10, and 12 hours, following a water quenching procedure. The heat treated and melt spun ribbons' magnetic properties were observed by vibrating sample magnetometer (VSM), the Curie temperatures were obtained from differential scanning calorimeter (DSC), and the microstructures were observed by optical microscope (OM). The better magnetic properties were obtained from the samples treated at 500 ^{o}C, for 10 hours. The maximum energy product BHmax was obtained as 4.5 MGOe at 305 K, and the Curie temperature was found as 670 K. Increasing the heat treatment temperature deteriorates both the magnetic properties and Curie temperature. The magnetic properties were favored by τ phase which was detected by x-ray diffractometer. Increasing the heat treatment temperature affects the vicinity of τ phase by transforming into γ2 and β phases.

Keywords: Rapid Quenching, Magnetism, Phase Transformations, X-Ray Diffraction

Introduction

Magnetic materials have many important applications in energy production and utilization as well as numerous information science applications ranging from small, precise actuator motors to electronic storage media. The basic principles of magnetism can be explained by first explaining the different types of magnetism. The fundamental properties of magnetism arise from unpaired inner shell electrons which have an intrinsic spin. This spin gives rise to an individual magnetic moment attributed to each atom with these unpaired electrons.

Kono (Kōno, 1958), was discovered the metastable ferromagnetic τ phase, he studied about the composition of the MnAl alloy responsible for the presence, formation and the structure of ferromagnetic τ phase. He found that the ferromagnetic τ phase was in closed pack hexagonal (HCP) structure, this structure was a metastable phase. The ferromagnetic τ phase was obtained by quenching the ε-phase from high temperature by a martensitic transformation. The following studies were realized by Koch (Koch, Hokkeling, v. d. Steeg, & de Vos, 1960), and Zijlstra et al. (Zijlstra & Haanstra, 1966). Kenji (Kenji, Tadashi, & Yoshinori, 1970) added Boron in MnAl alloy to stabilize the metastable τ phase. More systematic approaches were done by Jakubovics (Jakubovics & Jolly, 1977) to explore the effect of the ferromagnetic phase and lattice defects to magnetic properties in detail.
Sakamoto (Sakamoto, Ibata, Kojima, & Ohtani, 1980) added C to MnAl alloy, and obtained the maximum energy product (BHmax) 4.1 MGOe.

There were numerous studies to stabilize the τ phase. In 1989 Sakka et al. (Sakka & Nakamura, 1989), was the first to produce Mn-Al-X (X = C, Ti, Ni, C, B melt-spun ribbons on single disk. He compared these ribbons with water quenched samples. The BHmax, and the magnetic susceptibility was found to be increased. The Ti, C, and B addition to ribbons increased the magnetic properties. The other studies were about the effect of grain size to magnetic properties Van Roy et al. (Van Roy, De Boeck, et al., 1995) conducted a detailed research on τ-MnAl structure and its magnetic properties, this study showed that the better magnetic properties could be obtained by 450 ^{o}C, if the temperature raised up to 550 ^{o}C, τ-MnAl structure transforms gradually to ε-MnAl. Van et al. (Van Roy, Bender, Bruynseraede, De Boeck, & Borghs, 1995) investigated the range of order of have a strong relationship with increase in magnetization of τ-MnAl ribbons.

Materials and Methods

In this study cast $Mn_{54}Al_{46}$ alloy and melt spun thin ribbons was produced and used, heat treatment was done at 500^{o}C for three duration time of 8, 10 and 12 hours. The effects of heat treatment on magnetic properties of this binary alloy were observed.

The Mn, and Al metals of high purity were obtained from Sigma-Aldrich. The melting of alloying elements were done in Leybold-Heraus vacuum induction furnace, melting atmosphere was cleaned and sweep at least three times with argon.

The cast $Mn_{54}Al_{46}$ alloy chuck was cut into small pieces for melt spin process. The alloy was melted, and spout out with argon. The circumferential speed of rotating copper disk adjusted to 20 m/s. The schematic view of the melt spin apparatus was shown in Figure 1(Wang & Mitra, 2014). The ribbons were 300 µm thick, and 3 mm wide.

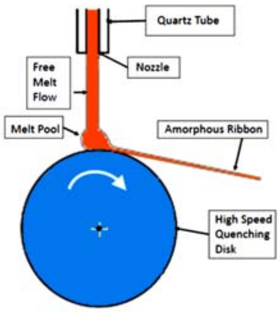


Figure 1. Schematic view of melt spin apparatus (Wang& Mitra, 2014)

Crystal structures were determined by X-ray diffraction (XRD; Philips PANalytical X'Pert-Pro) using Cu-Kα radiation.
Heat treatment procedures were performed on samples of the as-melt spun $Mn_{54}Al_{46}$ alloy sealed in quartz tubes following a vacuum assisted argon sweep procedure to protect against oxidation during heat treatment. The heat treatment sequence was 500°C, for three duration times of 8, 10 and 12 hours. After each heat treatment interval, the magnetic properties of each of the vacuum-sealed sample were analyzed. Magnetic measurements were carried out using a superconducting quantum interference device magnetometer (SQUID; Quantum Design MPMS) at 305 K. The Curie temperature of the samples were obtained from Perkin-Elmer Diamond DSC with a scan rate of 5°C/min.

The microstructures of both melt spun and cast samples were taken with Olympus PMG-3 metallurgical microscope. The microstructures were evaluated with Kameram software.

Results and Discussion

XRD results showed that the vicinity of τ phase occurs with increasing the heat treatment temperature, but further increase in temperature results with undesired transformation of τ phase into γ2 and β phases which deteriorates the magnetic properties. The XRD patterns of melt spun sample, heat treated at 500°C for 10 hrs was given at Figure 2.

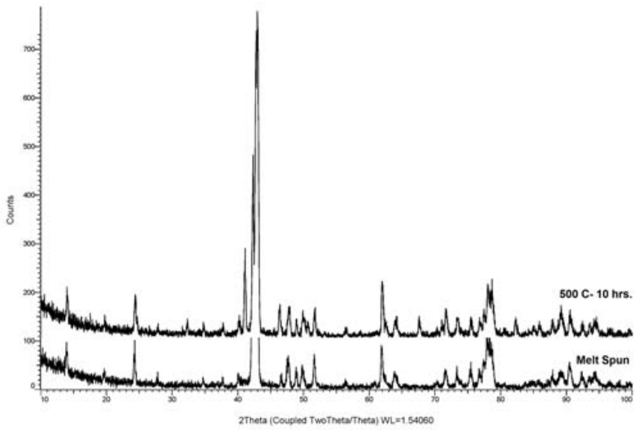


Figure 2. XRD of melt spun and heat treated at 500°C for 10 hrs melt spun ribbons.

Magnetic measurements were determined from SQUID; Quantum Design MPMS, at 305 K. The hysteresis curves revealed that ribbons treated at 500°C for 10 hrs have relatively high magnetic strength which gives maximum energy product of BH_{max} value of 4.5 MGOe at 305 K, a reasonable value for a permanent magnet. The hysteresis

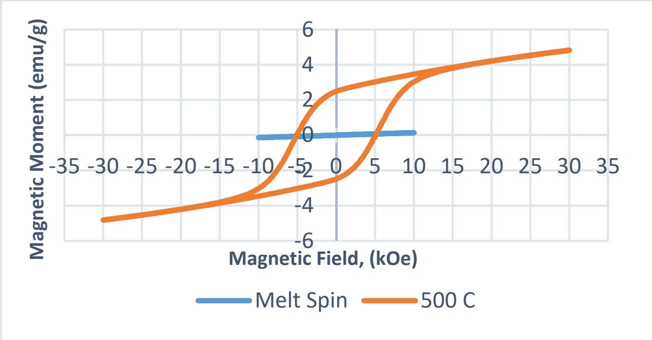
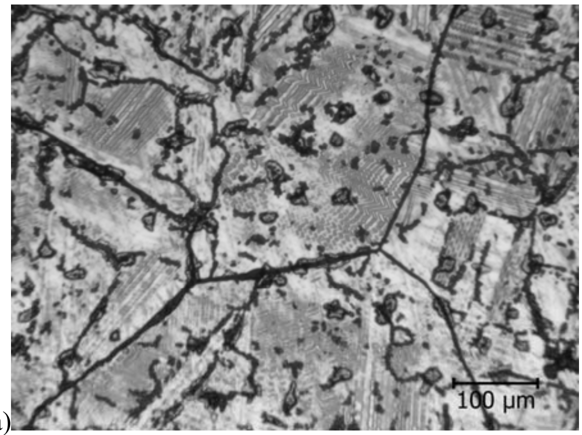


Figure 3. Magnetic hysteresis of Melt spin and heat treated at 500°C for 10 hrs melt spun ribbons at 305 K

curves for both melt spin and heat treated at 500°C for 10 hrs melt spun ribbons were given at Figure 3. The Curie temperature was obtained as 670 K from Perkin-Elmer Diamond DSC with a scan rate of 5°C/min.

The microstructures of both heat treated at 500°C for 10 hrs. cast alloy and melt spun ribbons were compared at Figure 4. Figure 4a shows as cast and heat treated at 500°C sample, Figure 4b shows the heat treated at 500°C melt spun ribbon's microstructure. The grain size of as cast and heat treated samples were pretty higher than the melt spun and heat treated samples. The quenching effect of melt spinning procedure highly obvious.

a) 

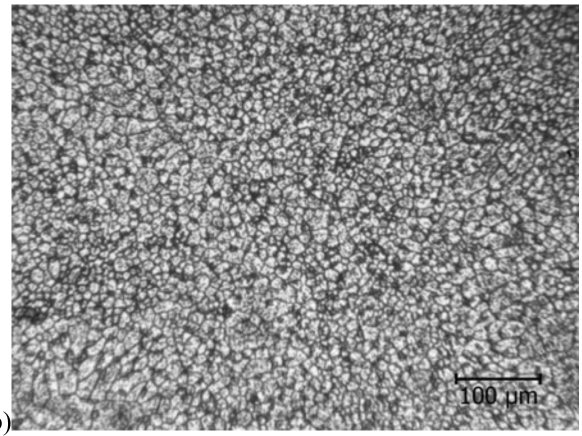
b) 

Figure 4. a) Cast and heat treated sample, b) melt spun and heat treated sample, both heat treated at 500°C for 10 hrs

From XRD results it is seen that the heat treatment temperature increase worsening the magnetic properties due to transformation of τ phase into γ2 and β phases. The magnetic strength is highly related with τ phase, which is ordering the crystal structure together with the effect of rapid quenching the fine grain size is not sufficient therefore a heat treatment should be realized to start the formation of τ phase. The time for optimum magnetic properties limited with 10 hours, exceeding the 10 hours also promotes the formation of γ2 and β phases.

The magnetic properties as seen from Figure 3 shows a characteristic curve for a permanent magnet for melt spun and heat treated sample. The fine grain size have no effect on the magnetic properties therefore a heat treatment should follow melt spin procedure. The hysteresis curve shows that solely melt spun sample have no giant hysteresis, but after heat treatment the arrangement magnetic domains and also in our case the vicinity of τ phase, promotes the magnetic properties up to 4.5 MGOe maximum energy product achieved.

Conclusion

The production of binary magnetic $Mn_{54}Al_{46}$ alloy was successful. The production steps including casting, melt spinning, and heat treatment. The optimum magnetic properties was obtained from the melt spun ribbons heat treated at 500°C for 10 hrs. However this alloy group had been an early studied alloy, by the discovery of modern production methods may have positive effect on production of hard to produce alloys.

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