Preparation of Tb-Fe giant magnetostrictive alloys under microgravity conditions

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TbFe₂ exhibits huge magnetostriction over 1000 ppm. However, it is very difficult to control microstructure of TbFe₂ for the peritectic reaction in solidification. It has been growing interest that the alloy solidification under the microgravity environment yields a unique morphology. The magnetostriction of the microgravity sample was larger than the terrestrial gravity sample.

Keywords: microgravity, Giant magnetostrictive materials, TbFe₂

I. INTRODUCTION

Pb(Zr,Ti)₃ ceramics (PZT) has been widely used to various application such as solid actuator and acoustic transducer. Giant magnetostrictive materials (GMM) are expected to replace PZT devices, which yields a severe metallic pollution during scraping PZT containing Pb. An improvement of the magnetostriction characteristics could create wider application field for electric-mechanical energy conversion, such as a precision machine control device and an actuator device of micro machine.¹ It is difficult to control microstructure of GMM in the Tb-Fe alloys, because the alloy has to be pass through multi step peritectic phase transformations. As a result, very complex alloy morphology is obtained, implying the difficulty to produce highly efficient giant magnetostrictive materials production. It has been growing interest that the alloy solidification under the microgravity (μ G) environment yields a unique morphology.²⁻⁴ In this

study, the crystal growth of Tb-Fe giant magnetostrictive materials under microgravity (μ G) and terrestrial gravity (1G) was investigated.

II. EXPERIMENTAL PROCESSES

The microgravity (μ G) conditions of 10^{-5} G for 10 seconds were obtained by the drop shaft experiment system at the Japan Microgravity Center (JAMIC) in Japan. The total path length of the free fall was 490m and the time of microgravity was 10 seconds.

TbFe_{1.8} alloy with 1 gram and cubic form (5 mm x 5 mm x 5 mm) was prepared for microgravity experiment and terrestrial gravity (1G) experiment. The samples were put on quartz crucible in dish shape (10 mm innerdiameter and 3 mm deep). A background pressure of directional solidification apparatus was less than 6×10^{-3} Pa. Experiments were performed in an argon atmosphere at a pressure of 0.11 MPa with flow rate of 20 sccm. The samples were melted at 1873 K before 30 seconds to drop.

The temperature of the sample was measured by Pt-Pt/Rh(13%) thermocouples (Type R) and optical pyrometer (thermo spot sensor). They were solidified by touching Cu-chill against a sample at the over cooled state in a period of microgravity after dropping.

The microstructures of samples were observed under an optical microscope and scanning electron microscope (SEM). The compositions were analyzed using energy dispersion X-ray spectroscopy (EDX). The magnetization of samples were measured using a vibrating sample magnetometer (VSM). The magnetostriction of samples were determined with strain gauge.

III. RESULTS AND DISCUSSION

The optical micrographs of samples are shown in Fig. 1. Both samples have porosities caused by molten gas in master alloy. The samples have two areas. The bright area was TbFe₃ and TbFe₂, and the dark area was recess by oxidation of Tb. In 1G sample, content of the Tb phase which was observed dark area by optical micrograph was larger than μ G sample. The 1G sample showed the microstructure that was radiate in mostly direction from touching chill side to quartz crucible side. The microstructure of μ G sample showed randomized.

Fig.1. Optical micrographs of μ G and 1G samples. Top side of figure is touching chill side.

Figure 2 shows the SEM micrographs of the samples. There were three phases. White was Tb phase, gray was TbFe₂ phase, and dark gray was TbFe₃ phase. The μ G sample has larger TbFe₂ phase as compared with 1G sample.

The magnetization of samples are shown in Fig. 3. There were no remarkable differences in saturation magnetization between μ G sample and 1G sample. The μ G sample was larger than the 1G sample about coercive force. The coercive force of μ G sample was 272 Oe. The coercive force of 1G sample was 218 Oe. The 1G sample has directional microstructure at cooling direction, so it is considered that the coercive force was smaller than the μ G sample.

Figure 4 shows the magnetostriction, $\lambda_{||}$ of μ G sample and 1G sample. The magnetostriction of the μ G sample was larger than the 1G sample. The 1G sample has longer dark area as shown in Fig. 1. In SEM observation, the dark area was not TbFe₂ phase but recess by oxidation of Tb. It is thought that Tb phase became hindrance of magnetostriction. In Fig. 2, the μ G sample has larger TbFe₂ phase than the 1G sample. So magnetostriction of the μ G sample was larger than the 1G sample.

Fig.2. Scanning electron micrographs of μ G and 1G samples.

Fig.3. Magnetization of μG and 1G samples at cooling direction.

Fig.4. Magnetostriction of μG and 1G samples at cooling direction.

IV. CONCLUSION

The solidified Tb-Fe giant magnetostrictive

materials under microgravity (μG) and terrestrial gravity (1G) were investigated. There were no remarkable differences in saturation magnetization between μG sample and 1G sample. Magnetostriction of the μG sample was larger than the 1G sample. The difference of magnetostriction was assigned to width of other segregated phase such as TbFe_3 and Tb in TbFe_2 .

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