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Temperature Dependence of Magnetic Field-Induced Strain of Fe_3Pt

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An ordered Fe_3Pt which transforms to the so-called f.c.t. martensite shows a giant magnetic field-induced strain (a part of which is recoverable without biasing stress) along $[001]_P$ ("P" stands for the parent phase) direction due to the conversion of variants. Temperature dependence of the fraction of the variant whose c-axis lies along the field direction under a magnetic field of 3.2 MA/m shows a broad maximum between 20 and 40 K. The recoverable field-induced strain exhibits a maximum value of about 1 % at 20 K. These behavior can be explained by considering the work done by magnetic field which is related to temperature dependence of the offset stress for the rearrangement of variants and the magnetocrystalline anisotropy constant.
Key words: iron-platinum alloy, ferromagnetic shape memory alloy, rearrangement of variants

1. INTRODUCTION

Martensitic transformation behavior of Fe-25Pt (at.%) alloy (known as an Invar alloy[1]) changes from the burst-type to the thermoelastic-type as the degree of order increases[2]. Particularly, highly ordered alloys transform from the $L1_2$-type parent to the so-called f.c.t. martensite[3], whose c-axis is slightly smaller than a-axes and is the easy axis of magnetizaiton. In our previous papers, we demonstrated that the f.c.t. martensite exhibits giant magnetic field induced strain (MFIS) of more than 2% at 4.2 K due to conversion of variants when the magnetic field is applied along $[001]_P$ direction[4-5] ("P" stands for the parent phase). However, the fraction of the preferable variant under the magnetic field does not reach 100% in Fe_3Pt while it reaches 100% in other ferromagnetic shape memory alloys such as Ni-Mn-Ga and Fe-31.2Pd (at.%) alloys. Furthermore, a part of the MFIS (about 0.6%) recovers in the field removing process in Fe_3Pt while the recovery is very small for Ni-Mn-Ga[6] and Fe-31.2Pd[7].

Usually, the offset stress for the rearrangement of variants and also the magnetocrystalline anisotropy constants depend on temperature. Thus a significant temperature dependence of MFIS is expected for Fe_3Pt. In the present paper, some essential results of the temperature dependence of MFIS of Fe_3Pt are presented.

2. EXPERIMENTAL PROCEDURE

A single crystal of Fe_3Pt was prepared by a floating zone method, and a parallelepiped specimen was cut out. One surface of it is parallel to $\{001\}_P$ and the remaining surfaces $\{110\}_P$ ("P" stands for the parent phase). The specimen was solution treated at 1373 K followed by ordering heat treatment at 923 K for 360 ks. The degree of order will be about 0.8[3], and the martensitic transformation temperature of the present specimen is about 85 K.

The strain of the specimen was measured by a strain gage method. A strain gage (Kyowa KFL-02) was attached to the (110) surface along the $[001]_P$ direction by using an adhesive (Kyowa PC-6). The magnetic field was applied along the $[001]_P$ direction and the strain along this direction was detected. In this process, the specimen was fixed on a stage by using a vinyl phenolic adhesive applied on the bottom surface ((001) plane).

3. RESULTS AND DISCUSSION

Firstly, the specimen was cooled from room temperature down to 77 K (with a rate of 17 mK/s) under zero magnetic field with the thermal expansion along $[001]_P$ direction monitored. When the temperature of the specimen was stabilized at 77 K, magnetic field of up to 3.2 MA/m was applied and then removed with a rate of 1.8 kA/m·s. This application and removal of the field were repeated three times. The MFIS of the second and the third runs is completely recoverable although the first run includes irrecoverable strain. The result of the third run is shown in Fig. 1(h).

Subsequently, the specimen is cooled to the next measuring temperature, and then the magnetic field was applied and removed three times. This sequence was repeated in a successive cooling process. The MFIS of the second and the third runs is completely recoverable at all temperatures examined. The results of the third runs for all temperatures are shown in Fig. 1(a)-(h). It is seen from Fig. 1 that the recoverable MFIS increases with decreasing temperature and shows a maximum value of about 1 % at 20 K, and then decreases as temperature decreases.

From the thermal expansion, the MFIS and the temperature dependence of lattice parameters of the present Fe_3Pt[5], we can calculate the fraction of the variants whose c-axis lies along the field direction (f_c) at any temperature and magnetic field. We can also calculate the faction of variants whose c-axis is

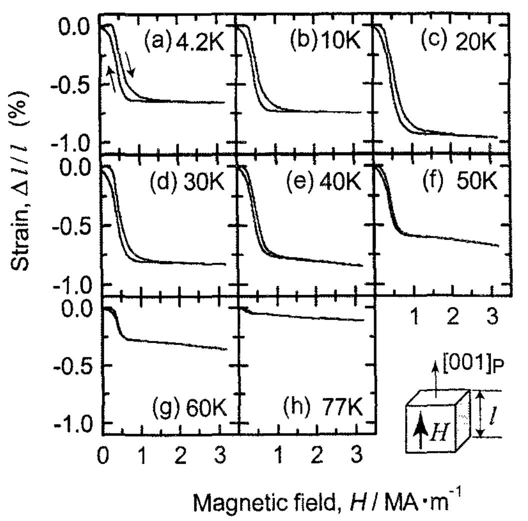

Fig. 1 Temperature dependence of recoverable MFIS of Fe_3Pt.

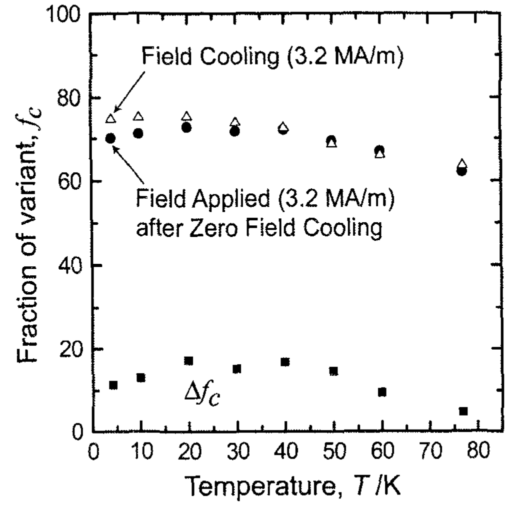

Fig. 2 Temperature dependence of the fraction of the variant whose c-axis lies along the field direction, f_c, and its change through the recoverable MFIS Δf_c.

converted from the direction $c \perp H$ to the direction $c \parallel H$ during the recoverable MFIS (Δf_c). The value of Δf_c corresponding to Fig. 1 is shown in Fig. 2 with solid square marks. It is seen from Fig. 2 that Δf_c shows a broad maximum between 20 and 40 K. The total fraction of the preferable variant f_c under magnetic field is also shown in Fig. 2 by solid circular marks. This fraction also shows a broad maximum between 20 and 40 K. It is apparent from the results that conversion of variants proceeds most easily between 20 and 40 K.

In the above experiments, the magnetic field was applied after zero-field cooling. We also measured the thermal expansion under an magnetic field of 3.2 MA/m, and the f_c in this process is shown by open triangular marks in Fig. 2. The fraction f_c in the field cooling process is in good agreement with that obtained by the application of magnetic field after zero-field cooling in the temperature range above 40 K. However, a significant difference are seen below 30 K, i.e., f_c is nearly constant for field cooling while it decreases as temperature decreases for the MFIS after zero-field cooling. It seems that the formerly converted variants does not recover by changing the temperature if the magnetic field is not removed.

The present experimental results will be explained qualitatively as the following. In order to initiate the movement of variants interface, a threshold stress (corresponds to the offset stress in a stress-strain curve) will be required. Considering the thermal activation process, the threshold stress will increase as temperature decreases. On the other hand, the maximum stress produced by the magnetic field will be proportional to the magnetocrystalline anisotropy constant, which will also increase as temperature decreases. Normally, the magnetocrystalline anisotropy constant does not change in the same way as the threshold stress does when the temperature changes. Then, we may expect that the difference between the threshold stress and the maximum stress due to the magnetic field have a maximum at a temperature T_1. Furthermore, we may assume that the fraction f_c increases monotonically as this stress difference increases. Under the condition described above, f_c will show a maximum at T_1. as observed in Fig. 2.

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