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Influence of Magnetic Field Direction on Recoverable Strain Due to Rearrangement of Variants in Fe_3Pt

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An ordered Fe_3Pt with degree of order nearly 0.8 is one of ferromagnetic shape memory alloys exhibiting a giant magnetic field-induced strain (MFIS) in association with rearrangement of martensite variants. A part of MFIS of Fe_3Pt is recoverable. In this study, we have examined the recoverable MFIS behavior of Fe_3Pt at various temperatures by applying magnetic field along $[001]_P$, $[110]_P$ and $[111]_P$ directions ("P" stands for the parent phase). For all the field directions, the strain was measured along $[001]_P$ in which the largest strain appears. The recoverable MFIS under the $[001]_P$ field exhibits a maximum of about 1% around 20 K, and that under the $[110]_P$ field exhibits a maximum of about 0.6% around 50 K. On the other hand, the recoverable MFIS under the $[111]_P$ field is very small compared with other two directions. The magnetic field at which rearrangement of variants starts also depends strongly on temperature and field direction.

Key words: iron-platinum alloy, ferromagnetic shape memory alloy, rearrangement of variants

1. INTRODUCTION

A properly heat treated iron-platinum alloy containing about 25 mol% of platinum is one of ferromagnetic shape memory alloys exhibiting a giant magnetic field-induced strain (MFIS) due to rearrangement of martensite variants[1,2]. This alloy exhibits an order-disorder transition near 1100 K, and its martensitic transformation behavior changes from a burst-type to a thermoelastic-type as the degree of order increases[3]. Particularly, a highly ordered alloy (Fe_3Pt) transforms from the $L1_2$-type parent phase to the so-called f.c.t. martensite phase[4], whose *c* axis (easy axis) is slightly shorter than its *a* axes and which exhibit giant MFIS.

The MFIS behavior of Fe_3Pt is apparently different from that of other ferromagnetic shape memory alloys such as Ni_2MnGa[5,6] and Fe-31.2Pd(mol%)[2]. That is, the fraction of the most preferable variant under the magnetic field does not reach 100% in Fe_3Pt while it reaches 100% in Ni_2MnGa and Fe-31.2Pd. Furthermore, a part of the MFIS recovers in the field removing process in Fe_3Pt while it does not in Ni_2MnGa and Fe-31.2Pd. In order to understand the reason of these differences, we need more information about the recoverable MFIS of Fe_3Pt.

In the present study, we examine effects of magnetic field direction on the recoverable MFIS of Fe_3Pt at various temperatures. The reason of examining field direction dependence is that we can control the magnetocrylline anisotropy energy, which is considered to be the dominant energy for the rearrangement of variants, by changing the field direction.

2. EXPERIMENTAL PROCEDURE

A single crystal of Fe_3Pt was prepared by a floating zone method, and two specimens (A, B) were cut out from it. Specimen A is a parallelepiped, whose surface is composed of one $\{001\}_P$ and two $\{110\}_P$ planes ("P" stands for the parent phase) Specimen B is also a parallelepiped, whose surface is composed of $\{111\}_P$, $\{112\}_P$ and $\{110\}_P$ planes. They were solution treated at 1373 K followed by ordering heat treatment at 923 K for 360 ks. The degree of order is about 0.8[4], and the martensitic transformation temperature of the present specimen is about 85 K.

The MFIS of the specimen was measured by a strain gage method. Strain gages (Kyowa KFL-02) were attached to the two specimens on their (110) surfaces along their $[001]_P$ directions by using an adhesive (Kyowa PC-6). Magnetic field *H* was applied along $[001]_P$, $[110]_P$ or $[111]_P$ direction, and MFIS ($\Delta l/l$) was measured along $[001]_P$ direction as schematically illustrated in Figs. 1, 2 and 3.

3. RESULTS AND DISCUSSION

Firstly, each specimen was cooled from room temperature down to measuring temperatures under zero-magnetic-field, and then magnetic field of up to 3.2 MA/m was applied and removed. This application and removal of the field were repeated three times. The MFIS of the second and the third runs are completely recoverable, and the results of the third runs are shown in (a)-(g) of Figs. 1, 2 and 3.

For all the field directions examined, the recoverable MFIS depends strongly on temperature. It exhibits the maximum of about 1% around 20 K under the $[001]_P$ field and of about 0.6% around 50 K under the $[110]_P$ field. In contrast, the MFIS under the $[111]_P$ field is very small, and it decreases monotonically as temperature decreases. We can evaluated the volume fraction which contributed to the rearrangement of variants by using the obtained recoverable MFIS and lattice parameters[7]. This fraction exhibits the maximum of about 20% between 20 and 40K under the $[001]_P$ field; it exhibits a maximum of about 15% between 50 and 60 K under the

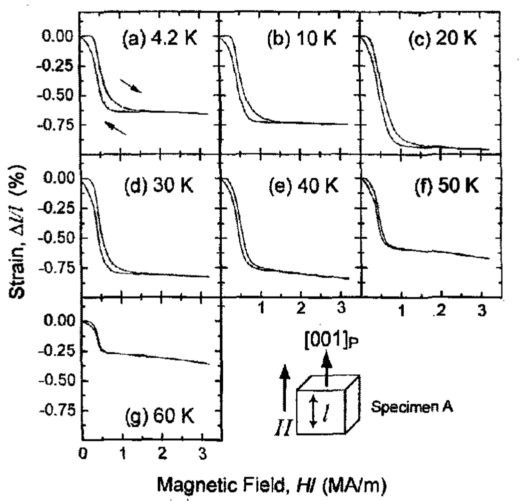

Fig. 1 Temperature dependence of recoverable MFIS. Field is applied along $[001]_P$ direction and strain is measured along $[001]_P$ direction

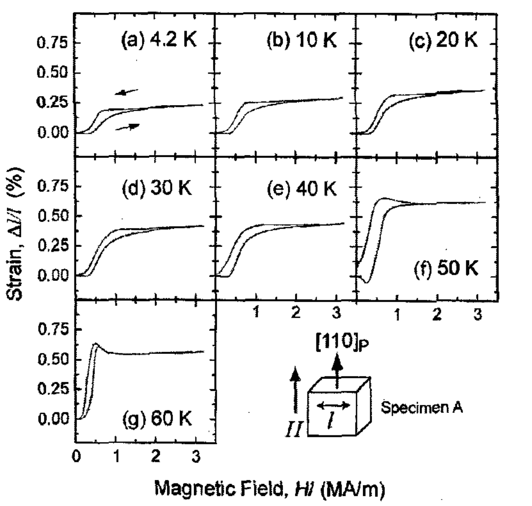

Fig. 2 Temperature dependence of recoverable MFIS. Field is applied along $[110]_P$ direction and strain is measured along $[001]_P$ direction.

$[110]_P$ field; and it is very small at all temperatures under the $[111]_P$ field. The field at which the rearrangement of variants starts, H_s, also depends both on temperature and on field direction. This field H_s increases as temperature decreases regardless the field direction, and H_s of $[110]_P$ is higher than H_s of $[001]_P$ at any temperatures.

We discuss these temperature and field direction dependencies by considering magnetic shear stress acting across the twinning plane τ_{mag} and the shear stress required for the rearrangement of variants τ_{req}. Since the strain recovers in the field removing process, τ_{req} should include elastic stress τ_{el} which pushes back the twinning plane. Then τ_{req} will be expressed as $\tau_{req}=\tau_{fric}+\tau_{el}$, where τ_{fric} is the frictional stress, which causes energy dissipation. We may assume that τ_{el} increases as strain increases and that τ_{fric} is essentially independent of strain. The temperature dependence of H_s described above

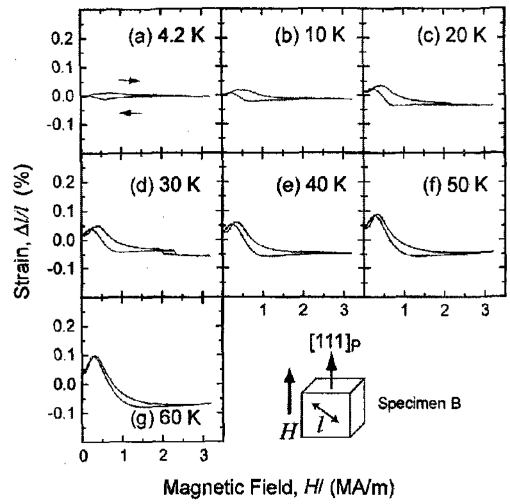

Fig. 3 Temperature dependence of recoverable MFIS. Field is applied along $[111]_P$ direction and strain is measured along $[001]_P$ direction.

probably comes from the increase of τ_{fric} with decreasing temperature. The field orientation dependence of H_s will come from the orientation dependence of τ_{mag}. That is, τ_{mag} under the $[110]_P$ field will be smaller than that under the $[001]_P$ field, provided that their field strengths are the same. Then higher field strength is required for the $[110]_P$ field in order to start the rearrangement of variants. The reason of the existence of the maximum of MFIS suggests that although τ_{mag}, τ_{el} and τ_{req} will increase as temperature decreases, they will change in a significantly different manner. For further discussion, we need temperature dependencies of magnetocrystalline anisotropy and stress-strain curves.

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