Transactions of the Materials Research Society of Japan 29[7] 3057-3058 (2004)

Rearrangement of Martensite Variants of Fe-31.2at.%Pd under Magnetic Field

Tatsuaki Sakamoto, Keiichi Yoshinaka, Takashi Fukuda, Tomoyuki Kakeshita,
and Kohji Kishio*
Department of Materials Science and Engineering, Graduate School of Engineering, Osaka University,
2-1, Yamadaoka, Suita, Osaka, 565-0871, Japan
Fax: 81-6-6879-7522, e-mail: fukuda@mat.eng.osaka-u.ac.jp
* Department of Superconductivity, Graduate School of Engineering, University of Tokyo,
Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan

Rearrangements of martensite variants of a single crystal and a polycrystal of Fe-31.2Pd(at.%) by applying a magnetic field are investigated. The maximum shear stress acting across the twinning plane generated by a magnetic field is evaluated from the magnetocrystalline anisotropy constant. In the single crystal and the polycrystal, we compared the magnetic shear stress and the stress required for the rearrangement of variants obtained from the tensile tests. When the rearrangement of variants occurs under the magnetic field, the former stress is larger than the latter. This explains the reason why a large magnetic field-induced strain appears.

Key words: iron-palladium alloy, ferromagnetic shape memory alloy, magnetocrystalline anisotropy, stress-strain curve, rearrangement of variants

1. INTRODUCTION

An Fe-Pd alloy containing about 30at.%Pd is one of ferromagnetic shape memory alloys. Its martensite phase exhibits magnetic field-induced strain (MFIS) due to rearrangement of variants [1-3]. That is, when a magnetic field is applied along $[001]_P$ ("P" represents "parent" phase), a specific variant, whose easy axis (*a* axis) is parallel to the magnetic field, is selected to grow consuming others.

When a magnetic field is applied to martensite variants, a shear stress acting across the twinning plane will be generated by the magnetic field. Thus a criterion for occurrence of rearrangement of variants by applying a magnetic field is considered to be the following: the shear stress generated by a magnetic field exceeds the shear stress required for the rearrangement of variants. However, its propriety for Fe-Pd has not been clarified yet.

In the present study, we examine the propriety by investigating MFIS's and stress-strain curves of a single crystal and a polycrystal of Fe-31.2Pd(at.%).

2. EXPERIMENTAL PROCEDURE

A single crystal of Fe-31.2Pd(at.%) was prepared by a floating zone method in argon atmosphere. Specimens for a magnetization measurement and tensile tests were cut from the single crystal. The former specimen has the dimension of 3.7 mm along $[001]_P$, 3.1 mm $[011]_P$ and 3.1 mm $[01\bar{1}]_P$, and the latter one has 1.6 mm in thick, 3.8 mm in width and 10.0 mm in gauge length along $[001]_P$. For the tensile test, a polycrystalline specimen was also prepared. Its dimension is 1.3 mm in thick, 3.3 mm in width and 9.5 mm in gauge length. Magnetization curve was measured under the magnetic field applied along $[001]_P$ at 77 K. The tensile tests for the single crystal and the polycrystal specimens were made at 80 K.

3. RESULTS AND DISCUSSION

Figure 1 shows the results of MFIS of the single crystal and the polycrystal specimens at 77 K. In the single-crystal specimen, about 3% of MFIS appears, meaning that rearrangement of variants occurs under the magnetic field. In contrast, a MFIS of the polycrystalline specimen is about 1.5×10^{-2} %, meaning that rearrangement of variants hardly occurs in the polycrystalline specimen.

Rearrangement of variants under a magnetic field means that a shear stress τ_{mag}, which acts across the twinning plane, is generated by the magnetic field. This

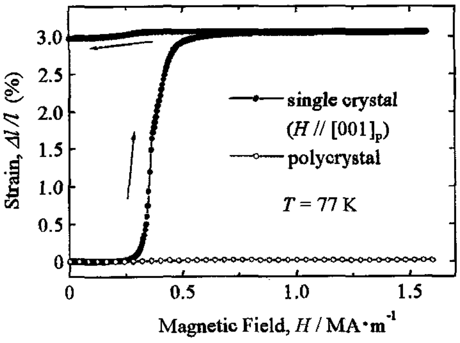

Fig. 1 Magnetic field-induced strains of a single crystal and a polycrystal at 77 K. For the single-crystal specimen, a magnetic field was applied along $[001]_P$.

shear stress τ_{mag} is expressed as $\tau_{mag}= \Delta U_{mag}/S$, where ΔU_{mag} is the difference between the magnetic energy before and after the rearrangement of variants, and S is the twinning shear (0.124 at 77 K). The maximum value of ΔU_{mag} is the magnetocrystalline anisotropy constant $|K_u|$. In order to evaluate $|K_u|$, a magnetization curve of the single crystal was measured under the magnetic field applied along $[001]_P$ at 77 K, and the result is shown in Fig. 2. From this magnetization curve, $|K_u|$ is evaluated to be about 350 kJ/m^3 based on the equation $|K_u|=H_A M_s/2$, where H_A (390 kA/m) is the anisotropy field and M_s (2.0 μ_B/atom or 1.8 T) is the saturation magnetization. From the value of S and $|K_u|$, the maximum of τ_{mag} is evaluated to be 2.8 MPa. Thus corresponding uniaxial stress σ_{mag} is 5.6 MPa because the Schmid factor is 0.5 for the twinning mode of $\{011\}<01\bar{1}>$. In the magnetization curve, a hysteresis is observed. This hysteresis corresponds to the energy dissipation due to rearrangement of variants. Its value is about 150 kJ/m^3.

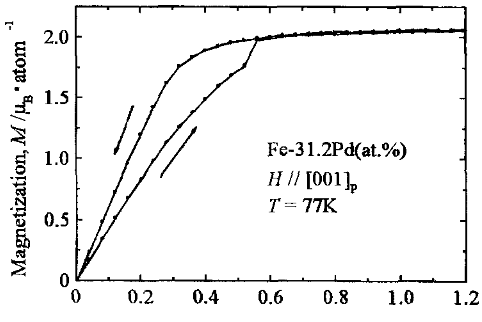

Fig. 2 Magnetization curve of an Fe-31.2Pd(at.%) single crystal under the magnetic field applied along $[001]_P$ at 77 K.

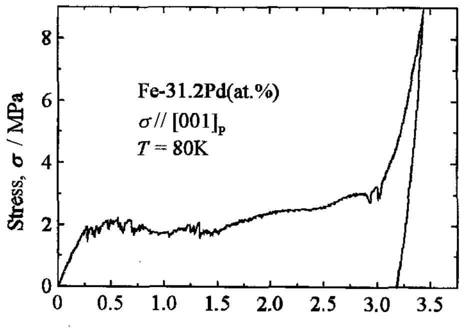

Fig. 3 Stress-strain curve of an Fe-31.2Pd(at.%) single crystal measured along $[001]_P$ at 80 K.

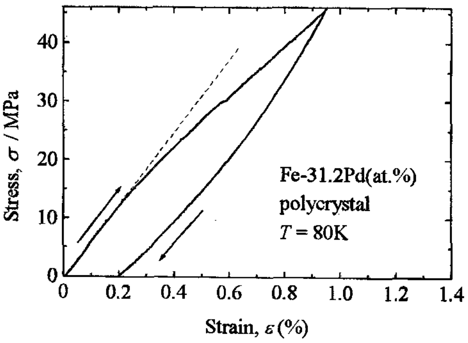

Fig. 4 Stress-strain curve of an Fe-31.2Pd(at.%) polycrystal at 77 K.

In order to compare τ_{mag} with the shear stress required for the rearrangement of variants, τ_{req}, the stress-strain curve of the single crystal was measured. The result is shown in Fig. 3. In the stress-strain curve, energy dissipation is observed due to rearrangement of variants. When the same experiment is repeated, its value is obtained to be between 140 and 220 kJ/m^3, which is essentially the same as that obtained from the magnetization curve described above. Thus, it is speculated that the path of the rearrangement of variants in the mechanical process is almost the same as that in the magnetic one. As for the uniaxial stress required for the rearrangement of variants, σ_{req}, it is obtained between 2 and 3 MPa. Thus, τ_{req} is evaluated to be between 1 and 1.5 considering the Schmid factor (0.5). This value of τ_{req} is smaller than τ_{mag}. Thus it is reasonable that rearrangement of variants occurs by applying a magnetic field along $[001]_P$. If the values of τ_{req} under the stress along $[001]_P$, $[011]_P$ and $[111]_P$ are the same, τ_{mag} under the magnetic field along $[011]_P$ is comparable with τ_{req} because τ_{mag} is $|K_u|/2S$ (1.4 MPa), and τ_{mag} under the magnetic field along $[111]_P$ (0 MPa) is smaller than τ_{req}. Thus it is reasonable that the rearrangement of variants under the magnetic field along $[011]_P$ and $[111]_P$ proceeds imperfectly and hardly, respectively as reported previously [4]. Furthermore, concerning the polycrystalline specimen as shown in Fig. 4, σ_{mag} is smaller than σ_{req}, which is about 13 MPa at which the slope changes. Therefore, it is also reasonable that rearrangement of variants under a magnetic field hardly occurs in the polycrystalline specimen. Accordingly, the criterion mentioned in the introduction is confirmed quantitatively.

ACKNOWLEDGEMENT

A part of this work is supported by "Priority Assistance of the Formation of Worldwide Renowned Centers of Research - The 21st Century COE Program (Project: Center of Excellence for Advanced Structural and Functional Materials Design)" from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

A part of this work is also supported by MEXT, through MEXT Special Coordination Funds for Promoting Science and Technology (Nanospintronics Design and Realization, NDR; Strategic Research Base's Handai Frontier Research Center).

REFERENCES

[1] R. D. James and M. Wuttig, *Philos. Mag.*, **77**, 1273-1299 (1998).
[2] J. Koeda, Y. Nakamura. T. Fukuda. T. Kakeshita. T. Takeuchi and K. Kohji, *Trans. Mat. Res. Soc. Japan*, **26**[1], 215-217 (2001).
[3] T. Sakamoto, T. Fukuda, T. Kakeshita, T. Takeuchi and K. Kishio, *J. Appl. Phys.*, **93** 8647-8649 (2003).
[4] T. Sakamoto, T. Fukuda, T. Kakeshita, T. Takeuchi and K. Kishio, *Mater.Trans.*, to be published.

(Received October 10, 2003; Accepted March 20, 2004)