BENDING OF Fe-30at.%Pd FERROMAGNETIC SHAPE MEMORY ALLOY BY A MAGNETIC FIELD

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ABSTRACT- The superelasticity of the polycrystalline Fe-30at.%Pd ferromagnetic shape memory alloy (FSMA) has been observed. This Fe-Pd alloy is also shown large magnetization and fast response to a magnetic field gradient either parallel or perpendicular to the applied magnetic field. Moreover, with comparison of a pure iron plate in the bending test, the Fe-30at.%Pd plate has the martensite transformation.

INTRODUCTION: Recently, many studies focused on ferromagnetic shape memory alloys (FSMA) with a strong emphasis on Ni_2MnGa which is ferromagnetic and has good shape memory effect (Wayman [1993]). However, Ni_2MnGa alloy is very brittle (Liang et al. [2000]). FSMA are considered as a strong candidate for fast responsive actuator material with higher strength. The shape memory effect of the Fe-Pd system was first found in a bending test (Sohmura et al. [1980]). It is not only much more ductile but also having higher magnetization than Ni_2MnGa.

PROCEDURES, RESULTS AND DISCUSSION: The Fe-30at.%Pd polycrystalline specimens were cut from an Fe-Pd thin sheet (Kato et al. [2000]). The Fe-Pd specimen was fixed on an aluminum block for the bending test for a pin-point observation. The martensitic transformation was observed by an optical microscope during cooling and heating. The majority of martensite in the specimen form around 23°C during cooling and disappear around 22°C during heating. Then, a force was applied at the end of the Fe-Pd specimen at 43°C. The superelasticity was confirmed also by the optical observation on the tension side surface of the specimen during loading and unloading. The stress at the observed point was estimated as about 29 MPa by a simple cantilever beam theory.

The Fe-Pd beam also showed large bending deflection upon application of a magnetic field (H ≅0.1 kOe) generated by a portable electromagnet while a ferromagnetic Fe beam with the same size as the Fe-Pd beam produced little deflection as shown in Fig.1. Since the ratio of the Young's modulus of Fe to Fe-Pd is about 2~5 range (Kato et al. [2000]), the ratios of the bending deflection of Fe to Fe-Pd could be also 2~5, but the deflection of the Fe-Pd beam is much larger (7 mm) than Fe (≅0mm). This implies that the Fe-Pd beam is not only very ductile but also underwent A (austenite)→M (martensite) phase transformation. This transformation is believed to be "stress-induced martensite transformation" as the Fe-Pd beam was subjected to the force induced by the magnetic field gradient which parallels to the applied magnetic (H) field.

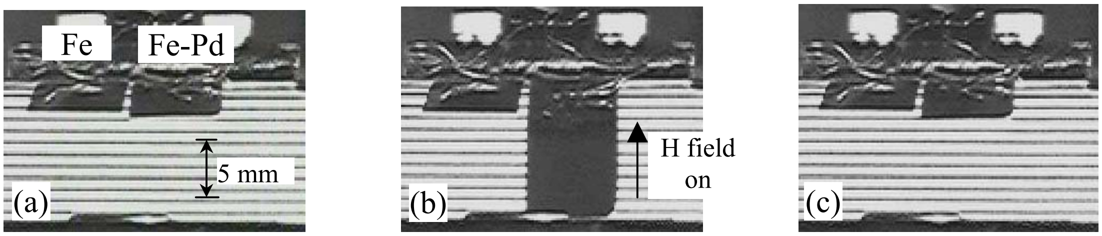

Figure 1 Bending of polycrystal Fe-Pd and Fe cantilever beams under applied magnetic field: (a) before applying, (b) applying, (c) after applying the field.

Another experiment is to record the reversibility of the actuation by a CCD camera and a strain gage, as shown in Fig.2, where a Fe-Pd cantilever beam (38.5mm× 7.5mm×0.16mm) is activated by setting it at an off-center location just above the electromagnet. Fig.2 (a) and (b) clearly show the bending around the axis parallel to the direction of the magnetic field, which had a gradient perpendicular to it since Fe-Pd has larger magnetization than Ni_2MnGa (Liang et al. [2000]). The strain gauge mounted on the beam also picked up its response as a function of time. Fig.2(c) demonstrates the reversibility of bending deflection by applying the magnetic field (at time t_1) and removing it (at time t_2). The beam deflection during t_0-t_1 period was also analyzed by a time elapse recorder indicating that the movement of the beam up to several mm was achieved within 0.05~0.1 second.

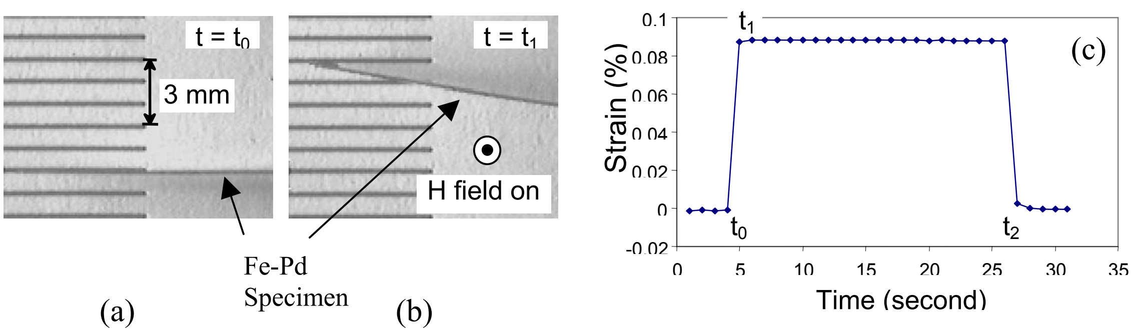

Figure 2 Reversibility of bending of Fe-Pd beam under applied magnetic field. (a) before applying H field, (b) applying H field, (c) bending strain

The force (P) – displacement (δ) relation experiment was also conducted during the recovery process, from which more meaningful data for work done by the actuation can be calculated. Fig. 3(a) shows the results of P-δ curves of a Fe-Pd beam (23mm× 7.84 mm×0.55mm) under various applied H-fields. The bending occurred to the nearer pole piece of the electromagnet and the direction of bending did not depend on the direction of the H-field. It is noted here that the work done by the Fe-Pd beam during the recovery process should be distinguished from the strain energy stored in the beam with the deflection δ_o by the H-field gradient alone. The values of the strain-energy and the work done divided by the weight of the Fe-Pd beam are estimated to be 12.1 J/kg and 9.0

J/kg (energy density), respectively. The reason for the former being larger than the latter is that the strain-energy based energy density is obtained by an assuming elastic beam where the work done by the Fe-Pd beam underwent an A→M transformation. The above reasoning is further evidenced by the fact that the Fe-Pd beam really underwent the A→M transformation at room temperature by the hybrid mechanism of the applied field – force induced by the magnetic field gradient – stress induced martensite transformation.

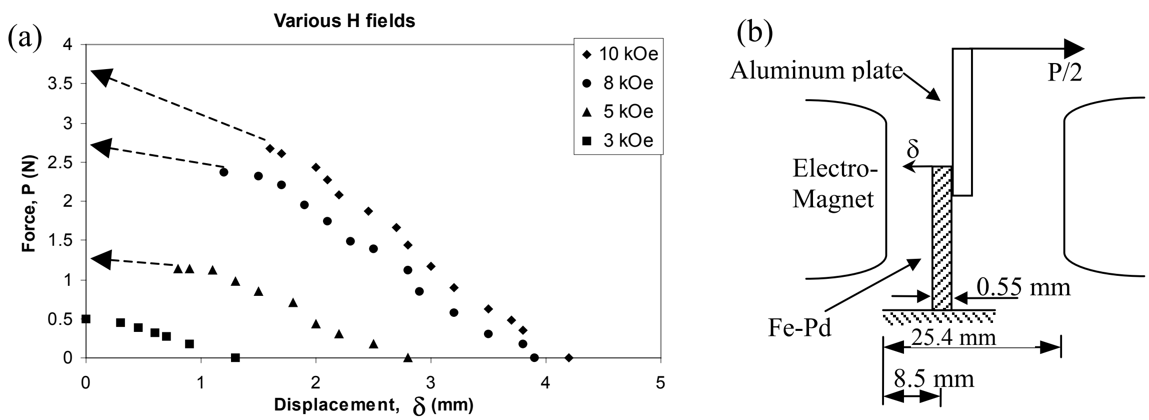

Figure 3 (a) Force-displacement relation of Fe-Pd beam under various applied magnetic field and (b) its experimental setup.

CONCLUSION: Since the influence of the magnetic field on changing the martensitic transformation is very small (Liang et al. [2000]), we conducted several experimental works on Fe-30at.%Pd by using the magnetic field gradient. This magnetic field gradient induces external stress on the Fe-Pd specimen and, further, this stress induces martensitic transformation. Moreover, the Fe-Pd alloy system shows superelasticity, fast response to the applied magnetic field gradient and has a good ductile property.

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