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Influence of Tensile Stress on Active Motion of Hydrogen Storage Alloy Film Actuator

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The hydrogen storage La-Ni alloy film on a polyimide substrate was prepared using a flash evaporation method. The hydrogen storage alloy film showed the reversible shape change, which was operated by hydrogen absorption and desorptions. This bi-material actuator was driven by the large volume expansion of hydrogen storage La-Ni alloy film. The maximum strain induced by hydrogen absorption was above 100 ppm of $LaNi_5$ alloy film.
Key words: hydrogen storage, La-Ni, flash evaporation, actuator

1. INTRODUCTION

Shape memory materials should find application in mechanical actuators, offering the advantages of relatively simple design, lightweight and low cost. Ni-Ti shape memory alloys are practical actuator materials controlled by temperature change [1-6]. However, a high power actuator cannot be achieved with these materials. Thus, it is important to develop new actuator materials. A hydrogen storage alloy is a potentially attractive tool to develop high power bimetal actuators, because of the large volume expansion brought about in these alloys by hydrogen absorption. Such a bimetal actuator induced by the volume expansion of a hydrogen storage alloy could be triggered by changes in hydrogen absolute pressure around the sample and could be operated without temperature change. Since the volume expansion of typical hydrogen storage $LaNi_5$ alloy is 24 % [7], high power levels, capable of generating plastic deformation of 18-8 stainless steel reaction tube, are expected to be reached with these alloys, which becomes potential candidates for powerful actuators (see Fig. 1). Thus, a bimetal actuator driven by a hydrogen storage $LaNi_5$ alloy has been studied. In previous work, $LaNi_5$ alloy has been pulverized by hydrogen absorption and desorption cycles [8-10].

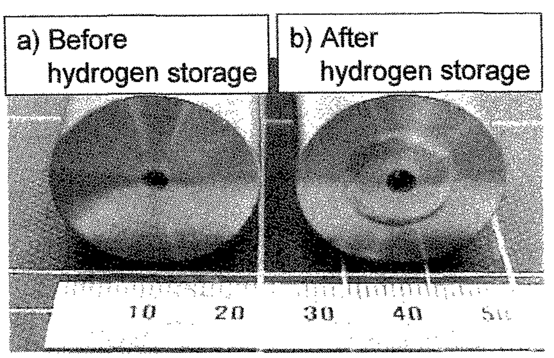


Fig. 1. Plastic deformation of 18-8 stainless steel reaction tube. a) before hydrogen storage (b) after hydrogen storage

In order to prevent pulverization and prolong the fatigue life, a $LaNi_5$ alloy thin film has been prepared by flash evaporation on polyimide sheet. A thin film of the alloy showed high resistance to pulverization and a long fatigue lifetime [11], which is expected for any new actuator driven by a $LaNi_5$ alloy film. A new high power bimetal actuator, driven by the large volume expansion of the alloy, was successfully constructed using this. In order to apply the new actuator in a practical design, the load dependence of strain yielded by the shape change becomes to be a serious problem. Thus, the purpose of the present work is mainly to evaluate the load dependence shape change of the new high power actuator.

2. EXPERIMENTAL

$LaNi_5$ hydrogen storage alloys were prepared by arc melting (ACM-DS01 DIAVAC LTD.) and subsequent annealing for homogenization. The block sample was pulverized by several hydrogen cycles of adsorption and desorption using ultra high purity H_2 gas (7N); the resulting powder was classified to obtain a mean grain size between 60 and 100 μm in diameter. To obtain hydrogen storage thin films that showed high resistance to pulverization and fatigue, thin films were prepared by the flash evaporation process using the pulverized $LaNi_5$ powders. The dimensions of the polyimide substrate were 5 mm in width, 30 mm in length, and 0.011 mm in thickness. The total pressure was less than 1.0×10^{-3} Pa, and the deposition rate was 0.7 nm/s. The substrate temperature was varied from 319 K to 325 K. The chemical composition of the hydrogen storage alloy film deposited was analyzed by energy dispersive X-ray spectroscopy (EDS: JSM-6301F, JEOL Ltd. Tokyo) as $LaNi_{6.5}$. The thickness of the $LaNi_{6.5}$ film was about 760 nm measured by laser microscope (VK-8550, KEYENCE). The final dimensions of the hydrogen storage alloy bimetal samples were $30 \times 5 \times 0.01176$ mm^3 (length × width × thickness). The prepared films were activated using ultra high purity H_2 (7N) at 60 bar in a reaction tube made of SUS316. Activation was performed by the hydrogen absorption for 10 minutes and evacuation for 10 minutes. The adsorption/desorption cycle was repeated 30 times. The activated bimetal was then transported to a reaction bed made of silica glass [12-13]. After evacuation for hydrogen desorption, the material shape change under different loads was monitored by a video recorder [12-13]. The strain measurement of the actuator was defined as shown in Figure 2 and equation (1) & (2). The movable strain (ε^s) which defined as ε^s that means strain of substrate, was expressed by equation (1) using the radius of curvature at the interface (ρ) and a substrate thickness (η^s) of the bending sample.

$$\varepsilon^s = \eta^s / \rho \quad (1)$$

The accuracy of radius of curvature is below 0.1 micrometer by using the video recorder and personal computer. Them the film thickness was measured with the accuracy of the nanometer. Therefore, the measurement accuracy of the strain was below 0.1 ppm. The strain difference $\Delta\varepsilon^s$ yielded by shape change of the hydrogen storage alloy bimetal before and after hydrogen gas absorption was defined as equation (2).

$$\Delta\varepsilon^s = \varepsilon^s - \varepsilon^s_0 \quad (2)$$

Here, ε^s_0 is initial strain of substrate before the first hydrogen absorption in glassy reaction tube.

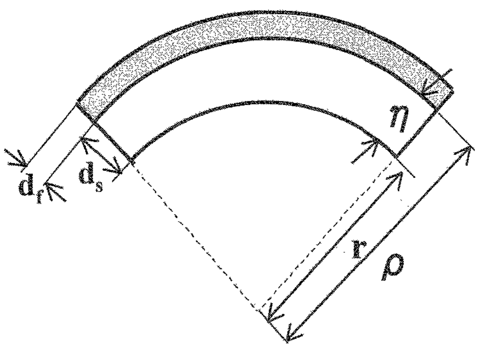


Fig. 2 Schematic diagram of the evaluation method for strain.

The loading method was hung the weight in the bottom of the bi-material. The weights were replaced with the every measurement under the different loads. Figure 3 (a) shows a schematic diagram of the calculation of loading stress (σ_L). The sample was fixing top and bottom and hung the weight in the bottom of the bi-material, if the stress at the bottom of the sample has uniformly been applied on the whole sample, the loading stress was shown in following equation (3).

$$\sigma_L = (L_w + L_s) / (A_f + A_s) \quad (3)$$

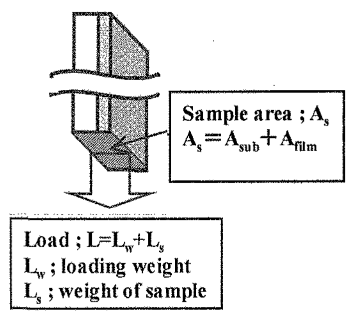
Here, L_w and L_s were the loading weight and sample weight, A_f and A_s were the area of the film and area of the substrate.

Since the substrate does not react on the hydrogen, it was assumed that a thin film witch removed the substrate shows sufficient deformation and power. In order to estimate the power of the hydrogen storage film, the film loading stress (σ_L^f) was calculated only using the area of a thin film.

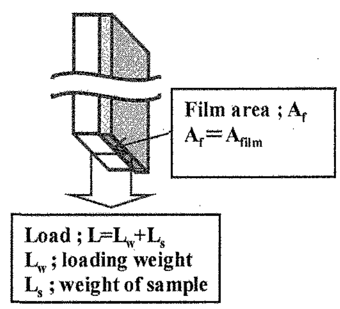
Figure 3 (b) shows a schematic diagram of the calculation of film loading stress (σ_L^f). The film loading stress (σ_L^f) was calculated by equation (4).

$$\sigma_L^f = (L_w + L_s) / A_f \quad (4)$$

Here, L_w and L_s were the loading weight and sample weight, A_f was the area of the film.



(a) loading stress (σ_L)



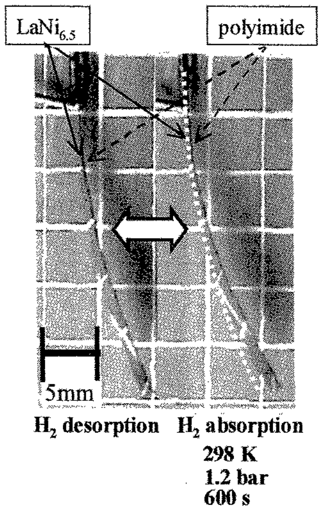
(b) film loading stress (σ_L^f)

Fig. 3 Schematic diagrams of the calculation of loading stress (σ_L) and film loading stress (σ_L^f).

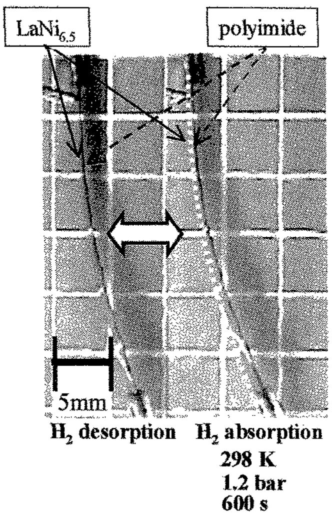
3. RESULTS and DISCUSSION

3.1 Strain difference ($\Delta\varepsilon^s$) yielded by shape change under different loads

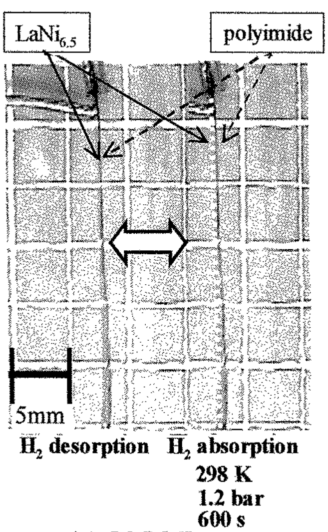
Figure 4 shows a photographs of the bimetal actuator developed under deferent loading stress of (a) 0.3 MPa, (b) 2.3 MPa and (c) 56.7 MPa after hydrogen desorption/absorption from 10^{-2} to 1.2 bar for 600 s at 298 K. Hydrogen gas, which was introduced into the reaction bed under 1.2 bar pressure at 298 K for 600 s after evacuation, induced a shape change in the hydrogen storage bimetal actuator.



(a) 0.3 MPa



(b) 2.3 MPa



(c) 56.7 MPa

Fig. 3 Photographs of the bimetal actuator developed under deferent loading stress after hydrogen desorption/absorption from 10^{-2} to 1.2 bar for 600 s at 298 K.

The shape change was induced by the large volume expansion of the hydrogen storage $LaNi_5$ alloy film prepared on the polyimide substrate. The reversible shape change was operated by hydrogen absorption and desorption. One serious obstacle to applying such a material to a practical actuator is its load dependence on strain yielded by the shape change. To evaluate the load dependence, the strain was measured at different loading stresses. Figure 4 shows the relationship between the hydrogen gas pressure P_{H2} (bar) at 298 K, and the strain difference $\Delta\varepsilon^s$ (ppm) yielded by shape change of the hydrogen storage alloy bimetal at different loads. Here, the $\Delta\varepsilon^s$ (ppm) value ($\Delta\varepsilon^s = \varepsilon^s - \varepsilon^s_0$) was the strain difference before and after hydrogen gas absorption. In this figure, the plots show the strain change of the bimetal under different loads of 0.3, 2.3 and 56.4 MPa; these plots are denoted using squares (□), triangles (△) and circles (○), respectively. The hydrogen pressure enhanced the $\Delta\varepsilon^s$ value of loaded samples. When the load was large, the maximum strain obtained by the P_{H2} - $\Delta\varepsilon^s$ curve was small. Hence, the load dependence was also observed. The results obtained suggest that a large strain difference was induced in the material, and that a shape change actuator made of this material could be operated by a hydrogen pressure change from 10^{-2} to 3.0 bar under large loading stress. Based on the results, a new, high power actuator could be developed, driven by hydrogen pressure changes.

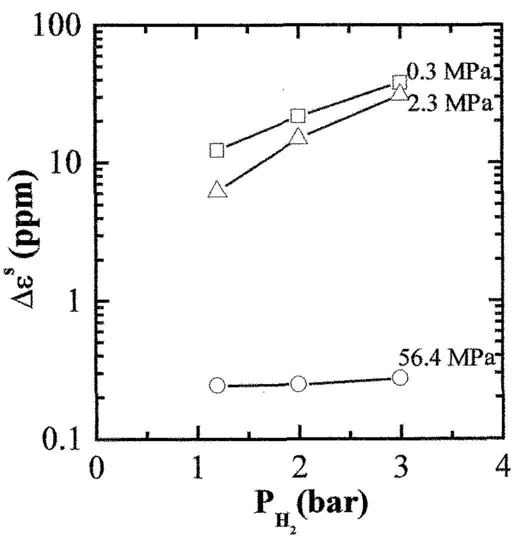


Fig. 4 The relationship between the applied hydrogen pressure P_{H2} (bar) for 600 s and the strain difference yielded by the shape change $\Delta\varepsilon^S$ (ppm) for three loading levels of the hydrogen storage alloy bimetal. Square (□), triangle (△) and circle (○) show the strain of the bimetal under different loads of 0.3, 2.3 and 56.4 MPa, respectively.

3.2 Loading stress σ^L_f and the maximum strain by shape changes $\Delta\varepsilon^f_{max}$

Figure 5 shows the change in the maximum strain yielded by shape changes $\Delta\varepsilon^s$ (ppm) against the overall loading stress σ^L_{f+s} (MPa) and film loading stress σ^L_f (MPa) of the hydrogen storage alloy bimetal, together with a $\sigma^L - \Delta\varepsilon_{max}$ curve of the Ni-Ti alloy. The loading stress σ^L decreased the maximum strain yielded by the shape change. The results indicate that the high hydrogen pressure induced the large strain and could operate under a large loading stress. It is about 1.7 times. It was larger than that of Ni-Ti alloy. These measurements suggest that a new hydrogen storage alloy actuator could be developed. It would be stronger than that of the Ni-Ti shape memory alloy.

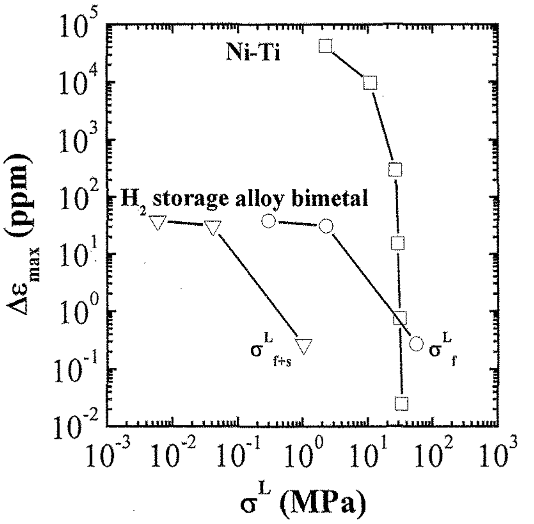


Fig. 5 The change in the maximum strain yielded by shape changes $\Delta\varepsilon^s$ (ppm) against the overall loading stress σ^L_{f+s} (MPa) and film loading stress σ^L_f (MPa) of the hydrogen storage alloy bimetal, together with a $\sigma^L - \Delta\varepsilon_{max}$ curve of the Ni-Ti alloy.

4. CONCLUSION

A new high power bimetal actuator, driven by the large volume expansion of hydrogen storage $LaNi_5$ alloy film on a polyimide substrate, was prepared using a flash evaporation method. The reversible shape change was operated by hydrogen absorption and desorption. One serious obstacle to applying such a material to a practical actuator is its load dependence on strain yielded by the shape change. Thus, the purpose of the present work is to evaluate the load dependence shape change of the new high power actuator. In this study, the strain change was measured under different loading stresses. The results indicate that the high hydrogen pressure induced the large strain and could operate under a large loading stress. It was about 1.7 times larger than that of Ni-Ti alloy actuator commercially used.

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6. References

[1]A. Ikai, H. Tobushi, S. Yamada, T. Hachisuka and K. Tanaka, Trans. Jpn. Soc. Mecha. Eng., A, 62, 1038 (1996).
[2]S. Yamada, T. Hachisuka, H. Tobushi and P.-hua Lin, Trans. Jpn. Soc. Mecha. Eng., A, 63, 702 (1997)
[3]T. Hachisuka, H. Tobushi, K. Tanaka and T. Hashimoto, Trans. Jpn. Soc. Mecha. Eng., 64, 178 (1998).
[4]H. Tobushi, S. Yamada, T. Hachisuka and K. Tanaka, Trans. Jpn. Soc. Mecha. Eng., 64, 1288 (1998).
[5]Y. Shimeno, H. Tobushi, K. Tanaka, S. P. Gadaj and W. K. Nowacki, Trans. Jpn. Soc. Mecha. Eng., 66, 496 (2000).
[6]H. Tobushi, Y. Shimeno, K. Takada and K. Okumura, Trans. Jpn. Soc. Mecha. Eng., 66, 1812 (2000).
[7]T. Sakai, K. Oguro, H. Miyamura, N. Kuriyama, A. Kato and H. Ishikawa, J. Less-Common Metals, 161, 193 (1990).
[8]H. Uchida, H-H. Uchida and Y. C. Huang, J. Less-Common Metals, 101, 459 (1984).
[9]Y. Ozu, Y. Nishi, H-H. Uchida and T. Kuji, J. Adv. Sci., 12, 95 (2000).
[10]Y. Ozu, T. Kuji and H-H. Uchida, J. Alloys and Compounds, 330-332, 632 (2002).
[11]H. Uchida, T. Ebisawa, A. Denda, T. Itoh and S. Tsuzuki, Zeitschrift fur Physikalische Chemie Neue Folge, Bd. 164, S. 1313 (1989).
[12]B. Kim, N. Motai, H. Yabe, H-H. Uchida and Y. Nishi, Proc. 6th Japan-Korea Joint Symp. '01 on Hydrogen Energy, (Hiratsuka, Japan, Oct. 18, 2001) 189 (2001).
[13]B. Kim, H. Yabe, H-H. Uchida and Y. Nishi, Proc. 7th Jpn Inter. SAMPE Symp. (Tokyo, Japan, Nov. 13-16, 2001) 943 (2001).

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