Transactions of the Materials Research Society of Japan 32[3] 631-634 (2007)

Mechanical Properties of Ti-Nb-Mo-Al Alloys

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This paper describes effects of Mo and Nb contents on mechanical properties of Ni-free Ti-Nb-Mo-Al alloys. The materials are Ti-8Nb-4Mo-3Al, Ti-8Nb-(5-6)Mo-5Al and Ti-(10-12)Nb-4Mo-5Al (mol%). Loading-unloading tensile tests were carried out at 173K, 296K and 413K. Young's modulus decreases with increasing Mo and Nb contents, and the Ti-8Nb-6Mo-5Al and Ti-12Nb-4Mo-5Al alloys show low Young's modulus. Also, there is scarcely an effect of temperature on Young' modulus. The elastic strain increases with increasing Mo and Nb contents. The Ti-8Nb-5Mo-Al and Ti-12Nb-4Mo-5Al alloys show the large superelastic recovery strain at 173K and 296K. However, there is scarcely the superelastic recovery strain at 413K. The large total recovery strain is seen in the Ti-8Nb-(5-6)Mo-5Al and Ti-12Nb-4Mo-5Al alloys at 173K and 296K.

Key words: biomaterial, Ti-Nb-Mo-Al alloy, superelasticity, effect of Mo content, effect of Nb content

1. INTRODUCTION

With the advent of an aging society and demand for minimally invasive surgical procedure, it is required to develop safety and highly-reliable medical devices, and research and development of an outstanding biomaterial are being carried out. Shape memory effect (SME) and super-elasticity (SE) of shape memory alloys (SMAs) have been specifically attracting more attention from biomaterials industry. In particular, Ti–Ni SMAs have been widely applied to medical devices because they have superior SE, SME and high corrosion resistance [1].

However, in case of using Ti-Ni SMAs as medical devices in a human body, there is concerned about the possibility of Ni hypersensitivity [2]. Thus, it is necessary to develop Ni-free SMAs for medical devices. Ni-free SMAs such as Ti-Mo-Sn and Ti-Nb-O alloys have ever been researched in various research institutes, and it have been reported that Ni-free Ti based alloys have distinguished properties [3-6], only they are no sufficiency as the research of biomaterials to replace Ti-Ni alloys.

Consequently, this study is intended to investigate effects of Mo and Nb contents on mechanical properties, such as SE and Young's modulus, of Ni-free Ti-Nb-Mo-Al alloys composed of nontoxic elements. An effect of temperature on mechanical properties of Ni-free Ti-Nb-Mo-Al alloys has been also researched.

2. EXPERIMENTAL PROCEDURES

The chemical compositions of alloys are Ti-8Nb-4Mo-3Al, Ti-8Nb-(5-6)Mo-5Al and Ti-(10-12)Nb-4Mo-5Al (mol%). All of them were prepared by Ar arc melting method. Sheet specimens were cold-rolled by 95% reduction (0.15-0.3 mm in thickness) after homogenization at 1273K for 7.2ks in vacuum. Then specimens were solution-treated at 1273 K for 1.8ks in vacuum followed by quenched into water.

To investigate mechanical properties of the alloys, loading-unloading tensile tests were carried out at 173K, 293K and 413 K using sheet specimens, the gauge length and width of which were 20 mm and 3 mm, respectively. In the tensile tests, the tensile stress was loaded until the applied strain reaches 3%, and then the tensile stress was

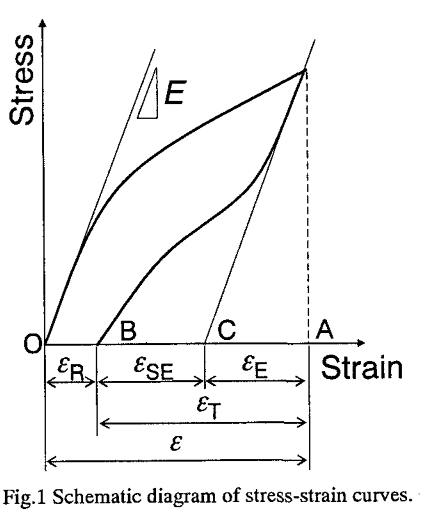

Fig.1 Schematic diagram of stress-strain curves.

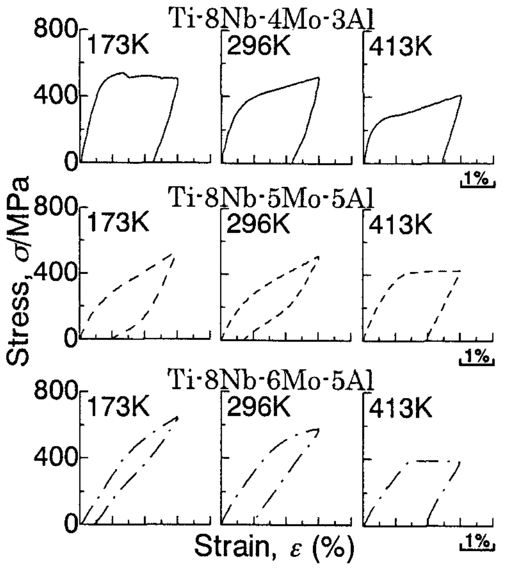

Fig.2 Stress-strain curves of Ti-8Nb-4Mo-3Al and Ti-8Nb-(5-6)Mo-5Al at 173K, 296K and 413K.

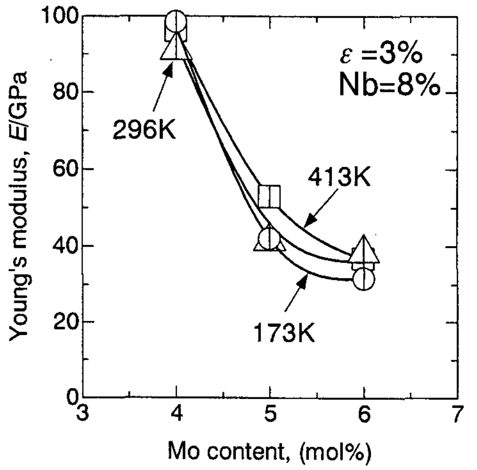

Fig.3 Variation of Young's modulus with Mo content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

unloaded under the strain rate of 5.8×10^{-4} /s.

Figure 1 shows a schematic diagram of stress-strain curve. Young's modulus (E), applied strain (ε), total recovery strain (ε_T), residual strain (ε_R), elastic recovery strain (ε_E) and superelastic recovery strain (ε_{SE}) are evaluated as shown in this figure. E is defined as the applied strain of the specimen. ε_T (A-B) and ε_R (O-B) are the recovered strain and remained strain after unload, respectively. ε_E (A-C) is defined as the resiliently recovered strain, and ε_{SE} (B-C) is the recovered strain due to superelastic behavior.

3. RESULTS AND DISCUSSION

3.1 Effect of Mo content on mechanical property

Figure 2 shows the stress-strain curves of the Ti-8Nb-4Mo-3Al and Ti-8Nb-(5-6)Mo-5Al (mol%) alloys at 173K, 296K and 413K obtained by the loading-unloading tensile tests. The Ti-8Nb-(5-6)Mo-5Al alloys shows the superelastic behavior at temperatures of 173 K and 296 K but Ti-8Nb-4Mo-3Al scarcely shows that. From the results, the effects of Mo content on mechanical properties of the Ti-Nb-Mo-Al alloys were investigated.

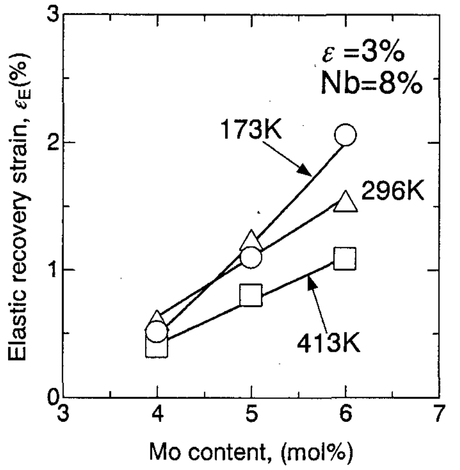

Fig.4 Variation of elastic recovery strain with Mo content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

Figure 3 shows the variation of Young's modulus with Mo content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K. Young's modulus quickly decreases with increasing Mo content up to about 5mol%, and the gradual reduction of Young's modulus is found in the Mo content more than 5mol%. The Ti-8Nb-4Mo-3Al alloy shows the largest Young's modulus and the Ti-8Nb-6Mo-5Al alloy the smallest. From the viewpoint of mechanical compatibility between a biological body and a biomaterial, the biomaterial with low Young's modulus is suited for the born plate and staple. Therefore, the Ti-8Nb-6Mo-5Al alloy is appropriate for the born plate and staple. Also, there is scarcely an effect of temperature on Young' modulus.

The variation of the elastic recovery strain with Mo content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K is shown in Fig.4. The elastic recovery strain clearly increases with increasing Mo content and decreases with increasing temperature. In case the stress stay constant at a given pre-strain, the elastic recovery strain increases with decreasing Young's modulus. As shown in Fig.2, the variation of the stress with Mo content is small compared to the variation of Young's modulus with Mo content, and a decrease in the stress is found at 413K. Therefore, the elastic recovery strain increases with increasing Mo content correspond to the variation of Young's modulus with Mo content, and Young's modulus at 413K is smaller than those at 173K and 296K.

Figure 5 shows the variation of the superelastic recovery strain with Mo content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K. The superelastic recovery strain is found in the Ti-8Nb-(5-6)Mo-5Al alloys. However, there is hardly the superelastic recovery strain in the Ti-8Nb-(5-6)Mo-5Al alloys at 413K. This indicates that the slip deformation get preference over the stress induced martensite transformation at temperature above 413K. The largest

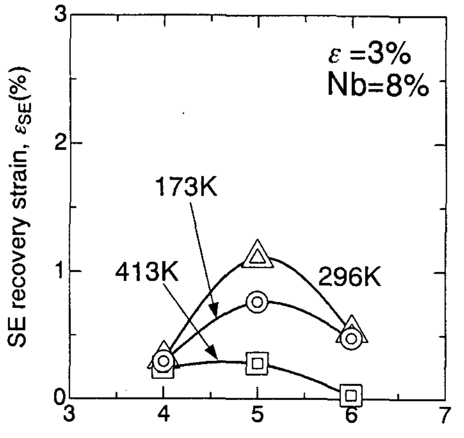

Fig.5 Variation of superelastic recovery strain with Mo content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

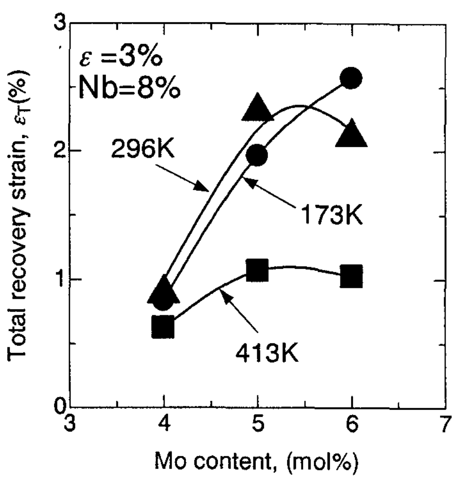

Fig.6 Variation of total recovery strain with Mo content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

superelastic strain is seen in the Ti-8Nb-5Mo-Al alloy. For the Ti-8Nb-4Mo-3Al alloy, the superelastic recovery strain is scarcely observed at all test temperatures.

Figure 6 shows the variation of the total recovery strain with Mo content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K. The total strain is comprised of the elastic recovery strain and the superelastic recovery strain. Since the Ti-8Nb-5Mo-5Al alloy shows the largest superelastic recovery strain and the Ti-8Nb-6Mo-5Al alloy the largest elastic recovery strain, the Ti-8Nb-(5-6)Mo-5Al alloys show the large total recovery strain at 173K and 296K.

3.2 Effect of Nb content on mechanical property

The stress-strain curves of the Ti-8Nb-4Mo-3Al and Ti-(10-12)Nb-4Mo-5Al (mol%) alloys at 173K, 296K and 413K are shown in Fig.7. The superelastic behavior is found in the Ti-12Nb-4Mo-5Al alloy at 173K and 296K but hardly found in the Ti-8Nb-4Mo-3Al and Ti-10Nb-4Mo-5Al alloys. From the results, the effects of Nb content on mechanical properties of the Ti-Nb-Mo-Al alloys were studied.

Figure 8 represents the variation of Young's modulus

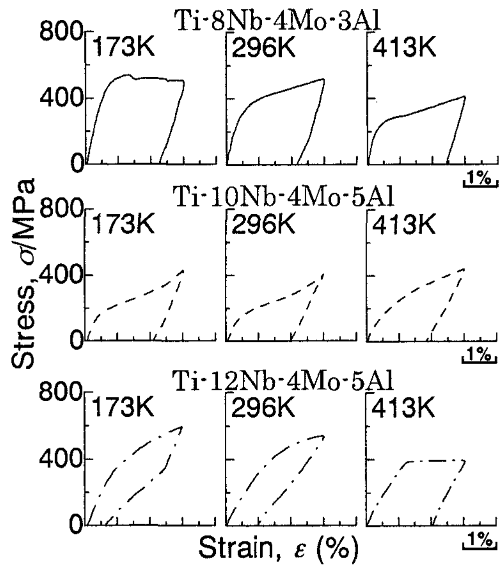

Fig.7 Stress-strain curves of Ti-8Nb-4Mo-3Al and Ti-(10-12)Nb-4Mo-5Al at 173K, 296K and 413K.

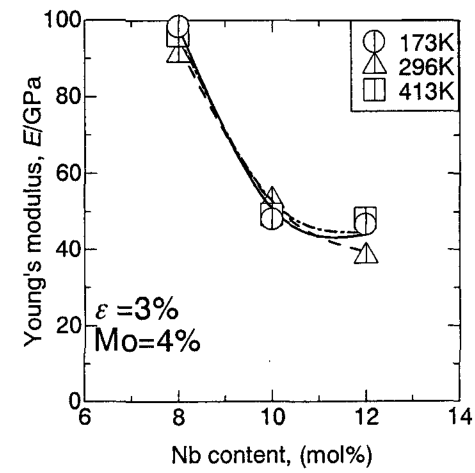

Fig.8 Variation of Young's modulus with Nb content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

with Nb content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K. Young's modulus decreases with increasing Nb content up to about 10mol%, and the Nb content more than 10mol% gradually reduced Young's modulus. The effect of the temperature on Young's modulus in the alloys is very few, as a whole, the results are similar tendency at each test temperature. The largest Young's modulus is seen in the Ti-8Nb-4Mo-3Al alloy and the smallest in the Ti-12Nb-4Mo-5Al alloy. Also, Young's modulus of the Ti-12Nb-4Mo-5Al alloy is slightly larger than that of the Ti-8Nb-6Mo-5Al alloy.

Figure 9 shows the variation of the elastic recovery strain with Nb content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K. Since the variation of the stress with Nb content is small compared to the variation of Young's modulus with Nb content, the elastic recovery strain tends to increase with increasing Nb content. Also, the Ti-12Nb-4Mo-5Al alloy shows the small elastic recovery strain at 413K caused by a decrease in the stress.

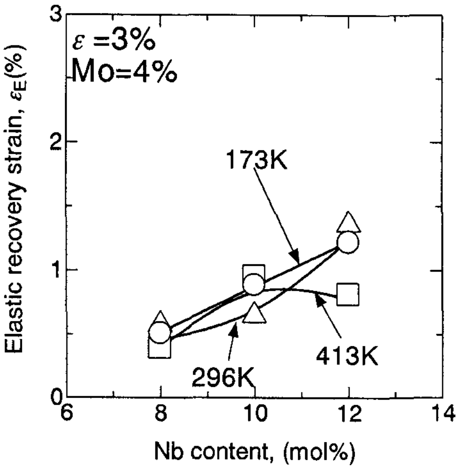

Fig.9 Variation of elastic recovery strain with Nb content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

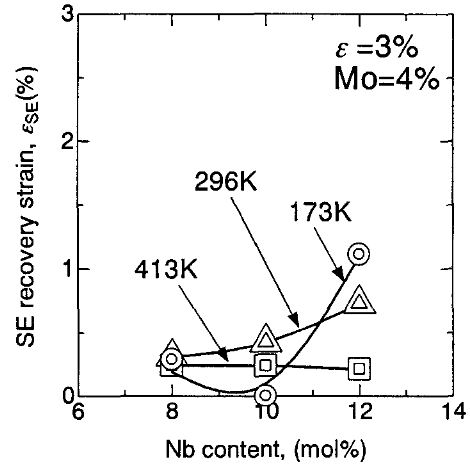

Fig.10 Variation of superelastic recovery strain with Nb content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

The variation of the superelastic recovery strain with Nb content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K is shown in Fig.10. The Ti-12Nb-4Mo-5Al alloy shows the superelastic recovery strain at 173K and 296K. However, there is scarcely the superelastic recovery strain in the Ti-12Nb-4Mo-5Al alloy at 413K. The reason is that the slip deformation get preference over the stress induced martensite transformation at temperature above 413K. On other hand, the superelastic recovery strain in the Ti-8Nb-4Mo-3Al and Ti-10Nb-4Mo-5Al alloys is very small compared to that in the Ti-12Nb-4Mo-5Al alloy.

The variation of the total recovery strain with Nb content in the Ti-Nb-Mo-Al alloys at 173K, 296K and 413K is shown in Fig.11. The Ti-12Nb-4Mo-5Al alloy shows the large total recovery strain at 173K and 296K because it shows the largest elastic recovery strain and superelastic recovery strain as shown in Fig.9 and 10.

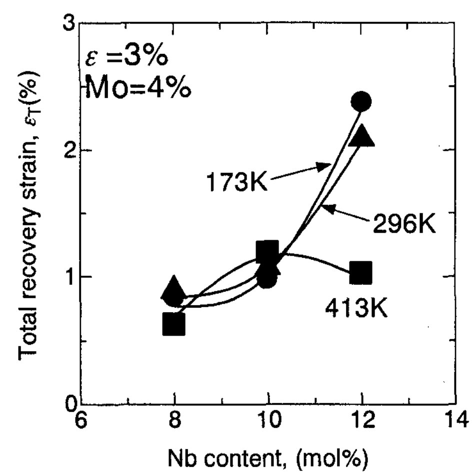

Fig.11 Variation of total recovery strain with Nb content in Ti-Nb-Mo-Al alloys at 173K, 296K and 413K.

4. CONCLUSIONS

(1) Young's modulus has decreased with increasing Mo and Nb contents, and the Ti-8Nb-6Mo-5Al and Ti-12Nb-4Mo-5Al alloys have showed low Young's modulus. Also, there has been scarcely an effect of temperature on Young' modulus.

(2) The elastic strain has increased with increasing Mo and Nb contents.

(3) The Ti-8Nb-5Mo-Al and Ti-12Nb-4Mo-5Al alloys have showed the large superelastic recovery strain at 173K and 296K. However, there has been scarcely the superelastic recovery strain at 413K.

(4) The large total recovery strain has been seen in the Ti-8Nb-(5-6)Mo-5Al and Ti-12Nb-4Mo-5Al alloys at 173K and 296K.

ACKNOWLEDGEMENT

This study has been supported by Research Fund at the Discretion of the President, Oita University.

REFERENCES

[1] S. Miyazaki, et al. (eds.), Engineering Aspects of Shape Memory Alloys, Butterworth-Heinemann, Guildford, UK, 394-413 (1990).

[2] S. Shabalovskaya, Proc. First Inter. Conf. Shape memory and Superelastic Technologies, 209 (1994).

[3] T. Inamura, Y. Ono, H. Hosoda, K. Wakashima, S. Miyazaki and T. Higuchi, *IEEJ Trans.* SM, **126**, No. 4, 164 - 165 (2006).

[4] T. Maeshima, S. Ushimaru, K. Yamauchi and M. Nishida, *Materials Transactions*, **47**, No. 3, 513-517 (2006).

[5] J. I. Kim, H. Y. Kim, H. Hosoda and S. Miyazaki, *Materials Transactions*, **46**, No. 4, 852 - 857 (2005).

[6] T. Inamura, Y. Fukui, H. Hosoda, K. Wakashima and S. Miyazaki, *Materials Science and Engineering*, **C 25**, 426-432 (2005).

(Received January 20, 2007;Accepted May 10, 2007)