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Short Communication

Shape memory and superelastic behavior of Ti–7.5Nb–4Mo–1Sn alloy

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ABSTRACT

In the present work, a Ti-based shape memory alloy with the composition of Ti–7.5Nb–4Mo–1Sn was designed based on the d-electron orbit theory. The shape memory and superelastic behavior of the alloy were investigated. It is found that the martensitic transformation temperature of the alloy is near 261 K. The tensile and the thermal cycling testing results show that the alloy exhibits the stable shape memory effect and superelasticity at room temperature. The maximum recovered strain of the alloy is 4.83%.

1. Introduction

Nickel–titanium alloys have been found to be the most useful of all shape memory alloys (SMA) due to their large recoverable strain value in comparison with other binary, ternary or quaternary shape memory alloy systems. They have been widely applied for biomedical uses to date [1,2]. However, it has been reported that pure nickel exhibits hypersensitivity and carcinogenicity to human body [3]. There is a prohibition tendency for nickel–titanium alloy system in the biomedical field in European countries in recent years due to the problem of human nickel allergy. Therefore, it is preferable to develop absolutely safe nickel-free titanium-based shape memory alloys for biomedical applications. Recently, some Ni-free Ti alloys such as Ti–Mo [4–9] and Ti–Nb [9–20] have been extensively investigated as SMA due to their low elastic modulus, high biocompatibility and non-toxicity. It is well known that the shape memory effect (SME) of Ti–Nb alloys is attributed to the reversible martensitic transformation between α'' martensite and parent phase [19], and the martensitic transformation temperatures and the shape memory behavior of Ti–Nb alloys are strongly dependent on their compositions. Previous work revealed that the martensitic transformation temperatures of Ti–Nb alloys decreases with increasing Nb content from the melting point of Ti to −90 °C [16]. A SME of 3% has been obtained in Ti–(22–29 at.%) Nb alloys and the superelasticity strain can be improved up to 3.3% by cyclic loading–unloading training [18]. Furthermore, by adding some alloying elements such as Sn, Al, Ta, Pd, Zr, one can adjust the martensitic temperature and improve mechanical and shape memory behaviors of Ti–Nb alloys [14,17]. Martensitic transformation temperature of Ti–Nb–Sn alloys decreases rapidly with increasing Sn content and large superelasticity strain was obtained in Ti–16Nb–4.9Sn alloy [11], and a shape memory effect of 4% was reported in a Ti–Nb–Sn alloy [20]. In addition, it has confirmed that Mo has a stronger effect on the martensitic transformation start temperature M_s than Nb has, indicating that Mo is a stronger β-stabilizer. Moreover, the atomic sizes of Ti, Nb and Mo are known to be 0.146, 0.147 and 0.140 nm, respectively [21], from which the solid solution hardening effect of Mo is expected to be higher than that of Nb. Hence, there is a strong possibility of increasing the critical stress for slip deformation (σ_{CSS}) of the binary Ti–Nb alloys by the addition of Mo, which may in turn enhance their superelasticity (SE). Although the SME and SE were confirmed in Ti–Nb and Ti–Mo alloys containing a third or more alloying elements, there is no systematic research on the shape memory properties of Ti–Nb–Mo–Sn alloys. Therefore, in the present work, a quaternary Ti-based alloy, Ti–7.5Nb–4Mo–1Sn, was designed based on the d-electron orbit theory, and the structure, phase transformation point and mechanical properties of the alloy were investigated, aiming at developing a new Ti alloy with good SME and SE.

2. Experimental procedures

2.1. Alloy design

Recently, the $\overline{Bo}$—$\overline{Md}$ diagram has been generally used for the design of Ti-based alloys. Electronic structures were calculated for titanium alloys with a molecular orbital method, and two alloying parameters (*Bo* and *Md*) were determined theoretically [22]. *Bo* (the bond order) is a measure of the covalent bond strength between Ti and an alloying element, and *Md* (the metal d-orbital energy level) correlates with the electronegativity and the metallic radius of elements. For alloys, the average values of $\overline{Bo}$ and $\overline{Md}$ are defined by taking the compositional averages of the parameters and denote them *Bo* and *Md*, respectively. Fig. 1 [23] shows a $\overline{Bo}$—$\overline{Md}$ map, in which the boundaries of $\beta/\alpha+\beta$ phases and $\alpha+\beta/\alpha$ phases together with the boundaries for $M_s = RT$ (room

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