Acta Biomaterialia 8 (2012) 1990–1997

Contents lists available at SciVerse ScienceDirect

Acta Biomaterialia

journal homepage: www.elsevier.com/locate/actabiomat

Beta type Ti–Mo alloys with changeable Young's modulus for spinal fixation applications

Xingfeng Zhao [a], Mitsuo Niinomi [b,*], Masaaki Nakai [b], Junko Hieda [b]

[a] Department of Materials Science, Graduate School of Engineering, Tohoku University, Sendai 980-8579, Japan
[b] Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

ARTICLE INFO

Article history:
Received 29 November 2011
Received in revised form 18 January 2012
Accepted 2 February 2012
Available online 9 February 2012

Keywords:
Biomaterials
Changeable Young's modulus
Deformation-induced ω phase
Mechanical twinning
Springback

ABSTRACT

To develop a novel biomedical titanium alloy with a changeable Young's modulus via deformation-induced ω phase transformation for the spinal rods in spinal fixation devices, a series of metastable β type binary Ti–(15–18)Mo alloys were prepared. In this study, the microstructures, Young's moduli and tensile properties of the alloys were systemically examined to investigate the effects of deformation-induced ω phase transformation on their mechanical properties. The springback of the optimal alloy was also examined. Ti–(15–18)Mo alloys subjected to solution treatment comprise a β phase and a small amount of athermal ω phase, and they have low Young's moduli. All the alloys investigated in this study show an increase in the Young's modulus owing to deformation-induced ω phase transformation during cold rolling. The deformation-induced ω phase transformation is accompanied with $\{332\}_{\beta}$ mechanical twinning. This resulted in the maintenance of acceptable ductility with relatively high strength. Among the examined alloys, the Ti–17Mo alloy shows the lowest Young's modulus and the largest increase in the Young's modulus. This alloy exhibits small springback and could be easily bent to the required shape during operation. Thus, Ti–17Mo alloy is considered to be a potential candidate for the spinal rods in spinal fixation devices.

1. Introduction

Replacement of functionally disordered hard tissue with artificial instruments such as bone plates, hip joints, spinal fixation devices, and dental roots is becoming increasingly popular [1]. Presently, metallic biomaterials such as SUS 316L stainless steel (SUS 316L), commercial pure titanium (CP Ti) and Ti–6Al–4V extra-low interstitial alloy (Ti64 ELI) are widely used in biomedical applications [1,2]. However, these three alloys have some disadvantages. For example, SUS 316L contains nickel (Ni), which is often allergenic [3,4]. SUS 316L is ferromagnetic, which hampers magnetic resonance imaging (MRI) diagnosis [5], Ti64 ELI contains toxic vanadium (V) [6], and CP Ti possesses only moderate mechanical properties. Moreover, the Young's moduli of SUS 316L (∼200 GPa), Ti64 ELI (∼110 GPa) and CP Ti (∼105 GPa) [1,7] are much higher than that of human bone (10–30 GPa) [8]. As a result, the mismatch in the Young's modulus between metallic implants and human bones leads to a stress shielding effect [9]. Niimomi et al. [10] reported that low Young's modulus is effective in inhibiting bone atrophy and leads to excellent bone remodeling. In addition, bone atrophy becomes more distinct with increasing Young's modulus of the implants. Recently, many new Ti alloys containing nontoxic elements and having a low Young's modulus (40–60 GPa) have been intensively investigated [2,11,12]. However, metallic rods used in spinal fixation devices are required to have not only a low Young's modulus to avoid the stress shielding effect but also a high Young's modulus to suppress springback so that the implants offer better handling ability during operations [13]. These rods undergo bending when manually handled by surgeons within the small space inside the patient's body for in situ spine contouring [14]. In summary, the metallic rods used in spinal fixation devices are required to have a low Young's modulus, good biocompatibility as well as small springback [13,14]. Thus, the aforementioned alloys cannot meet the requirements of both surgeons and patients when used in spinal fixation applications.

Recently, there has been considerable research on the development of new types of Ti alloys that have good biocompatibility and a changeable Young's modulus [13,15]. For example, Ti–30Zr–3Cr–3Mo [15] was developed for spinal fixation applications. This alloy has a low Young's modulus under solutionized condition but has a high Young's modulus after cold rolling, owing to formation of a deformation-induced ω phase. Thus, it is possible to increase the local Young's modulus in certain parts of the rod by deformation at room temperature, while allowing the low Young's modulus in the rest of the rod to remain unchanged. However, Ti–30Zr–3Cr–3Mo contains a high percentage of expensive alloying elements. Accordingly, it is necessary to develop a new alloy with a

* Corresponding author. Tel.: +81 22 215 2574; fax: +81 22 215 2553.
E-mail address: niinomi@imr.tohoku.ac.jp (M. Niinomi).

1742-7061/$ - see front matter
doi:10.1016/j.actbio.2012.02.004