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# Microstructure, mechanical properties and springback behaviour of Ti-6Al-4V alloy connection rod for spinal fixation device

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ABSTRACT

The effect of annealing condition on microstructure, mechanical properties and springback behaviour was examined in the connection rod of Ti-6Al-4V alloy for spinal fixation devices. Compared with the deformed microstructure in the sample before annealing, relatively few equiaxed grains were present after annealing at 1003 K after 1.8 ks, and a considerable amount appeared at 7.2 ks. When annealing time was extended to 36 ks, the recrystallised grains further grew. Vickers hardness, tensile strength and bending strength decreased with increasing annealing time, whereas the elastic and bending moduli showed no significant change with annealing time of up to 7.2 ks and then slightly decreased at 36 ks. The springback ratio was closely associated with strength and modulus and applied bending deflection. The springback ratio reached the highest and lowest values in the sample before and after annealing for 7.2 ks, respectively. A good combination of strength, modulus and springback ratio was obtained in the sample after annealing for 7.2 ks.

## 1. Introduction

Metallic biomaterials, such as stainless steels, Co alloys and Ti alloys, play an important role in the reconstruction of failed tissues, especially failed hard tissues [1,2]. Stainless steels, for example, SUS 316L, are used for biomedical applications, such as bone fixation, spinal fixation, cardiovascular systems and catheters. However, their high modulus results in stress shielding effect, which leads to bone absorption and poor bone remodelling [3–5]. Co alloys are used as implant devices for their high strength and wear resistance, whereas the Co ions precipitating in the body fluid are approved to exert carcinogenic effect [6–8]. Compared with stainless steels and Co alloys, Ti alloys exhibit excellent biocompatibility and appropriate modulus, which are advantageous for biomedical applications [9,10]. Among Ti alloys, Ti-6Al-4V alloy is the most widely used for medical applications, such as spinal fixation devices [11,12].

Spine internal fixation technique originated in Europe, and it was suggested by Boucher in the 1950s [12]. Spinal fixation device was designed by Roy–Camille and Lousis for spine fusion to treat disease such as scoliosis [13,14]. Instrument posterior fusion using spinal fixation devices, such as Harrington and Cotrel–Dubousset system, is the most useful method in surgical treatment of scoliosis [15,16]. A spinal fixation device mainly includes a connection rod, pedicle screw (U-shaped nail) and cross-link device to stabilise vertebrae and facilitate bone fusion. Spinal fixation devices require biocompatibility and mechanical compatibility [17]. Recently, the mechanical compatibility of Ti-6Al-4V alloy has been improved through controlling the balance of modulus, strength, ductility, fracture toughness and wear resistance [18]. However, the problem of high springback ratio for the connection rod of spinal fixation devices was observed in spinal fixation surgery [19]. Low springback ratio of connection rod is desirable for the spinal fixation device; thus, the rod can be easily handled to manipulate its shape for meeting the curvature of the spine within the narrow space inside the patient's body [20-22]. However, systematic analysis needed to reduce the springback ratio of Ti-6Al-4V alloy connection rod remains lacking.

The effect of annealing condition on the microstructure and mechanical properties of Ti-6Al-4V alloy rod, which is used to fabricate U-shaped nail, has been investigated in our previous work [24] and unpublished data. After annealing at 1003 K, we observed that the rod exhibited a good combination of mechanical properties with appropriate necking size for the U-shaped nail. Although a similar process is

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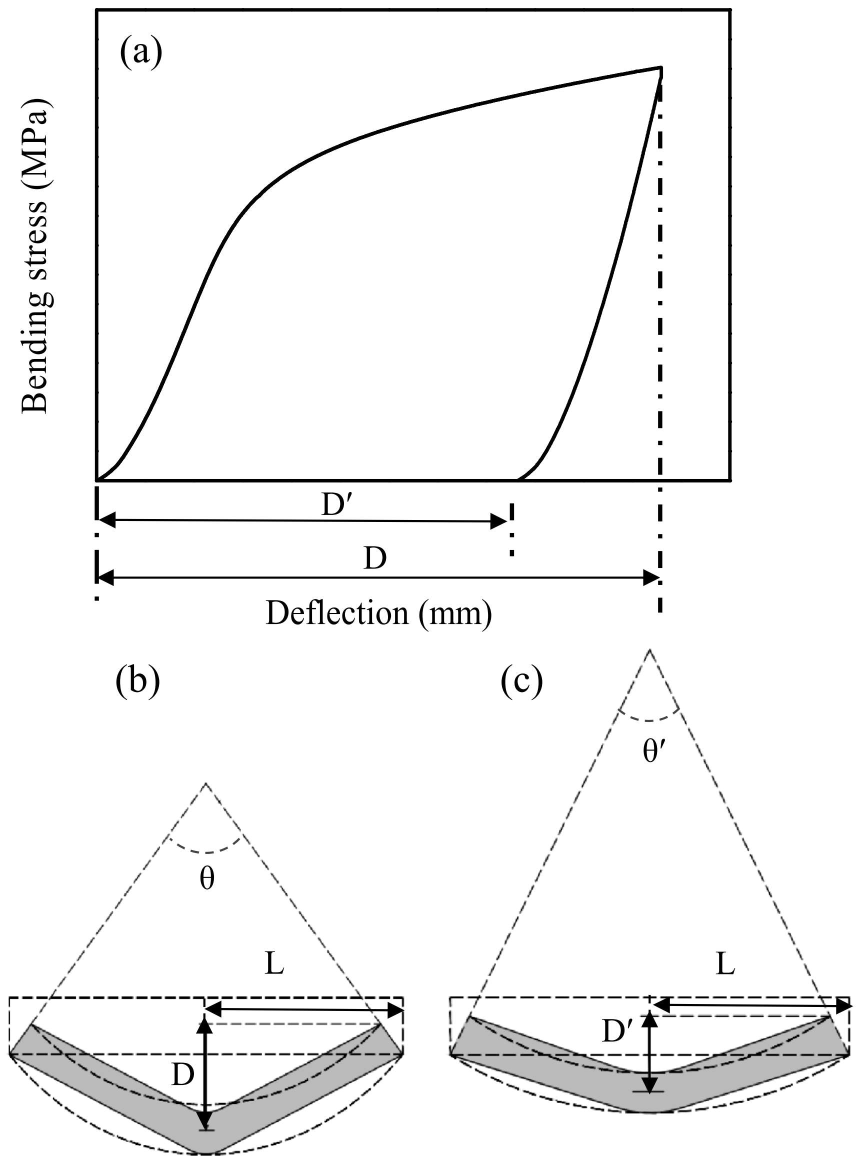


**Fig. 1.** Schematic for evaluating the springback ratio of connection rod. (a) Loading–unloading curve of three-point bending test, (b) loading specimen and (c) unloading specimen.

used to fabricate the Ti-6Al-4V alloy for the connection rod of spinal fixation device, the correlation between annealing condition and its springback behaviour remains unclear. Thus, this study aimed to examine the effect of different annealing times on the microstructure, tensile and bending properties and springback ratio of Ti-6Al-4V alloy connection rod at 1003 K and to further discuss the springback behaviour through the control of strength and elastic modulus.

## 2. Experimental procedures

### 2.1. Material preparation

The 150 kg ingot with 170 mm diameter of Ti-6Al-4V alloy was fabricated by vacuum-consumable electro-arc melting. The ingot was hot-rolled into a blank (60 mm diameter) at 1203 K, then into a rod with 17 mm diameter at 1173 K and finally hot-drawn into a rod with 14 mm diameter at 1033 K. After slider straightening, high-temperature annealing at 963 K, hyperbola straightening, low-temperature annealing at 823 K and centreless grinding, the rod with 14 mm diameter was processed into 6 mm diameter material. Drawing direction is defined as rolling direction (RD). Specimen with 3 mm length and 6 mm diameter was cleaned by ultrasonic cleaner in alcohol for 600 s and then analysed by ICP7300 ICP-AES for Ti, Al, V, C and Fe. For N, H and O, a specimen with 50 mm length, 3 mm width and 3 mm thickness was polished to obtain a smooth surface with SiC waterproof emery paper of up to 1500 grit, cleaned by ultrasonic cleaner in alcohol for 600 s and then analysed by TCH nitrogen, hydrogen and oxygen analyser. The chemical composition of the rod is 6.02Al-3.99V-0.18Fe-0.026C-0.003N-0.002H-0.104O with balanced portion of Ti (mass%). The rods were further annealed at 1003 K for 0, 1.8, 7.2 and 36 ks.

### 2.2. Microstructure charactersation

For cross-section microstructural observations, samples were cut into rods with a diameter of 6 mm and a length of 5 mm along the radial direction by a wire electric discharge machine. The samples were cut into half rods with a longitudinal-section size of 5 mm × 6 mm along the axial direction for longitudinal-section microstructural observation. All samples were subjected to mechanical–chemical polishing to obtain a smooth surface with SiC waterproof emery paper up to 320 grit,