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Microstructure and mechanical properties of Pt-added and Pd-added Zr-20Nb alloys and their metal release in 1 mass% lactic acid solution

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ABSTRACT

The effects of Pt and Pd addition to a Zr-20Nb alloy on its microstructure and mechanical property, as well as the elution of metals from the alloys in lactic acid solution, were investigated. The microstructure was characterized with an X-ray diffractometer (XRD), an optical microscope (OM), and a transmission electron microscope (TEM). The mechanical properties were evaluated by a tensile test. The β phase is dominantly observed in the Zr-20Nb as well as in the Pt-added and Pd-added Zr-20Nb alloys. Needle-like microstructures are observed in equiaxed grains in all alloys. Pd addition to the Zr-20Nb alloy suppresses ω phase formation more than Pt addition does. The 0.2% offset yield strength and the ultimate tensile strength of the Pt-added and Pd-added Zr-20Nb alloys increase with the Pt and Pd concentrations. XRD analysis revealed that the lattice parameter of β-Zr in the Pt-added and Pd-added Zr-20Nb alloys decreases with the Pt and Pd concentrations. Pt and Pd solute in β-Zr as a substitutional element and contribute to the increase in the strength by solid solution hardening. The addition of 2Pt and 2Pd to the Zr-20Nb alloy also improves metal elution from the alloys in lactic acid solution.

1. Introduction

Ti and Ti alloys have been widely used as bone fixators, such as bone plates, screws, and bone nails, because their high strength and corrosion resistance [1–3] allow firm fixation between the Ti fixator and bone [4]. This unique property, however, is not always preferable for removal during surgery. Fixators may be removed because of healing, inflammation, pain, or patient request [4–7]. Removal enhances the risk of re-fracture due to strong adhesion between the fixator and the cortical bone. Therefore, a fixator with moderate hard-tissue compatibility is required.

Among various metals, we focused on Zr because it has low cytotoxicity [8] and high corrosion resistance due to passive oxide formation on the surface [9]. While there was no calcium phosphate formation on Zr in Hanks' solution, the formation on Ti was large [10]. Because the formation of calcium phosphate is considered to be closely related to strong adhesion between bone and Ti [11], Zr is a candidate material for a removable bone fixator. However, the mechanical reliability is insufficient (ultimate tensile strength: 450 MPa, elongation: 14%) [12] if unalloyed Zr is applied to structural biomaterials. As an alloying element with Zr, we employed Nb because it is an effective strengthening element for Zr [12] and has low cytotoxicity [8]. It has been reported that a Zr-20Nb alloy showed high strength (655 MPa) and elongation (15%) [12]. However, from the viewpoint of metal elution, the amount of Zr released from the Zr-Nb alloys in lactic acid solution increased with increasing Nb content from 16 to 24 mass% [13], which is one of the drawbacks of alloying Zr and Nb. Thus, metal elution from the Zr-20Nb alloy should be decreased.

Passive oxide films are formed on the surface of Ti and Zr because of their low standard electrode potentials [14–17]. The corrosion resistance of Ti was improved when elements having high standard electrode potentials, such as Ag and Pd, were added [15,16] because the mixed potentials of Ti-noble metal alloys are more noble than the critical potential for the passivity of Ti [18]. The corrosion resistance of the Zr-20Nb alloy can be improved by the addition of Pt and Pd. However, the addition of Pt and Pd may influence the microstructure, constituent phases, and mechanical properties of alloys. Therefore, the purpose of this study was to investigate the microstructures and mechanical properties of Pt-added and Pd-added Zr-20Nb alloys. The dissolution of metals from the alloys in lactic acid solution was also examined.

2. Experimental procedure

2.1. Specimen preparation

Pure Zr buttons were prepared by arc-melting from sponge Zr (99.6 mass%). Zr-20mass%Nb, Zr-20mass%Nb-(1–3)mass%Pt, and

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Zr-20mass%-(1–3)mass%Pd alloys were arc-melted as buttons from a pure Zr button, Nb shot (99.9 mass%), Pt sheet (99.95 mass%), and Pd sheet (99.9 mass%) under an Ar atmosphere on a water-cooled copper hearth in an arc-melting furnace. Each alloy button was flipped and re-melted at least ten times to homogenize the composition. The buttons were re-melted and cast with a centrifugal casting machine into a sand mold consisting mainly of ammonium phosphate and alumina. The mold was kept at room temperature. A plate-shaped specimen (10 mm × 10 mm × 1 mm) was obtained by casting for the evaluation of metal elution from the alloys. A dumbbell-type specimen 3 mm in diameter and 18 mm in the gauge length was cast for the evaluation of the mechanical properties. Dumbbell-type

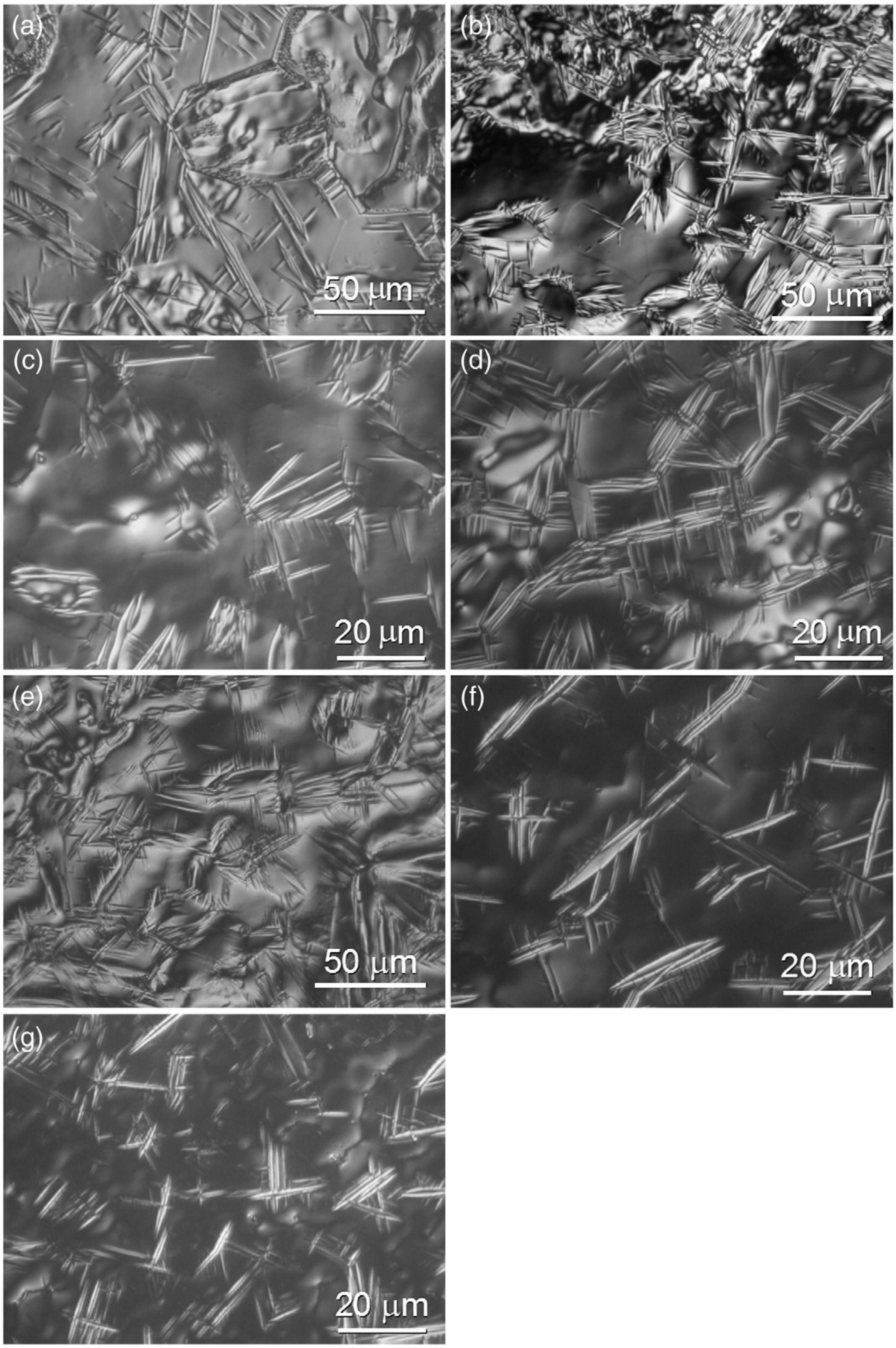

Fig. 1. Optical micrographs of as-cast Zr-Nb alloys: (a) Zr-20Nb, (b) Zr-20Nb-1Pt, (c) Zr-20Nb-2Pt, (d) Zr-20Nb-3Pt, (e) Zr-20Nb-1Pd, (f) Zr-20Nb-2Pd, and (g) Zr-20Nb-3Pd.