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Influence of ω phase precipitation on mechanical performance and corrosion resistance of Ti–Nb–Zr alloy

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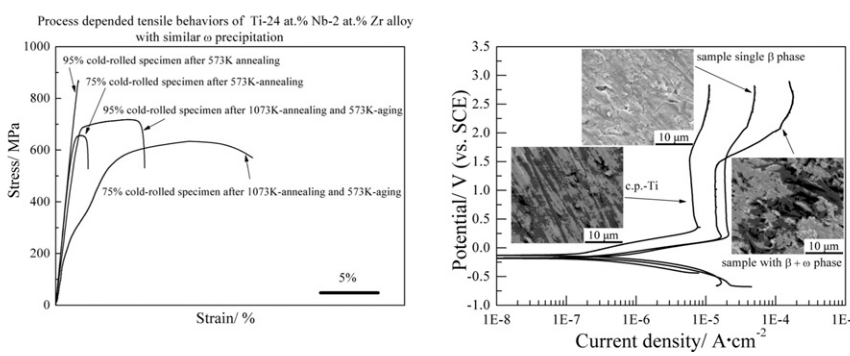
HIGHLIGHTS

- The ω phase improves super-elasticity of 75%-rolled Ti–24 at.% Nb–2 at.% Zr alloy.
- The ω phase inhibits stress-induced martensitic transformation in 95%-rolled Ti–24 at.% Nb–2 at.% Zr alloy.
- The ω phase promotes pitting, and decreases corrosion resistant of the alloy.

GRAPHICAL ABSTRACT



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ABSTRACT

A recently investigated Ti–24 at.% Nb–2 at.% Zr alloy was cold-rolled with reductions of 75% and 95%, and the resulting materials were heat-treated under the same conditions. The two types of specimens obtained through this procedure show the same phase composition. Precipitation of an isothermal ω phase leads to some improvement in the properties of the 75%-rolled specimens. The 95%-rolled and subsequently heated specimens exhibit different performances compared to the 75%-rolled samples heated under the same processing conditions. The stress-induced martensitic transformation is inhibited in the 95%-rolled specimens, owing to the combined effects of the isothermal ω phase and texture. The Ti–24 at.% Nb–2 at.% Zr alloy shows open circuit potential and corrosion behavior similar to commercially pure Ti. The corrosion resistance of the alloy is reduced upon precipitation of the ω phase, owing to an unstable passive film.

1. Introduction

Titanium and its alloys are widely used in the biomedical field owing to their good biocompatibility [1,2]. Recently, β-type Ti alloys attracted considerable interest owing to their low Young's modulus, which can prevent stress shielding effects [3]. Many β-stable elements, such as Nb, Mo, and Ta, have been utilized as main alloying elements to obtain a single β phase in Ti alloys [4–6]. Zr, usually considered as a neutral element and belonging to the same group of Ti, is often added for optimizing the phase transformation characteristics and improving the mechanical properties [7–9]. Moreover, some metastable β-type Ti alloys exhibit super-elasticity and shape memory effects as a result of a stress-induced α″ martensitic transformation (SIMT) [10]. Due to the

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allergic reactions potentially caused by the Ni ions released from Ni-Ti alloys, metastable β-type Ti alloys attracted significant interest in the past decades [11–15]. As the main disadvantage of β-type Ti alloys is their low strength, second-phase precipitation is often used an effective method to improve the strength. A fine and uniformly distributed isothermal ω phase, precipitated during aging, was found to yield significant improvements in the mechanical properties of some β-type Ti alloys, including yield strength, fatigue strength, and super-elasticity [16–18]. The Ti–24 at.% Nb–2 at.% Zr alloy belongs to a group of recently developed β-type Ti alloys exhibiting super-elasticity, whose performance could be significantly improved by an aging treatment [19,20]. The present study investigates the tensile performance and corrosion behavior of the Ti–24 at.% Nb–2 at.% Zr alloy subjected to cold rolling, annealing, and aging, and indicates the influence of isothermal ω, which forms during aging.

2. Experimental procedures

The Ti–24 at.% Nb–2 at.% Zr alloy ingots were arc-melted in a water-sealed copper crucible under an Ar atmosphere. The ingots were homogenized at 1273 K for 36 ks, solutionized at 1123 K for 3.6 ks, followed by quenching in water. In previous study, 75%-cold rolled and subsequently heat-treated Ti–24 at.% Nb–2 at.% Zr alloy showed good combination of mechanical properties and super-elasticity [20]. As higher reductions are usually required to obtain Ti alloy sheets for more wide applications, 95%-cold rolling reduction was also carried out in present study. The solutionized samples were then cold-rolled into sheets with reductions of both ~75% and ~95% (samples hereafter labeled CR75 and CR95, respectively) without intermediate annealing. In particular, the specimens were cut into pieces with thickness round 2.5 mm before ~75% cold rolling, to ensure CR75 owns the same final thickness (~0.6 mm) with CR95. The cold-rolled sheets were further annealed at low temperature (573 K, samples labeled CR75L and CR95L hereafter) and high temperature (1073 K, samples hereafter labeled CR75H and CR95H) for 3.6 ks. The 1073 K-annealed specimens were aged at 573 K for 7.2 ks (samples labeled CR75AG and CR95AG hereafter).

All specimens were grinded and polished after the heat treatment to remove the oxidized layer on the surface. The microstructures of the samples were observed by optical microscopy, whereas their phase compositions were determined by an X-ray diffraction (XRD) using a Bruker D8 X-ray diffractometer with Cu-Kα radiation at a voltage of 40 kV and a current of 40 mA. Transmission electron microscopy (TEM) measurements were conducted using a JEOL JEM-2000EX transmission electron microscope at a voltage of 200 kV. Tensile specimens with a gauge part of 18 mm × 2 mm size were cut using an electro-discharge machine followed by removing damaged layers. Tensile tests were carried out at a strain rate of $4.63 \times 10^{-4}\ s^{-1}$ using an Instron-type testing machine at room temperature, with a strain gauge fixed to the samples to improve the measurement accuracy. The super-elasticity of the samples was measured by unloading from a fixed pre-strain of 6%.

Electrochemical measurements were conducted using a Gamry Reference 600 electrochemical workstation with a conventional three-

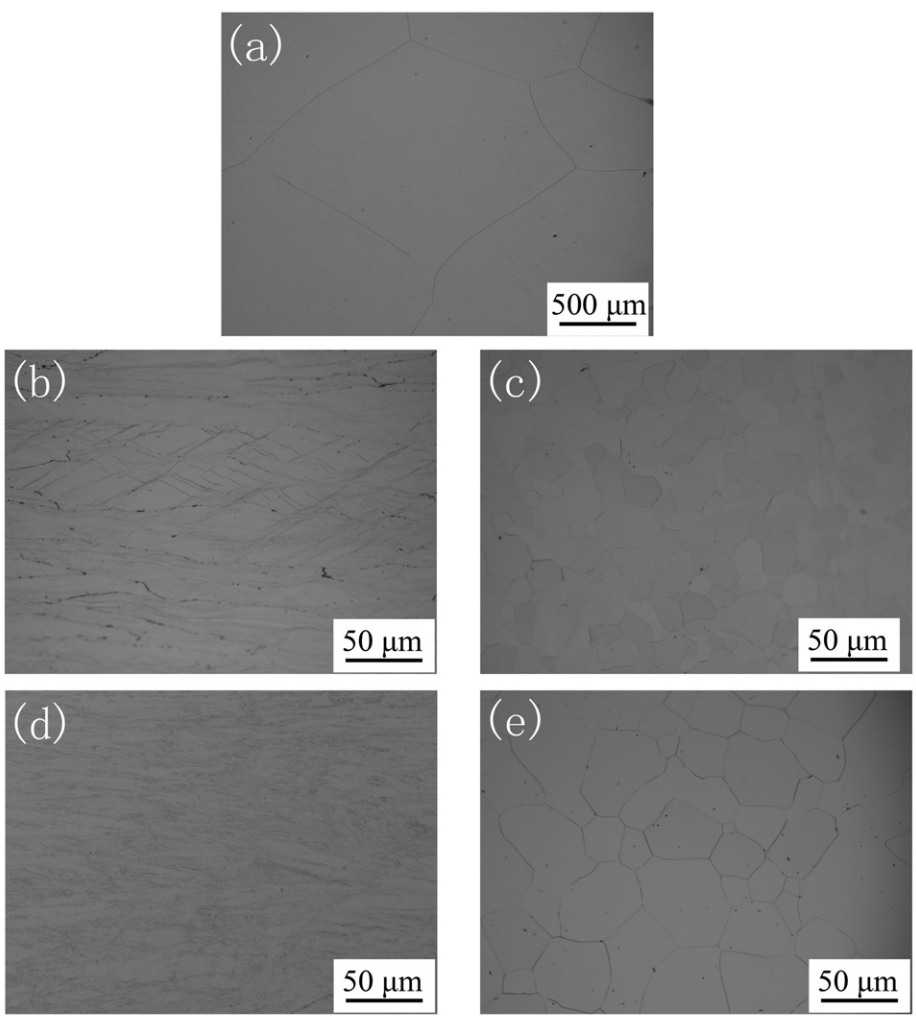

Fig. 1. Optical microstructures of (a) ingots, (b) 75% cold-rolled and then (c) 1073 K-annealed, (d) 95% cold-rolled and then (e) 1073 K-annealed specimens.