Qualifying the Metastable, Biomedical β-Titanium Alloy TiNb13Zr13 via Tuning of Gradiental Mechanical Properties and Partial Surface Modification

F. Depentori, W. Fürbeth
e-mail: depentori@dechema.de
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Background and problem

- TiNb13Zr13 is a promising biomedical titanium alloy
- the elastic modulus of 78 GPa is closer to that of bone (30 GPa) than Ti6Al4V
- a femoral stem requires locally different mechanical and surface properties

high strength
wear resistance
corrosion resistance

low elastic modulus
biocompatibility
corrosion resistance

Fig. 1: requirements of a femoral stem for a hip implant[1]

Approach

- tuning of different mechanical properties on upper and lower part of shaft

→ α-precipitation, α''-hardening or ω-phase precipitation

- different mode of anodizing, depending on needed surface properties

Plasma Electrolytic Oxidation (PEO)

anodizing + hydroxyapatite (HA)

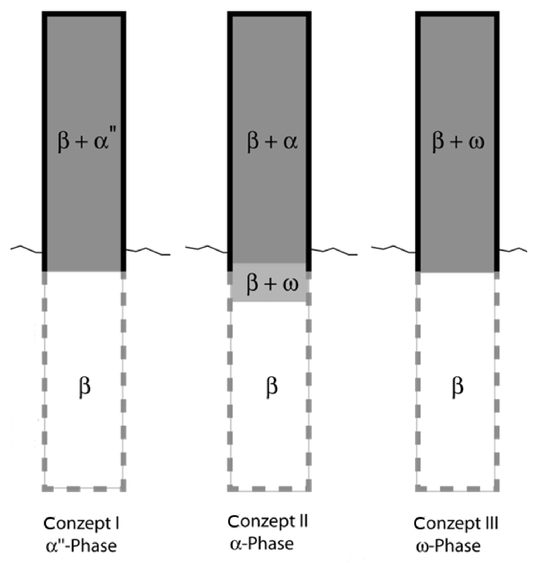

Fig. 2: Schematic view of planned mechanical and chemical modification of TiNb13Zr13

Mechanical and heat treatment

- cold forging of upper part of the stem

→ precipitation of α''-phase (concept I)

- hot forging and solution treatment of upper stem

→ precipitation of α-phase (concept II)

- hot forging and heat treatment in ω-range

→ precipitation of ω-phase (concept III)

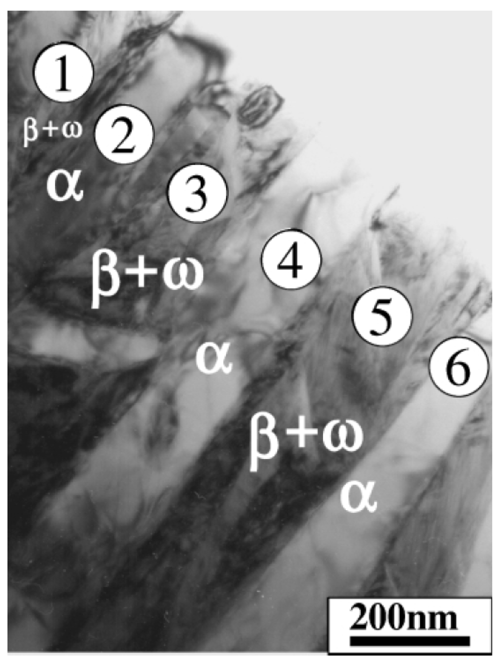

Fig. 3: TEM image of different phases in TiNb13Zr13 alloy[2]

Corrosion testing

- electrochemical testing phase 1:

base material
concept I material
concept II material
concept III material
→ integral testing, local testing

- electrochemical testing phase 2:

concept I, anodized
concept II, anodized
concept III, anodized
→ integral testing, local testing

→ Effect of different anodizing properties determined by local testing and investigation of boundary areas → AFM

Anodizing, biocompatibility increase

- PEO for anodising upper stem part

→ anodizing voltages up to 400 V
→ dense and wear resistant oxide layer
→ different electrolytes

- conventional anodizing of lower part of stem

→ simultaneous electrophoretic deposition of hydroxyapatite (HA) nanoparticles

→ increased biocompatibility due to incorporated, bone growth promoting material

Results

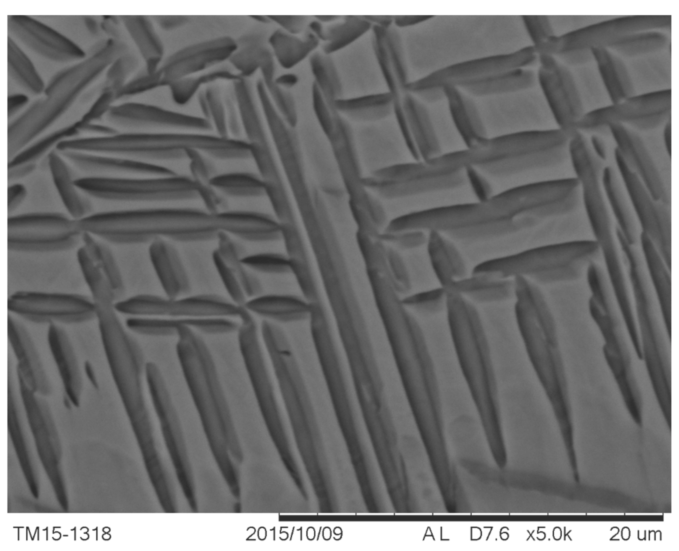

Fig. 4: SEM image of TiNb13Zr, 800 °C for 30 min, furnace cooled to 650 °C and held for 1 hour. Dark phase is assumed to be α.

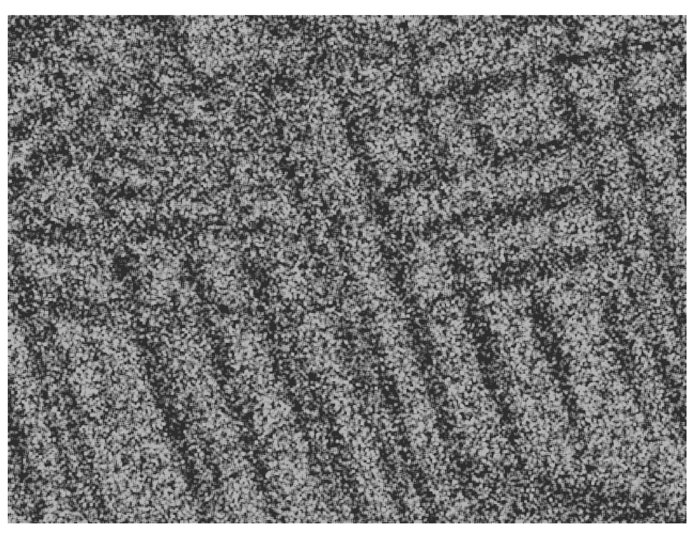

Fig. 5: Elemental mapping of Niobium from Fig. 4, showing diffusion of Nb out of the α-phase.

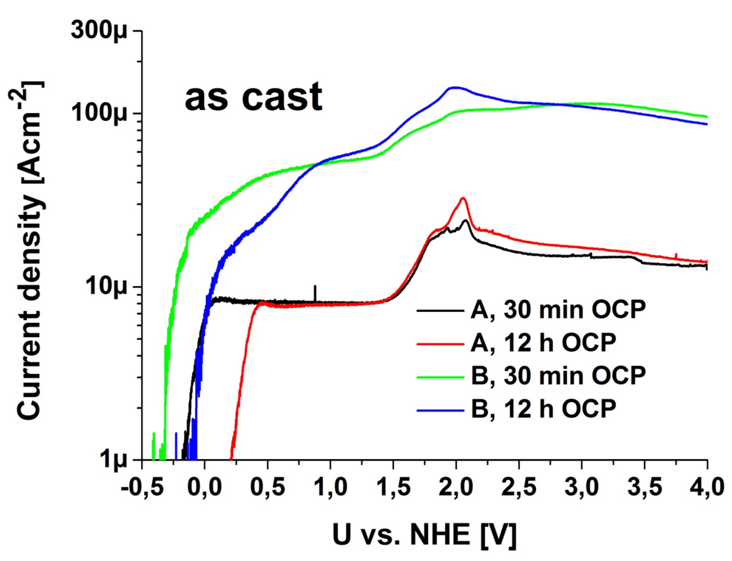

Fig. 6: Polarization curves of TiNb13Zr13, as cast. T = 37 °C, after 30 min and 12 hours. A: 1.5 wt% NaCl, B: 1.5 wt% NaCl + 1000 ppm F⁻.

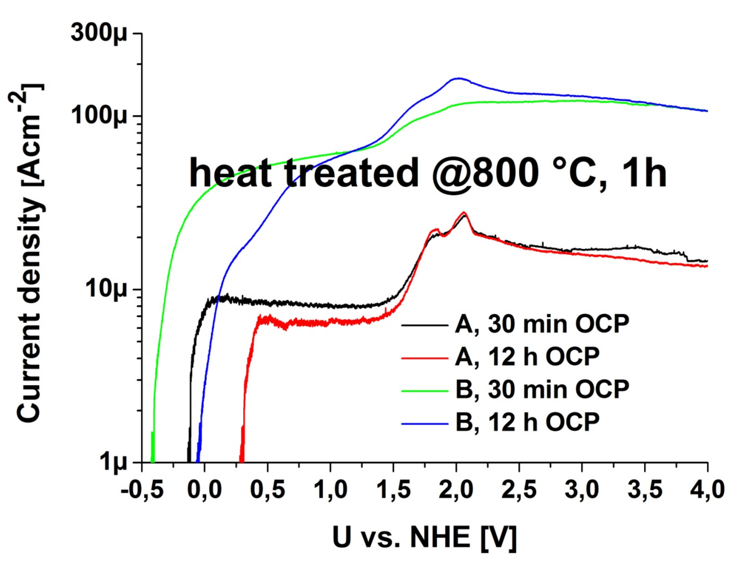

Fig. 7: : Polarization curves of TiNb13Zr13, heat treated for one hour at 800 °C. A, B like in Fig. 6.

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Technische Universität Braunschweig
Institut für Werkstoffe

1) http://www.bjj.boneandjoint.org.uk/content/93-B/5/665/F2.large.jpg
2) S. Kobayashi et al., Material Transactions, Vol. 43, 12, 2002, 2962