Alloys and Intermetallics

MS.6.P178
Evolution of ω_o-phase in a TiAl-Nb-Mo alloy: microstructural characterization and mechanical properties

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Keywords: titanium aluminides, Omega-phase, TEM, mechanical properties

Third generation TiAl-Nb-Mo alloys are multi-phase γ-TiAl-based alloys, where the microstructure is determined by the manufacturing process as well as subsequent heat treatments. It has been established that the formation of ω_o ($B8_2$)-phase takes place in β_o (B2)-phase during heat treatments [1,2]. In this work we studied the evolution of ω_o-phase and its mechanical properties during long term heat treatments and creep experiments in a nearly lamellar microstructure. The investigated TiAl-alloy was centrifugal cast, hot-isostatically pressed, forged and had an analyzed composition of Ti-43.6Al-4.06Nb-1.01Mo-0.09B (in at.%). Subsequently, the alloy was subjected to a multi-step heat treatment (HT) to adjust a nearly lamellar microstructure with globular γ- and β_o-grains, which are arranged on the grain boundaries of the α_2/γ-colonies. The last heat treatment step was performed at 850°C for 6h followed by furnace cooling. Creep experiments were carried out for 310h at 750°C with 150 MPa, whereby the sample reached an elongation of 1.8%. The microstructure was studied by transmission electron microscopy (TEM). Conventional TEM was carried out using a Philips CM 12 operating at 120 kV. High resolution TEM (HRTEM) studies were performed using a JEOL 2100F operating at 200 kV equipped with an image-side spherical aberration corrector (CEOS). The chemical composition of the phases was determined by energy dispersive X-ray (EDX) microanalysis with an INCA system (Oxford Instruments, UK). All specimens for TEM investigation were cut, ground, polished and electrolytically thinned to electron transparency using an electrolyte A3 from Struers. The mechanical properties were determined by nano-hardness indentation utilizing a Hysitron Triboscope, an add-on device mounted on the scanner head of a commercial, large stage scanning probe microscope (SPM) Veeco Dimension 3100. Hardness and elastic modulus were calculated from the unloading curve using the standard Oliver-Pharr method [3]. During the HT, ω_o-phase and γ-platelets (γ_p) precipitates in the β_o-phase (Fig. 1a). The evaluation of the diffraction pattern taken from $\beta_o(\omega_o)$ area (insert in Fig.1a) substantiates an ordered ω_o-phase and the following orientation relationship: $\langle 111\rangle_{\beta o}\{110\}_{\beta o}$ // $[0001]\omega_o$ $\{11\ 0\}\omega_o$. Detailed HRTEM studies (Fig. 1b) reveal that the ω_o-phase coherently precipitates with grain size mostly of 5 to 100 nm in diameter in the β_o-matrix. After the creep test, globular ω_o-grains with diameter between 50 and 200 nm inside the β_o-phase can be clearly seen (Fig. 2a). The phase fraction of the ω_o-phase increases. Quantitative analyse of 8 vol.% $\beta_o(\omega_o)$-phase reveals a ratio of 57 % ω_o-phase and 43 % β_o-phase. Many neighbouring particles in the β_o-grain possess similar contrast indicating a well-defined orientation relationship within the matrix, which was proven by evaluation of the diffraction pattern. Fig. 2b shows a Cs-corrected HRTEM image of one, dislocation free, segment of the atomically abrupt and coherent β_o/ω_o interface along the $\langle 111\rangle\beta_o$ and $[0001]\omega_o$ zone axes. The analysis of the Fourier transformed image shows that the {11 0} and { 010} lattice planes from the ω_o-phase are parallel to the {1 0} and {11 } planes from the β_o-matrix. Fig. 3 presents EDX line scans of a region with ω_o-grains in the β_o-matrix. The intensity of Mo reveals an inverse trend at the transition to the β_o/ω_o-interface. In the ω_o-grains the Mo content decreases whereas in the β_o-phase it increases (Fig. 3b). The formation of the ω_o-phase seems to depend on the local Mo content. To characterize the mechanical properties of β_o-phase containing ω_o-precipitates nano-hardness indentation was performed after different HT. After the last HT step the hardness of $\beta_o(\omega_o)$-phase is 11.3 GPa. After the growth of the ω_o-phase to spherical grains with medium size of 100 nm the hardness decreases to 9.8 GPa. However, this value is well above the hardness of ω-free β_o-phase (8 GPa) and those of the existing globular α_2- and γ-phases. Thus, the formation of the ω_o-phase increases the hardness of β_o-phase due to precipitation hardening.

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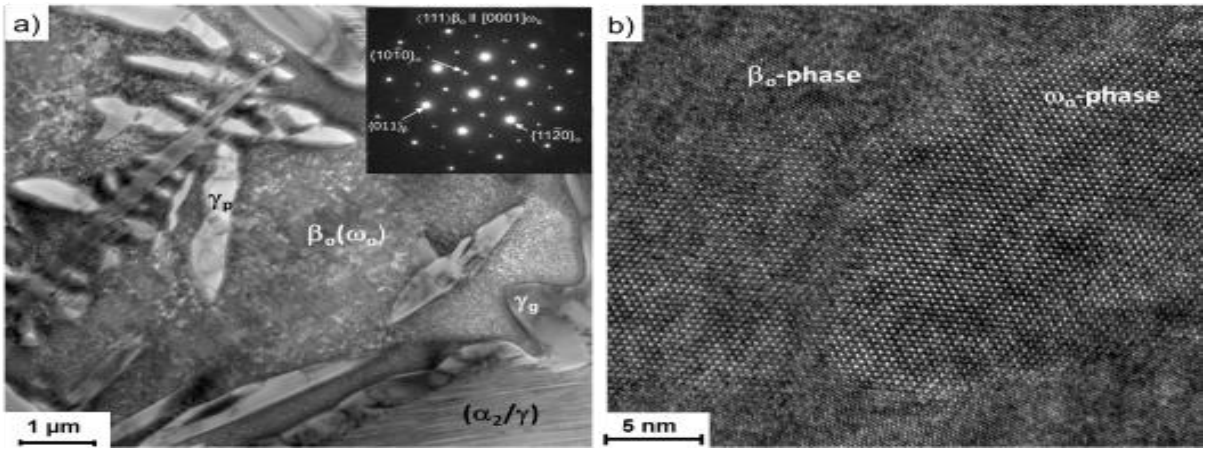

Figure 1. Microstructure and distribution of the constituent phases after HT. a) TEM BF image of β_o-phase containing ω_o-precipitates, surrounded by γ_g-grains and (α_2/γ)-colonies. The substructure inside the β_o-phase arose from the presence of fine ω_o-domains interrupted by γ_p-platelets b) HRTEM image showing the ω_o-precipitates within the β_o-phase.

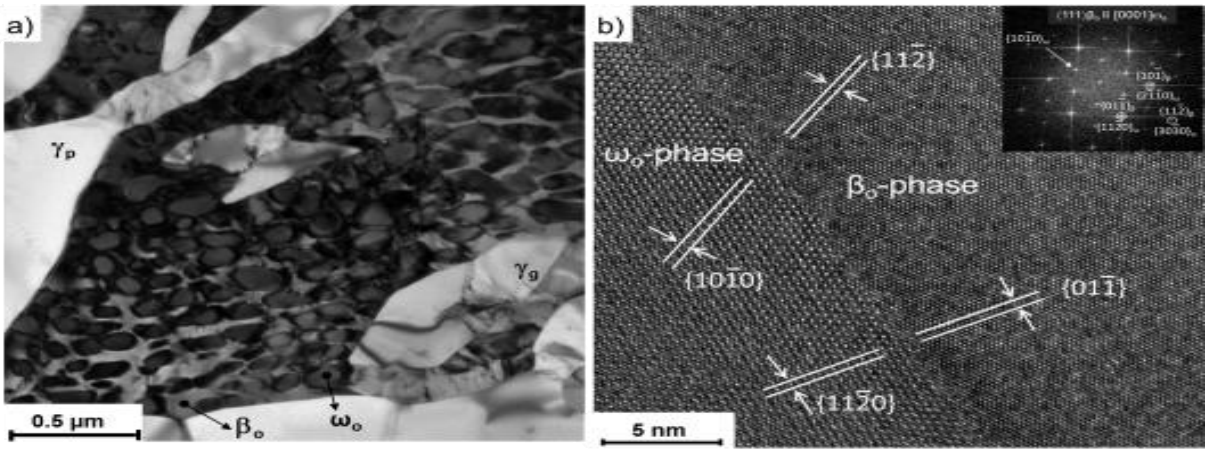

Figure 2. Microstructure after the creep test. a) TEM BF image shows ω_o-grains with a globular shape uniformly distributed in the β_o-phase, surrounded by γ_p- and γ_g-grains. b) a Cs-corrected HRTEM image of one, dislocations free, segment of the coherent β_o/ω_o interface along the $\langle 111\rangle\beta_o$ and $[0001]\omega_o$ zone axes.

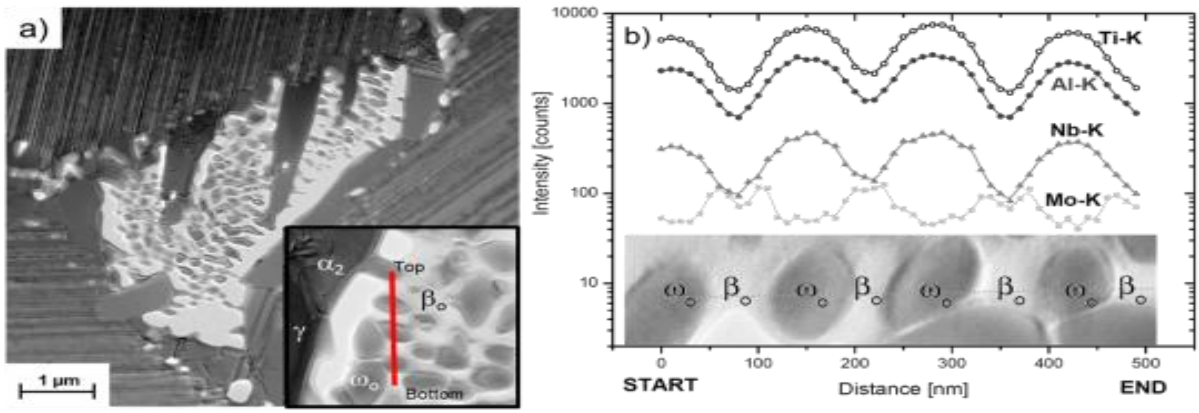

Figure 3. a) TEM BF image of a β_o-grain with ω_o-particles and γ_p-grains. The inset shows the position of the EDX-line scan. b) EDX line scans of region with alternating ω_o-grains in the β_o-matrix. The intensity of the Mo content increases at the transition to β_o-phase and shows an inverse trend to that in the ω_o-phase.