Evolution of orthorhombic phase in high Nb-containing lamellar γ-TiAl alloy: a transmission electron microscopy study

Ren, G.[1] and Sun, J.[1]

[1] School of Materials Science and Engineering, Shanghai Jiao Tong University, China

Recently, the formation of an orthorhombic (O1) phase from the α_2 parent phase with modulation has been reported by the present authors in a lamellar γ-Ti-45Al-8.5Nb alloy using transmission electron microscope (TEM) [1]. It was revealed that the O1 phase has a thin plate-like morphology with orientation relationships of $\{001\}_O//\{0001\}_{\alpha2}$ and $<110>_O//<11\text{-}20>_{\alpha2}$ at an initial precipitating stage. The habit plane for O1 phase variants lies at $\{350\}_O//\{13\text{-}40\}_{\alpha2}$. It was proposed that the formation of O1 phases arises from a phase separation reaction in the α_2 parent phase, dominated by a diffusion mechanism [1]. In this work, we report a TEM study of the evolution of O1 phases in the α_2 phase with modulation in a lamellar γ-Ti-45Al-8.5Nb alloy during prolonged annealing at 600 °C. We prepared a lamellar Ti-45Al-8.5Nb (at.%) alloy by plasma cold hearth melting. The samples were annealed at 900 °C for 2 hours followed by air-cooling and then, subjected to isothermal annealing at 600 °C from 24 to 500 hours. TEM observations were conducted by JEM-2100F and JEM-ARM200F microscope equipped with a probe-Cs corrector. Thin TEM foils were prepared by a standard twin-jet electro-chemical polishing.

TEM results have exhibited that the O1 phase nucleates at the γ/α_2 interface and grows towards α_2 laths along $[0001]_{\alpha2}$ and thus, the spatial arrangements of O1 phases can be directly observed along $[001]_O//[0001]_{\alpha2}$. Fig. 1(a-h) are bright-field TEM images of O1 phases together with corresponding SAED patterns along $[001]_O//[0001]_{\alpha2}$ at different annealing time. A dominant thin plate-like morphology of O1 phases with wavy interface is visible at 600 °C for 24 hours (Fig. 1(a)), and their corresponding reflections show slight angular and radial splitting around the primary reflections of $\{20\text{-}20\}_{\alpha2}$, indicating a collective arrangement of O1 phase variants within the α_2 parent phase. With an increase of annealing time, the volume faction of O1phases increase with a consecutive decomposition of remaining α_2 phases and O1 variants tend to interact with each other, leading to the formation of zigzag patterns (Fig. 1(c, e)). At annealing time of 500 hours, the O1 phase exhibits rectangle/square shape (Fig. 1(g)). Fig. 2(a-g) are Z contrast images of O1 phases at 500 hours. An atomic-resolution Z contrast image directly illustrates the crystalline structure of α_2 and O1 phases (Fig. 2(b)). There exist five basic morphological patterns where the retransformed α_2 II phase is enclosed by O1 variants in rectangle shape (Fig. 2(c-g)). Fig. 3(a) illustrates the O1 phase in rectangle shape with perpendicular interfaces, which maintains totally different orientation relationships with α_2-I and α_2-II, that is, $[0001]_{a2\text{-}I}//[001]_O$, $(\text{-}2020)_{\alpha2\text{-}I}//(\text{-}2\text{-}20)_O$ and $[0001]_{\alpha2\text{-}II}//[001]_O$, $(2\text{-}200)_{\alpha2\text{-}II}//(2\text{-}20)_O$, respectively. The $(2\text{-}200)_{\alpha2\text{-}I}$ plane is misaligned to $(2\text{-}200)_{\alpha2\text{-}II}$ by ~3.4 °, that is, the contiguous α_2-I and α_2-II are rotated around a common [0001] axis by ~3.4 ° with respect to each other. Such a rotation is closely associated with the formation of two orthogonal interfaces for single O1 variant in rectangle shape, as shown in superimposed pole figures (Fig. 3(d, e)).

Reference

[1] Guo-dong Ren, Jian Sun, Acta Materialia 144 (2018) 516-523.

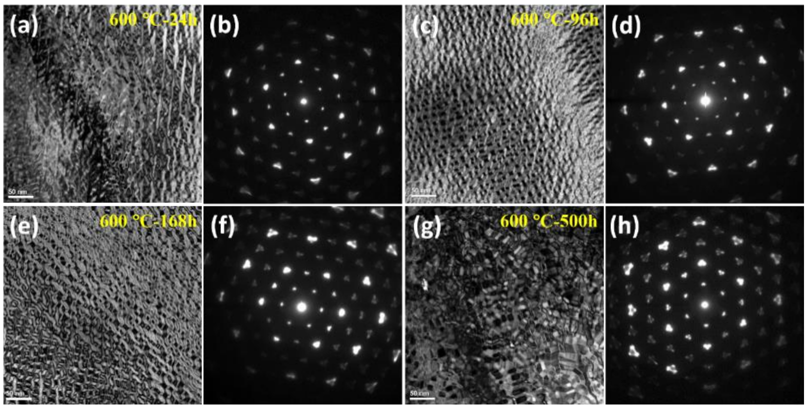

Fig. 1. Bright-field TEM images and corresponding SAED patterns showing evolution of O1 precipitates in α_2 phase after annealing at 600 °C for (a, b) 24 h, (c, d) 96 h, (e, f) 168 h, (g, h) 500 h.

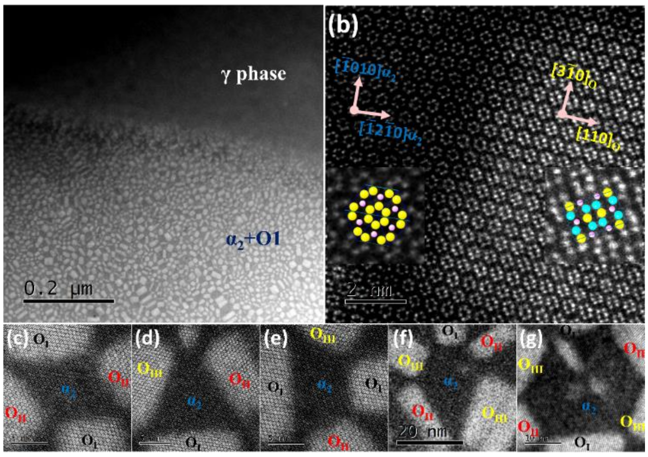

Fig. 2. Z-contrast images of O1 precipitates in α_2 phase after annealing at 600 °C for 500 h: (a) low magnification image of α_2+O1, (b) atomic-resolution image illustrating α_2 and O lattices, five basic morphological patterns in (c) rhomboid, (d) triangles, (e) trapezia, (f) pentagons, and (g) hexagons.

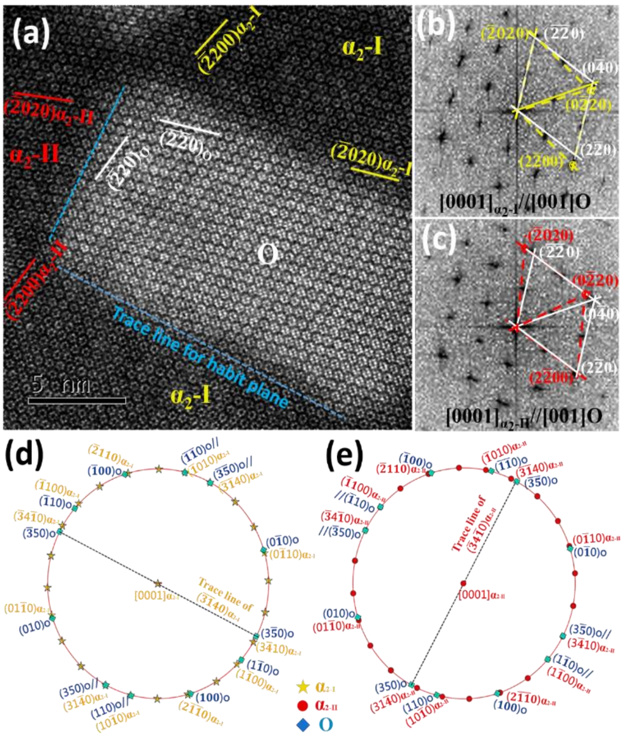

Fig. 3. (a) Atomic-resolution Z-contrast image showing single O1 variant with two perpendicular interfaces with α_2-I and α_2-II, (b, c) FFT diffractograms indicating orientation relationships between O1and α_2-I, O1 and α_2-II, (d, e) superimposed pole figures illustrating perpendicular habit planes.