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Monitoring Microstructure Evolution in TiAl Using TEM

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Abstract

The phase transformation, involving the ordering of disordered α-Ti phase with formation of ordered α_2 (Ti_3Al) and γ (TiAl) phases in TiAl-based alloys is of major importance in manufacturing these perspective lightweight high-temperature materials, as it controls the grain size and spacing of γ and α_2 lamellae, and hence the yield strength and other mechanical properties. The paper presents the results of the transmission electron microscopy (TEM) and energy-dispersive spectroscopy (EDS) experiments conducted on a Ti-46Al-1.9Cr-3Nb alloy before and after heat treatment. Heat treatment of the alloy at 1450°C followed by furnace cooling has led to the formation of a fully lamellar microstructure, which consists of γ lamellae mostly and of small volume fraction of α_2 lamellae. Microdiffraction and elemental composition data prove that the dark and the bright lamellae in the TEM bright field image belong to the ordered α_2 and γ structures respectively. The lamellar thickness of both α_2 and γ phases varies significantly, falling into the hundreds of nanometre range and is refined with increasing cooling rate. Based on the results obtained, the mechanisms of the transformation of the α_2 structure to γ structure are discussed.

Microstructural Analysis

Furnace cooling from the single phase (disordered α phase) or two-phase region (disordered α and β phases) generally results in a fully lamellar structure where the lamellae are mostly γ intermixed with α_2 lamellae. Slow cooling (with cooling rates of 5-10°C/min) results in a two phase lamellar structure consisting of different orientations of lamellae of γ and some α_2 lamellae. Fast cooling simply refines the lamellar structure.

The results of microdiffraction study of the fully lamellar structure of the Ti-46Al-1.9Cr-3Nb samples after the heat treatment are shown in Fig. 1 by the example of the sample cooled at 5°C/min.

The diffraction proved directly that the dark and the bright lamellae in the TEM bright field image belong to the different crystal structures - ordered α_2 (Ti_3Al with the DO_{19} structure based on hcp lattice) and γ (near-cubic face-centred tetragonal $L1_0$ crystal structure), respectively. This is in contradiction with [1], stating that bright and dark lamellae have the same $L1_0$ lattice but with different orientation, but in strict correspondence with [2-5].

The lamellar phase thickness was defined as the edge-to-edge dimension (measured perpendicular to the phase boundary) to the adjacent lamellae for a given phase. The existence of γ variant was not seen in the TEM micrographs (Fig. 1) and therefore each variant was not discriminated. The thickness of the bright regions was measured, whatever the number of variant (invisible), so the measured thickness is equivalent to inter-α_2 thickness or α_2 inter-spacing. The result of quantitative measurements of the average lamellar thickness of the fully lamellar microstructure for each phase after different cooling rates is presented in Table 1. For each cooling rate, on average ten images were collected and analysed, from different samples and different locations on one sample.

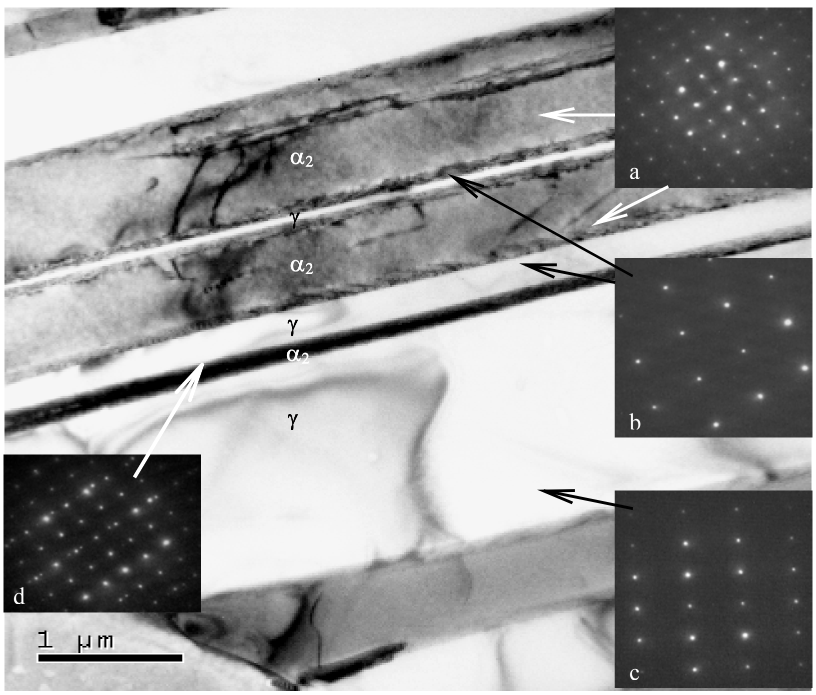

Fig. 1. TEM bright field micrograph showing α_2 and γ lamellar structure for the alloy cooled from 1450°C at 5°C/min. The insets show selected area diffraction (SAD) patterns correspondent to [010] axis of α_2 phase (a), [111] axis of γ phase (b), [110] axis of γ phase (c) and overlapped pattern with [111] γ and [010] α_2 axes (d).

TABLE 1. Lamellar thickness distribution in Ti-46Al-1.9Cr-3Nb alloy after furnace cooling with different cooling rates for γ and α_2 phases

Cooling rate (°C/min)	Average γ lamellar thickness (μm)	Standard deviation (μm)	Average α_2 lamellar thickness (μm)	Standard deviation (μm)
5	0.88	0.73	0.61	0.55
40	0.29	0.19	0.21	0.14

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