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ULTRAFINE FULLY-LAMELLAR STRUCTURES IN TWO-PHASE γ-TiAl ALLOYS

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ABSTRACT

Special ultrafine fully-lamellar microstructures have been found recently in γ-TiAl alloys with 46-48 at.% Al that are processed or heat-treated above the α-transus temperature (T_α). Hot-extrusion above T_α also produces a refined colony or grain size. Refined-colony/ultrafine-lamellar (RC/UL) microstructures produce an excellent combination of room-temperature ductility and high-temperature strength in Ti-47Al-2Cr-2Nb (at.%) alloys. UL structures generally have an average interlamellar spacing of 100-200 nm. Moreover, UL structures also have regularly alternating γ and α_2 lamellae, such that they are dominated by γ/α_2 interfaces with relatively few γ/γ twin boundaries. The focus of this study is how changes in processing parameters or alloy composition affect formation of the UL structure, particularly the α_2 component.

MASTER

INTRODUCTION

While fully-lamellar microstructures in two-phase γ-TiAl alloys have been known to improve the high-temperature tensile and creep strength of simple and complex Ti-(47-48)Al alloys, it was difficult to produce good room-temperature ductility in such alloys [1-5]. Recently, it was found that ingot- and powder-metallurgy (I/M and P/M) processed Ti-47Al-2Cr-2Nb alloys with refined lamellar colony (RC) sizes (20-70 μm) and ultrafine lamellar (UL) spacings (100-200 nm) can have an outstanding combination of room-temperature ductility (2-5%) and toughness (20-50 MPa $m^{1/2}$), *as well as* high-temperature strength (YS - 700-800 MPa at 800°C) [6-8]. The formation and stability of such RC/UL microstructures is sensitive to both alloy composition and processing parameters [6-9]. These microstructures require processing above the α-transus temperature (T_α, ≈ 1320°C for the base Ti-47Al-2Cr-2Nb alloy [6]) and alloying additions of boron and tungsten have been found enhance the formation and stability (aging resistance) of such UL structures [6-9]. The purpose of this paper is to present in more detailed characterization by TEM of I/M hot-extruded Ti-47Al-2Cr-2Nb alloys modified with boron and tungsten, with particular emphasis on the α_2 component of the structure.

EXPERIMENTAL

The compositions of the TiAl alloys examined in this work (designated as TIA-20, -21, and -25) are listed in Table 1 together with their hot-extrusion temperature. Details of alloy melting, processing and heat-treating, and data on grain size and mechanical properties are reported elsewhere [7,8].

Disk specimens for examination using transmission electron microscopy (TEM) were cut from the shoulders of buttonhead tensile specimens tested at room temperature, transverse to the extrusion direction. TEM disks were thinned by twin-jet electropolishing in a solution of perchloric acid, methanol, butyl cellusolve and glycerin (6/60/33.5/0.5 vol.%, respectively) at -20°C and 32 V. TEM was performed using Philips CM12 (120 kV), CM200/FEG (200 kV) and CM30 (300 kV) electron microscopes. Some of the electropolished TEM disks were also examined by scanning electron microscopy (SEM) to better view the overall structure, using Hitachi S4100/FEG or Philips XL30/FEG instruments. Lamellar microstructural parameters were determined quantitatively for each specimen by examining three representative grains, tilting each grain so that the lamellar interfaces were parallel to the electron beam direction (**Z**) and having >100 lamellae in the field of view. Generally diffracting conditions of **g**= $<111_\gamma>$ were used, with strong contrast images to show all interfaces and weaker contrast images to better show the α_2 phase being analyzed. A line-intercept method was used to determine average lamellar spacing (γ

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and α_2 lamellea) and α_2-α_2 spacing. Several of the largest and smallest individual lamellea of each phase in each analyzed area were measured to determine the maximum size range, but statistically significant size distributions were not determined here.

TABLE 1 - Alloy Compositions and Extrusion/Heat Treatment Conditions ($T_2 > T_1 > T_\alpha$)

Alloy	Composition (at.%)	Hot-Extrusion/Heat-Treatment Temperatures(°C)
TIA-20	Ti-47Al-2Cr-2Nb-0.15B	T_1/2h at 900°C T_1/2h at 1320°C
TIA-21	Ti-47Al-2Cr-1.8Nb-0.2W-0.15B	T_1/2h at 900°C T_1/2h at 1320°C T_2/2h at 900°C
TIA-25	Ti-46Al-2Cr-1.8Nb-0.2W-0.15B	T_2/2h at 900°C

RESULTS and DISCUSSION

The B and B+W modified alloys (TIA-20 and -21) extruded at T_1 were found to have somewhat more intercolony γ (10-20%) and more irregular lamellar structures relative to the same alloys extruded at the higher temperature T_2. This was particularly true of the B-modified TIA-20 alloy (Fig. 1). The alloys extruded at T_2 had less intercolony γ (<10%) and more regular lamellar structures, suggesting that T_1 was too close to T_α, and that alloys extruded T_1 at might not have remained completely above T_α during the deformation. Nonuniformities in the regular lamellar structures include branched or fragmented α_2 lamellea or equiaxed γ grains with coarse α_2 particles within the lamellar regions. Such lamellar structure defects have been found to be more prevelant in Ti-47Al alloys with additions of B alone and are greatly reduced in alloys with B+W additions [9,10].

Quantitative analysis of the lamellar spacings showed that for extrusion at T_1, the B+W modified TIA-21 alloy had a more uniform lamellar structure than alloy TIA-20. The TIA-20 alloy had clusters of very fine lamellea adjacent to larger regions of coarser lamellea within the same colony. This is reflected in the wider range of average spacing and maximum width of γ lamellea. Data presented here is also consistent with previous data on simpler Ti-47Al alloys which showed that B+W additions improved the uniformity of the lamellar structure relative to alloys with only B added [9]. Heat-treatments at 900°C do not change the as-extruded lamellar structure in Ti-47Al-2Cr-2Nb alloys [9], but heat-treatments at 1320°C continuously coarsened the lamellar structures significantly. However, comparison of two alloys both heat-treated at 1320°C shows that the TIA-21 alloy with B+W additions is more resistant to lamellar coarsening, as measured by both the average interlamellar and the α_2-α_2 spacings. Hot-extrusion at a higher temperature of T_2 further uniformly refines the lamellar structure of the TIA-21 alloy, particularly the α_2-α_2 spacing. However, many of the wider γ lamellea also contain γ/γ twins, so that relative fraction of γ/α_2 interfaces is lower in this I/M alloy than it was in the P/M Ti-47Al-2Cr-2Nb alloy in which such UL structures were first observed [6].

In order to increase the amount of α_2 phase in the lamellar structure, alloy TIA-25 with 46 at. % Al, but otherwise the same composition as TIA-21 (Table 1), was melted and also extruded at T_2. The TIA-25 alloy had a significantly refined lamellar structure, with a finer and more uniform average lamellar spacing (Fig. 2) and a finer distribution of thin α_2 lamellea more regularly between the γ lamellea (Fig. 3). Consistently, the α_2-α_2 spacing of TIA-25 is about half that of TIA-21, and the size ranges for both lamellar phase components is much narrower. Tensile tests indicate that the yield strength of TIA-25 is higher that that of TIA-21 by 10-20% from room temperature to 1000°C. The average lamellar and α_2-α_2 spacings of the I/M TIA-25 alloy are comparable to those observed previously in the P/M Ti-47Al-2Cr-2Nb alloy.

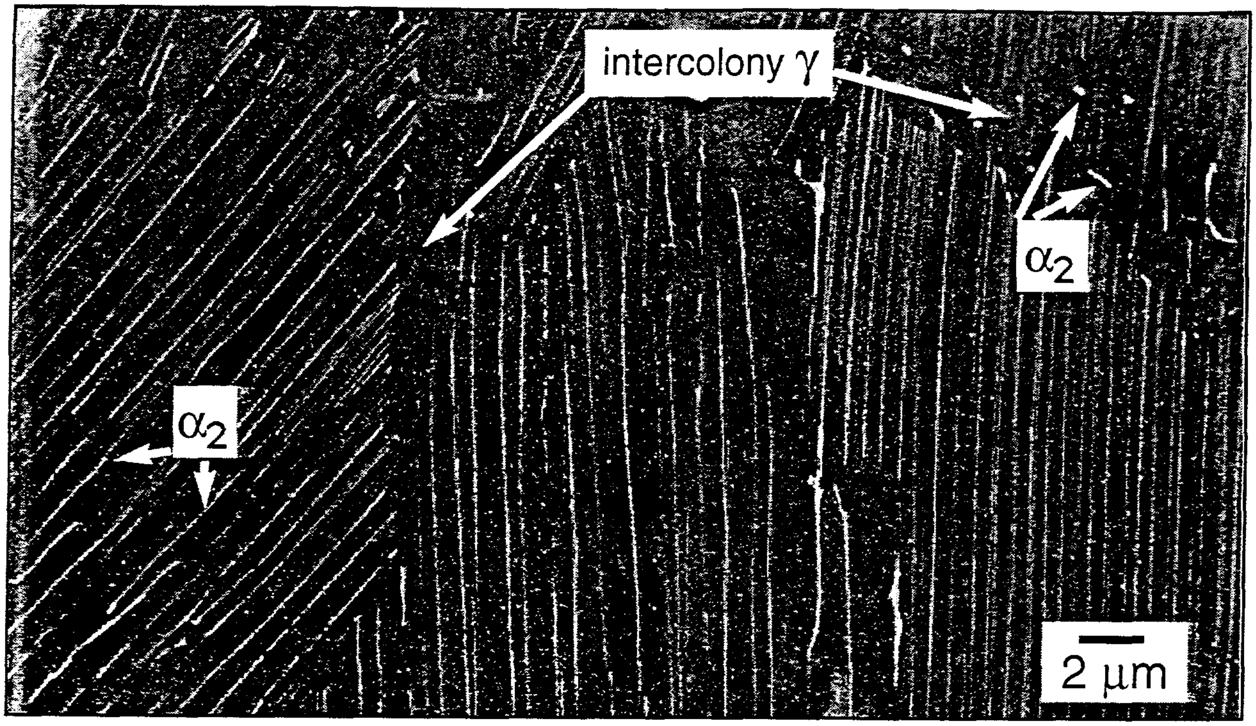

Fig. 1 - Secondary electron SEM image of an electro-polished TEM disk showing the lamellar colony structure of TIA-20 alloy extruded at T_1 and heat-treated for 2h at 900°C.

TABLE 2 - Quantitative Lamellar Microstructural Data on Hot-Extruded and Heat-Treated TiAl Alloys

Alloy and Heat Treatment		Interlamellar spacing (nm)	α_2-α_2 spacing (nm)	γ-width (nm)	α_2-width (nm)
TIA-20	T_1/2h at 900°C	140-325	400-500	95-870	30-60
	T_1/2h at 1320°C	440	1000	160-1250	55-265
TIA-21	T_1/2h at 900°C	160	460-500	75-635	20-55
	T_1/2h at 1320°C	300	800	290-1100	55-210
	T_2/2h at 900°C	140	400	40-750	15-110
TIA-25	T_2/2h at 900°C	105	215	20-520	15-40

It has been suggested that the fine α_2 lamellea act as the reinforcing phase in the "micro-laminate" lamellar structure [6]. These UL structures have also been shown to be the source of the outstanding strength and creep-resistance that these fully-lamellar TiAl alloys exhibit at 760-800°C [6,8,11]. In particular, it has been suggested that B+W additions enhance the resistance of the α_2 lamellea to dissolution, which appears to be the first step in the continuous coarsening of the UL structures during aging at 800-1000°C [9]. It is, therefore, important to better understand the effects of both alloying additions and processing on the formation and stability of both phase components of these UL structures to design microstructures for optimum properties.

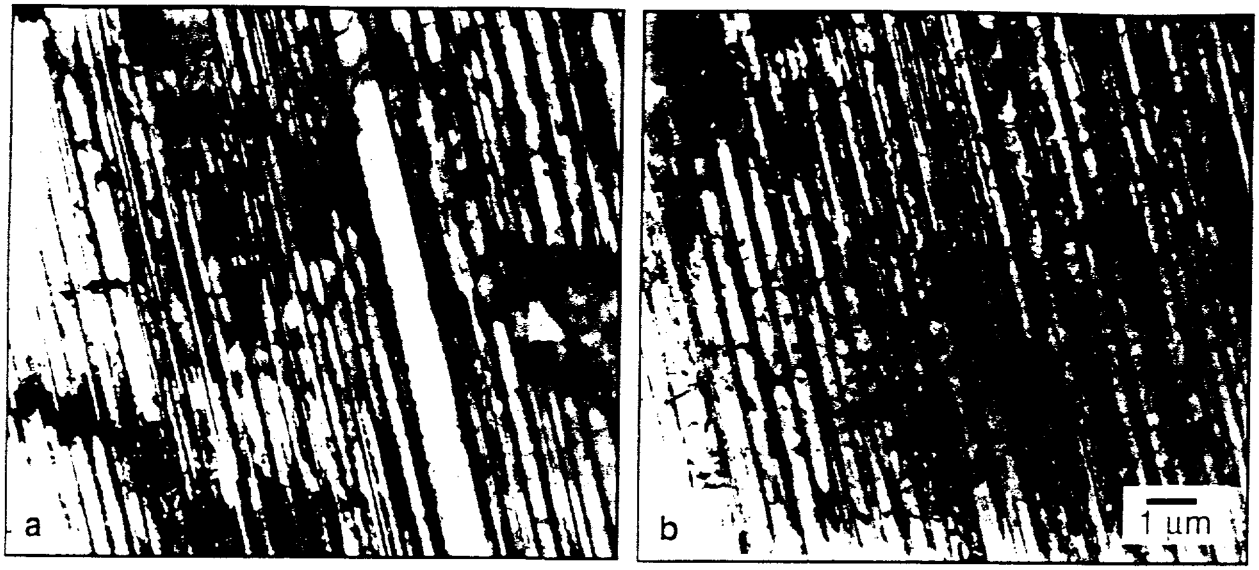

Fig. 2 - TEM at lower magnification showing the general lamellar structures of a) TIA-21 and b) TIA-25, extruded at T_2 and heat-treated for 2h at 900°C.

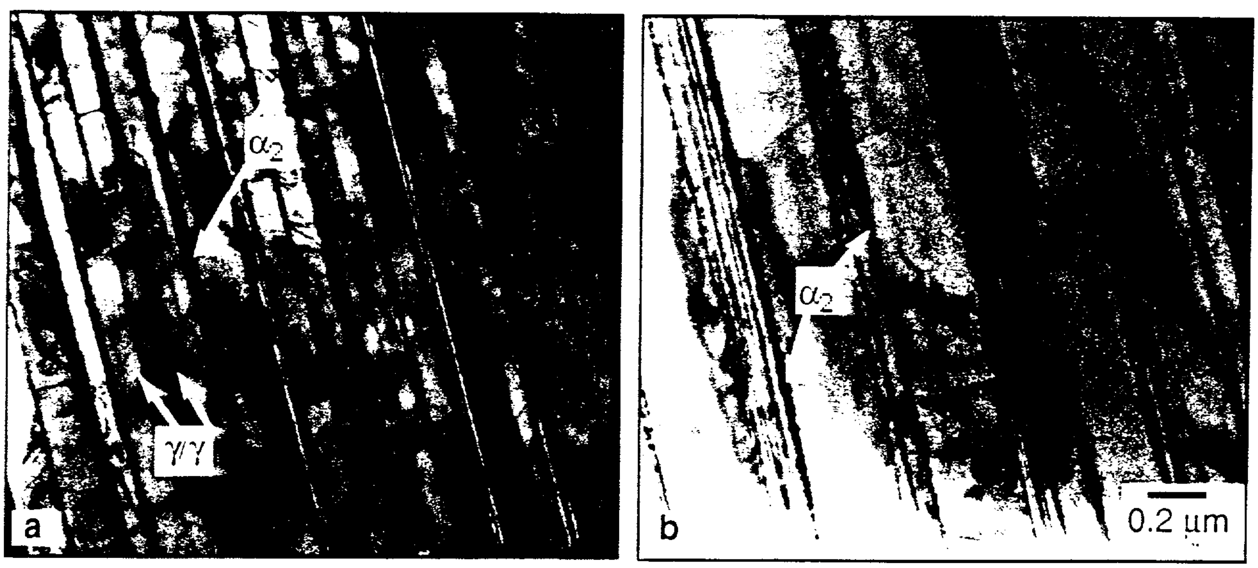

Fig. 3 - TEM at higher magnification showing the α_2 lamellea and γ/γ twins in the lamellar structures of a) TIA-21 and b) TIA-25, extruded at T_2 and heat-treated for 2h at 900°C.

CONCLUSIONS

Studies of alloying and processing effects on the formation of ultrafine lamellar structures in Ti-47Al-2Cr-2Nb-0.15B alloys hot-extruded above T_α indicate that:

1. W+B additions refine the scale and increase the uniformity of the lamellar structure.

2. Lowering the Al content from 47 to 46 at.% in the B+W modified alloy further refines the average lamellar and α_2-α_2 spacings, and increases the ratio of α_2 to γ lamellea to nearly 1:1.

3. Maintaining the extrusion temperature sufficiently above T_α is important for producing the best refined-colony/ultrafine-lamellar structure for a particular alloy composition.

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