A TEM study of ultra-fine lamellar structures in titanium aluminides

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γ-TiAl based alloys are promising candidates for high temperature applications in jet and automotive engines due to their attractive properties. Heat treatments and alloying are used to optimize the mechanical properties. In this study the relationship between microstructure, chemical composition and hardness in Ti-45at%Al-7.5at%Nb-(0,0.5)at%C alloys was investigated. Two-step heat treatments were applied to obtain ultrafine lamellar structures consisting of γ-TiAl and α_2-Ti_3Al [1].

The first heat treatment step was conducted in the single α-phase field (unordered α_2 phase) to control the grain size. The second heat step is used to obtain colonies with a lamellar microstructure consisting of γ-TiAl and α_2-Ti_3Al lamellae by annealing the material in the (α_2+γ)-phase field region. In this study we concentrated on the evolving microstructure for two different annealing temperatures, 790°C and 850°C. In addition, the influence of carbon (0 and 0.5 at%) was studied on the resulting microstructure. All four different samples were investigated by transmission electron microscopy (TEM) and micro-indentation (HV5) in order to correlate the microstructure with the resulting hardness.

Fig. 1 shows the resulting microstructure with ultra-fine γ-TiAl and α_2-Ti_3Al lamellae. The conventional TEM study reveals that heating to 790°C leads to a larger interface spacing than heating to 850°C. In addition, dark field images indicate that the wider lamellas are α_2-Ti_3Al which are separated by a few nm wide γ-TiAl lamellae. Comparing the lamellar microstructure for the carbon containing alloy with the carbon-free material demonstrate a refinement effect. Carbon leads to a significantly finer average lamellar width. The width of the α_2-Ti_3Al lamellae was found to decrease from 89nm for the carbon-free sample annealed at 790°C to 4nm for the sample containing 0.5at% carbon annealed at 850°C (see Table 1). The widths of the γ-TiAl lamellae remain rather constant at average values between 2.5nm and 7.5nm (Table 1). The actual widths of the ultra-fine lamellae were determined using high-resolution TEM. It is interesting to note that with increasing annealing temperature and carbon content the volume content of γ-TiAl increases towards the equilibrium value by nucleating more and more fine γ-TiAl lamellae leading to a ultra-fine lamellar microstructure with a high density of interfaces.

Hardness measurements reveal the highest hardness value of 504HV for this ultra-fine microstructure (sample No. 4, Table 1) while sample No. 1 (Table 1) with the coarsest α_2-Ti_3Al lamellae of 89nm possesses the lowest hardness of 447HV. This result is surprising when considering the volume content of the γ-TiAl phase which usually deforms plastically while the hexagonal α_2-Ti_3Al phase is known to be brittle. However, due to the small widths of the γ-TiAl lamellae (<7.5nm) dislocation nucleation and motion are suppressed and the

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hardness of the composite governed by the α_2-laths. If the α_2 lamellae are 89 nm wide, like in sample No 1, dislocations are found by TEM revealing plasticity (Fig. 2), while for thin α_2 lamellae although dislocation based plasticity gets confined resulting in high hardness. Thus, the two-step heat treatment used in this study provides a new route to tailor the microstructure and hardness of titanium aluminides.

1. L. Cha, C. Scheu, H. Clemens, G. Dehm, et al., Intermetallics **16** (2008) p868
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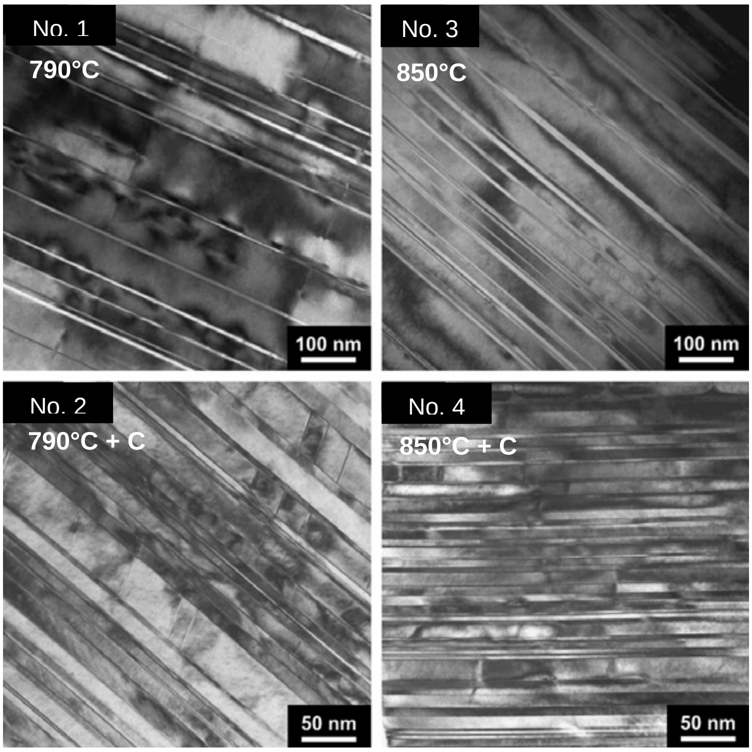
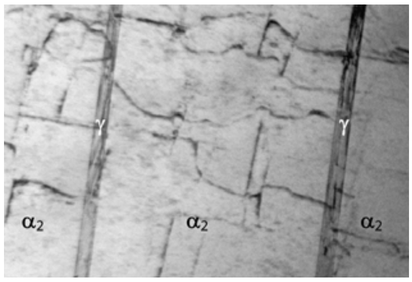


Figure 1. Bright field images taken from samples No. 1–4. The samples heated to 850 °C (No. 2 and 4) display a finer lamellar structure than those annealed at 790 °C (No. 1 and 3). The Ti–45Al–7.5Nb sample with carbon (No. 3 and 4) show smaller lamellar widths compared to the samples with identical heat treatment but without carbon (No. 1 and 2). Note that the scale bars are different for the upper and lower images.

Table 1. Microstructural parameters and hardness values of the four investigated samples with different carbon contents as well as different second heat treatment temperatures.

		No. 1 790 °C	**No. 2** 850 °C	**No. 3** 790 °C&0.5 C	**No. 4** 850 °C& 0.5 C
hardness	(kg / mm^2)	447± 12	494 ± 9	460 ± 15	504 ± 14
interface spacing	(nm)	37.9	10.4± 7.8	14.6	5.9± 4.0
width of α_2-laths	(nm)	89 ± 22	20 ± 10	48 ± 19	4 ± 2
width of γ-lath	(nm)	3.4 ± 2.2	7.5 ± 5.6	2.5 ± 1.4	5.8 ± 4.3
volume fraction of γ	(%)	0.12	0.29	0.17	0.40

Figure 2. Dislocations in α_2 laths which are separated by γ laths. The image is taken from sample No. 1.



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