EBSD characterisation of the B2 orientation in γ-TiAl based alloy

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Abstract. Electron backscattered diffraction (EBSD) has been conducted to determine the orientation relationship of the remnant B2 phase in an α-solidified γ-Ti-45Al-2Nb-0.3Si (at. %) based intermetallic alloy. The morphology and microstructural characterisation was investigated using conventional methods. The results showed that the B2-grains exhibits a Blackburn orientation relationship (BOR) with the α2 grains viz. \{111\}_B2 // \{0001\}_α2 and \{110\}_B2 // \{11-20\}_α2. Moreover, mis-orientation axes of B2-grains were found in the clusters between \langle101\rangle and \langle111\rangle in 57-630 angles, in the Y0 directions. In addition, it was also observed that the overall B2 grains in the alloy structure was textured and comprised of high angle boundaries of misorientations above 150 angles.

1. Introduction

The γ-based titanium aluminides are lightweight materials and are in continuous demand because of the higher temperature engine efficiencies in automotive, aerospace and energy industries. These intermetallic alloys offer a good combination of mechanical properties, and therefore, can withstand temperatures up to 800 °C, especially with additions of Nb and Mo, alloying elements [1]–[3]. The cast intermetallic alloys based on Ti-45Al, which solidify via the β-phase (retained as B2-phase at room temperature) consist of an isotropic equiaxed and texture-free microstructure with modest micro-segregation whereas, peritectic alloys (solidification via α-phase) show anisotropic microstructures with significant texture and segregation, respectively [1].

The β→α transition is a critical phase transformation in titanium and its alloys, because it plays a predominant role in ascertaining the microstructure and mechanical properties. This transformation reaction occurs by the Burger orientation relationship (BOR) viz. \{110\}_β // \{0001\}_α and \langle111\rangleβ // <1100>α, which can result in crystallographic equivalent twelve α-variants [4]. Studies [5-8] have shown that the α-phase exhibits an orientation relationship between the inherited γ-phase. Through the EBSD technique, nucleation mechanism of the γ-grains originated at α/α-grain boundaries was extensively investigated. It was reported that further cooling lead to a diffusion-controlled precipitation of γ-grains to a Blackburn orientation relationship with the α-phase i.e. (0002)α // (111)γ and [1120]α

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with one of the neighbouring α-grain, forming α/γ colonies and few of the γ-grains did not exhibit this BOR [5-8]. Therefore, the aim of this study is to investigate the orientation relationship of the remnant B2-phase with respect to the α-peritectic grains of the heat-treated α-solidified γ-Ti-45Al-2Nb-0.3Si based intermetallic alloy.

2. Experimental work
An arc button melted Ti-45Al-2Nb-0.3Si (at. %) alloy was isothermally heat-treated in the α-transus temperature of 1335 °C and cooled slowly in the (α2+γ) phase region in order to obtain a fully lamellar structure [2-3]. The alloy was characterised by SEM equipped with energy-dispersive X-ray spectroscopy (EDS) capabilities for chemical analysis. Phase identification was investigated by X-ray diffraction (XRD) using CuKα radiation λ = 0.154062nm and 2θ from 20-90° angles. PANalytical’s X’pert High Score program equipped with data organised in ASCII OR XRDML files was used to indexed lattice parameters of the obtained phases [2,9]. Orientations of the B2 and α (retained as α2) phases and their relationships were investigated through orientation imaging microscopy (OIM) software in SEM-EBSD, using Channel 5™ system developed by HKL® of which the procedure is reported elsewhere [6].

3. Results and discussion
3.1. Microstructure analysis
The phases formed after the isothermal treating and cooling process reported in our previous study [3] were: γ-TiAl, α2-Ti3Al, and B2-(Ti5Si3AlxNbx) evenly distributed as shown in Fig. 1. The chemical composition of the phases by SEM-EDS method is illustrated in Table 1.

Table 1. Chemical composition of the heat-treated Ti-45Al-2Nb-0.3Si alloy (at. %).

| Element | Composition (γ) | Composition (α2) | Composition (B2)-Ti5Si3 |
|---------|-----------------|-----------------|------------------------|
| Ti      | 49.29±1.58      | 62.89±0.72      | 54.24±1.47             |
| Al      | 48.15±0.46      | 34.41±1.89      | 33.38±0.81             |
| Nb      | 2.32±0.89       | 2.12±0.63       | 2.62±1.19              |
| Si      | 0.23±1.28       | 0.57±1.51       | 9.76±1.30              |
Figure 1: SEM-backscatter image (BSI) of the as-heat treated γ-Ti-45Al-2Nb-0.3Si intermetallic alloy.

3.2. EBSD analysis

The alloy was isothermally treated at temperatures of 1335 °C, for attempting to minimise the γ and β phases, followed by thermal stabilisation at 900 °C with subsequent furnace cooling. This resulted in a fully lamellar (FL) structure in Fig. 1, mainly comprising of (α2+γ). This resulting microstructure α2/γ colonies, with small amount B2 phase retaining after solution annealing along with few Ti5Si3 particles as shown in Fig. 1. In addition, the XRD results in Fig. 2 validates the stable phases present at room temperature. The lamellar structure (α2/γ) emanated from the γ lamellae precipitating in the transformed α-grains during the cooling process (β→α solid state transformation) [3].

Fig. 3 demonstrates that the {111}B2 // {0001}α2 and {110}B2 // {11-20}α2 is in agreement with the Burgers orientation relationship, see dotted circles in Fig. 3b. This is supplemented by the inverse pole figures in Fig. 4a showing the most intensity of B2 grains in the Y0 direction. According to the corresponding colour coding in Fig. 4b the highest intensity at a value of 10 indicates that the misorientation axes of the B2-grains is seen in the clusters between <101> and <111> directions in 57-63° angle Fig. 4b. This is substantiated by the mis-orientation angle distribution in Fig. 4c which, exhibits a large number of boundaries with misorientations above 15° when compared to the uncorrelated distribution. Furthermore, the results demonstrate that the misorientation angles 10-63° between the α-grains originate from the same β-grain, corresponding to 10° 53°, 60°, 63° 63° 26° or 90° [6]. As may be seen, the high angle boundary is a notable feature of the microstructure.
Figure 2. XRD pattern of the heat-treated $\gamma$-Ti-45Al-2Nb-0.3Si based intermetallic alloy.

Figure 3. Pole figures of a) $\alpha_2$, and b) B2 grains indicating orientation relationship.
Figure 4. (a) Inverse pole figure maps, (b) Misorientation axes, and (c) Misorientation angle distribution.
4. Conclusions

The EBSD analysis was conducted in order to characterise the orientation of the residual B2 phase of the heat-treated and stabilised $\gamma$-Ti-45Al-2Nb-0.3Si alloy, and the following conclusions were drawn:

- The orientation of the B2 phases, with respect to peritectic $\alpha$-grains followed the Burger OR: $(0002)_{\alpha} // (111)_{\gamma}$ and $[11\overline{2}0]_{\alpha} // [\overline{1}1\overline{0}]_{\gamma}$ and $\{111\}_{B2} // \{0001\}_{\alpha}$ and $\{110\}_{B2} // \{11\overline{2}0\}_{\alpha}$, respectively.
- It has been shown that the mis-orientation axes of B2-grains were found in the clusters between $<10\overline{1}>$ and $<11\overline{1}>$ in 57-63\(^\circ\) angle, in the Y0 direction.
- Misorientation angle distribution showed that a large number of boundaries with misorientations above 15\(^\circ\) (high angle boundary) were a significant feature of microstructure and possible product of texture.

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