Fatigue properties of high Nb TiAl alloy

T Kruml, A Dlouhý, M Petrenec, K Obrtlík and J Polák
Institute of Physics of Materials, Academy of Sciences, CZ 61662 Brno, Czech Republic
kruml@ipm.cz

Abstract. Fatigue properties of the new generation of TiAl alloys with high Nb content are studied. Comparison with the previous alloy with 2at% Nb shows that the new alloy resists better to cyclic deformation at high temperatures. The microstructural observation proved that at 750 °C, the easiest deformation mode is the glide of ordinary dislocations followed by superdislocation glide and twinning. Nevertheless, all three modes seem to be active.

1. Introduction
While TiAl alloys are already used in some applications, their development continue since their potential of a material with low density and good high temperature properties (both strength and corrosion resistance) is limited by the brittleness and difficult machinability. The third generation of these alloys contains high Nb addition, typically 7-8 at. %.

In the most foreseen applications, the low-cycle and/or high cycle fatigue as well as the crack growth resistance of the material are important [1]. The data on low cycle fatigue properties of the high Nb content alloy are rather scarce. Christ et al. [2,3] observed stable cyclic behaviour, satisfactory strength and lifetime at high temperatures and environmental surface embrittlement which increases with temperature.

The first results measured in our laboratory have been reported recently [4]. The microstructure of the material and deformation conditions (symmetrical strain controlled tests) are similar to those used by Gloanec et al. [5] who studied previous generation of TiAl alloy with 2at%. Nb. Their results are used for comparing the behaviour of low and high Nb content alloys and are complemented by TEM observation of dislocation structure.

2. Experimental details
2.1. Material and specimens
The material was delivered in the form of an ingot of 70 mm in diameter and 1.2 m in length prepared by casting and subsequent hot isostatic pressing. Chemical composition of the material in at.% is: 44Al – 48Ti – 7.8Nb – 0.2Ni. The majority of the volume consists of fine lamellar microstructure of γ and α2 phases. The grains of irregular but not elongated shape have the average size of about 1 mm. Some larger γ phase islands are present on the grain boundaries, the microstructure thus can be called as nearly lamellar (Fig. 1). The structure is not completely homogeneous across the diameter of the ingot; the fatigue specimens were prepared from the outer regions of the ingot with the axis parallel to the ingot axis. Cylindrical specimens with 6 mm in diameter were carefully mechanically and electrolytically polished.
2.2. Mechanical testing
Cyclic deformation tests were performed in a MTS 810 servohydraulic machine. Strain amplitude was kept constant as well as strain rate of $2 \times 10^{-4}$ s$^{-1}$. The loading cycle was symmetrical ($R_\varepsilon = -1$). Tests were performed at room temperature and at temperatures of 700 °C and 750 °C in air. Three thermocouples were used to monitor the homogeneity and stability of the temperature during testing.

2.3. Microscopy
Light microscopy and SEM was used for the inspection of the as-received microstructure and fatigue fracture surfaces. The thin foils for TEM were prepared from the slices cut perpendicularly to the specimen axis. The direction of the axis was conserved during the foil preparation, consisting from the mechanical polishing and final thinning in a double jet electropolishing apparatus. The foils were inserted in the Philips CM 12 TEM in the manner that the holder axis was parallel to the specimen axis. It was thus possible to relate crystallographic planes and directions of individual grains to the specimen geometry and to calculate Schmid factors for observed deformation modes.

3. Results and discussion
3.1. Cyclic response and fatigue life
In all three test temperatures, stable cyclic response of the material was observed. Almost the same behaviour was found by Christ and Bauer [3] who observed slight cyclic hardening for temperatures below 500 °C. On the contrary, significant cyclic hardening was observed at RT in 2at.%Nb alloy [5].

At 750 °C, stable cyclic response is found in both types of alloy. Fatigue life curves are shown in Fig. 2. If total strain amplitude is considered, the fatigue life curves of both materials remarkably overlap (Fig. 2a). Nevertheless, the fatigue lifetime of the 8Nb alloy is one – two orders of magnitude longer if the saturated stress amplitudes are compared (see the derived Wöhler curve in Fig. 2b). The reason for this is the higher strength of the 8Nb alloy in comparison with the 2Nb alloy. The yield stress is higher and the cyclic deformation curve is shifted to higher stresses for the 8Nb alloy. It means that at the same stress amplitude, the plastic strain amplitude is lower for 8Nb and the fatigue life is longer. Both life curves at 750 °C change their slopes at about $N_f \sim 2000$. The two observed deformation regimes are characterized by different exponents of Manson-Coffin and Basquin laws [4]. The same sudden change in slope of the fatigue life curves was observed also at $T = 700$ °C. The lower slope of the Basquin curve at low stresses results in even more important improvement of fatigue life for low loading levels.
3.2 Deformation mechanisms at 750 °C

Dislocation arrangement in γ phase containing also four twins has been analysed (Fig. 3a, \( \mathbf{g} = 020 \)). The crystallographic orientation of the stress axis is close to \([-10 3]\). The investigated region was cut so that the foil plane is close to \((655)\). The dislocation arrangement was observed using five different diffraction vectors which enabled finding Burgers vectors \( \mathbf{b} \) of dislocations. In Fig. 3b (\( \mathbf{g} = T \mathbf{1} \mathbf{1} \)), the twins lying along \((\mathbf{T} \mathbf{1} \mathbf{1})\) plane are edge-on. Ordinary dislocations from the primary ordinary slip system \((\mathbf{T} \mathbf{T} \mathbf{1}) [\mathbf{T} \mathbf{1} \mathbf{0}]\) are present in high density. They have elongated screw segments. The Burgers vector of primary ordinary dislocation is assessed using invisibility diffraction conditions for \( \mathbf{g} = \mathbf{T} \mathbf{T} \mathbf{1} \) in Fig. 3c. If \( \mathbf{g} = 002 \) is applied, only superdislocations with non zero c component of \( \mathbf{b} \) are visible. This condition allows separation of ordinary dislocations and superdislocations. It can be observed that superdislocations are present with a low density in the investigated volume.

It suggests that the main deformation mode is the slip of ordinary dislocation, in spite of the fact that the slip of superdislocations and twinning are significantly more favoured by the crystallographic orientation, as can be seen from the Schmid factors shown in Table 1. The two latter modes require higher flow stress but apparently it is possible to activate them. This is important for the appearance of the interlamellar fracture since according to the von Misses criterion, five independent deformation modes must be available to adapt deformations in between neighbouring grains or lamellas.

| Deformation mode plane | (T11) | (TT1) | (T11) | (T11) |
|------------------------|-------|-------|-------|-------|
| \( \mathbf{b} \)       | [0T1] | [T10] | [12T] | [T12] |
| Schmid factor          | 0.475 | 0.366 | 0.37  | 0.44  |
| Comment                | primary SD | primary OD | twinning | twinning |
Figure 3. Micrographs of the same area using four different diffraction vectors g. Specimen cycled with $\varepsilon_a = 0.41\%$ at $T = 750 \, ^\circ C$ up to the fracture ($N_F = 438$).

4. Conclusions

- The TiAl alloy with high Nb is cyclically stable in the investigated temperature interval (RT – 750 °C).
- The fatigue life curves of the low and high Nb alloys are similar in $N_F$ vs. $\varepsilon_a$ representation. In $N_F$ vs. $\sigma_a$ representation the fatigue life of the high Nb alloy is shifted more than one order of magnitude to longer fatigue life.
- Glide of ordinary dislocations seems to be the most easy deformation mode at 750 °C.

Acknowledgement. Financial support was provided by projects GACR 106/07/0762 and 106/08/1631.

References

[1] Henaff G and Gloanec AL 2005 Intermetallics 13 543
[2] Heckel TK and Christ HJ 2008 6th Int. Conf. on Low Cycle Fatigue, eds. Portella PD et al., 579
[3] Christ HJ and Bauer V 2008 6th Int. Conf. on Low Cycle Fatigue, eds. Portella PD et al., 585
[4] Kruml T, Obrtlík K, Petrenec M and Polák J 2009 Int. J. Mat. Res. 100 349
[5] Gloanec AL, Jouiad M, Bertheau D, Grange M and Henaff G 2007 Intermetallics 15 520