A STUDY OF FATIGUE CRACK INITIATION IN A TWO PHASE β-METASTABLE TITANIUM ALLOY

A. Lenain and P. J. Jacques
Université catholique de Louvain, Département des Sciences des Matériaux et des Procédés, IMAP, Place Sainte Barbe 2, B-1348, Louvain-la-Neuve, Belgium
lenain@imap.ucl.ac.be, jacques@imap.ucl.ac.be

Abstract

α/β titanium alloys are choice materials for aeronautical and automotive industries due to their high performance to density ratio. For several applications, fatigue resistance is one of the critical design parameter. Particularly, initiation of fatigue crack plays a key role. Furthermore, hardly anything can be found in the literature on the fatigue crack initiation in multiphase microstructures.

This work deals with the characterisation of the high cycle fatigue crack initiation in the TIMETAL LCB α/β titanium alloy. Microstructure was characterised by SEM, XRD, EBSD and TEM. Fatigue tests were carried out on a microstructure presenting a finely grained and equiaxed α/β morphology. Observations of the crack initiation were conducted at the scale of the microstructure thanks to SEM. Orientation Image Microscopy (OIM) allowed to correlate microstructural and micromechanical aspects.

Introduction

Titanium alloys are more and more used for structural applications. Automotive and aerospace industries are certainly the main application fields. These alloys are in fact choice materials due to their high performance to density ratio. Particular attention has been raised recently on metastable beta titanium alloys, i.e. alloys that can remain β at room temperature by quenching. Thanks to an appropriate thermomechanical treatment, the suitable two-phase α/β microstructure can then be generated. These alloys present good mechanical and forming properties, excellent corrosion resistance and good cold deformability.

Despite these advantages, the use of titanium alloys was often slowed down owing to their cost with respect to other materials. To overcome this difficulty, new processing routes are developed. This is the case for the new TIMET Ti LCB (for low cost beta) that presents a lower cost compared to other Ti alloys by using an inexpensive Fe-Mo master alloy widely used in the steel industry. New applications then emerged, particularly in the automotive industry (suspension springs) (Schauerte [1]).

The resistance to crack initiation under cyclic loading is one of the critical design parameter for several applications in the automotive and aerospace industries. The way the first defects appear must be studied at the scale of the microstructure in order to be understood. It is well documented that fatigue initiation is strongly influenced by several characteristics of the microstructure like grain size, grain orientation and misorientation of the grains (Jin and Mall [2]). Numerous publications recently dealt with the general behaviour of small fatigue cracks in several materials (Rodopoulos and de los Rios [3]). Particularly, the initiation of fatigue cracks in the Ti LCB was characterised but in the case of a fully β microstructure (Hu *et al.* [4], Krupp *et al.* [5], Floer *et al.* [6]). However, hardly anything can be found in the literature on the fatigue crack initiation in multiphase microstructures. It is thus necessary to scrutinise precisely the microstructure that is studied in order to correlate the relevant microstructural parameters with the resistance to crack initiation under cyclic loading.

The present contribution aims at presenting a first insight into the crack initiation of a finely grained α/β microstructure of the Ti LCB alloy.

Material and Experimental Procedure

This study was carried out on the TIMET Ti LCB low cost β-metastable titanium alloy. Its chemical composition is Ti - 6.38 wt.% Mo - 4.22 wt.% Fe - 1.75 wt.% Al. This alloy presents a metastable BCC structure (β) when solution heat-treated above the β transus ($T_\beta \sim$ 810°C) and subsequently quenched. The α phase (HCP) precipitates in various ways depending on the ageing schedules. Furthermore, another nanometric HCP phase (ω) can also precipitate in this alloy after either quenching (athermal ω) or ageing in a given temperature range (isothermal ω) (Prima [7]).

The material was received as rolled rods of 12mm in diameter. After heating, the ingot was rod-rolled and double aged. This one consists in (i) annealing at 760°C for 30 min (ii) water quenching and finally (iii) ageing at 538°C for 6 hours before air cooling. The static properties are very good as illustrated on Fig.1 with the tensile stress-strain curve of the Ti LCB compared with the traditional TA6V. Yield strength (σ_Y) is about 1150 MPa, while σ_{TS} and ε_u are 1317 MPa and $\varepsilon_u = 0.155$, respectively.

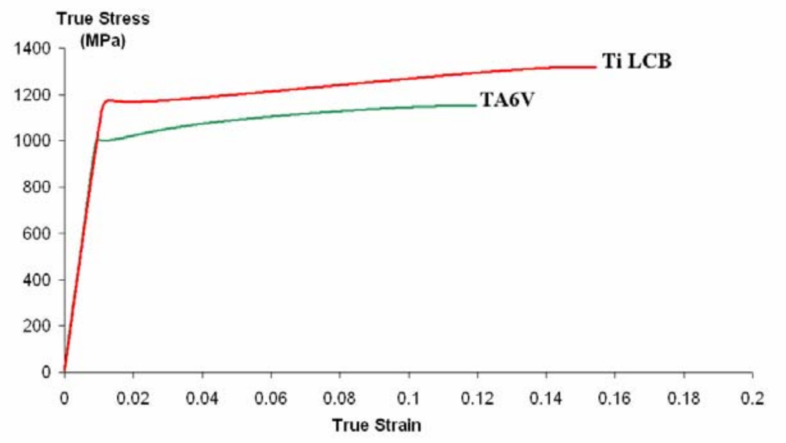


FIGURE 1. True stress - true strain tensile curves of Ti LCB and TA6V

Fatigue tests were carried out on a particular cylindrical geometry depicted in Fig.2. A flat zone was machined at the center of the specimens in order to allow the observation of the damaging processes. In order to remove any surface defects induced by the machinig and to allow the examinations of the microstructure, the specimens were mechanically polished and finally electro-polished in a solution of 95 vol.% acetic acid and 5.vol % perchloric acid at 25V and 14°C. Fatigue tests were carried out at room temperature on a hydraulic machine operating at a frequency of 2Hz. Stress amplitude of $\Delta\sigma/2$ = 335MPa and at a stress ratio of R = 0.1 were applied.

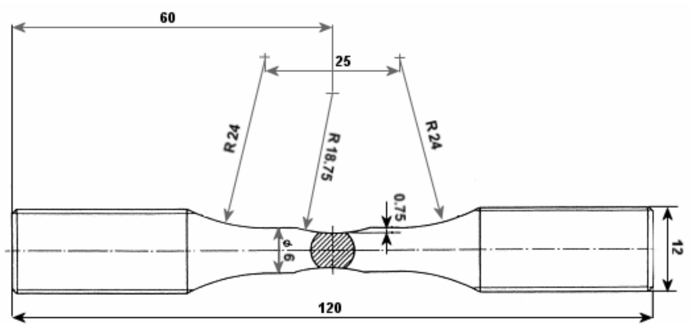


FIGURE 2. Geometry and dimensions of the fatigue samples

The microstructure was characterised essentially by FEG-SEM and OIM (orientation image microscopy). These techniques allowed to measure the grain size, phase proportions,… The measurements were carried out on the section transverse to the rolling direction.

Furthermore, during fatigue tests, crack initiation was observed thanks to SEM-FEG. The tests were regularly stopped (every 10^5 cycles) for these observations. This method allowed to precisely determine where crack initiation occurs and to characterise how the damage evolves. Thanks to EBSD, it was also possible to determine the crystallographic orientation of the grains surrounding the crack initiation.

Results and Discussion

Microstructure

As shown in Fig.3, the as-received microstructure consists in a finely grained α/β microstructure. It is also worth noting that the α grains are equiaxed and homogeneously distributed within the β matrix.

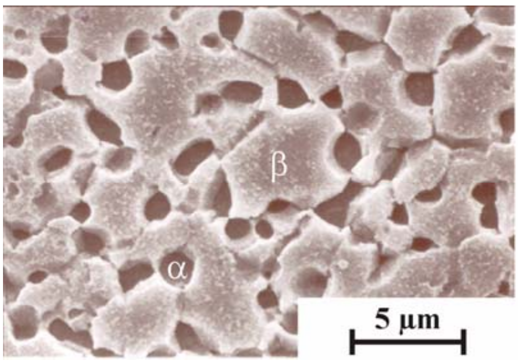


FIGURE 3. Microstructure of the as-received Ti LCB

Beside α and β, micro-diffraction by Transmission Electron Microscopy (TEM) showed the presence of nanometric ω precipitates within the β phase. Fig.4 presents a diffraction pattern resulting from this ω phase (Prima [7]).

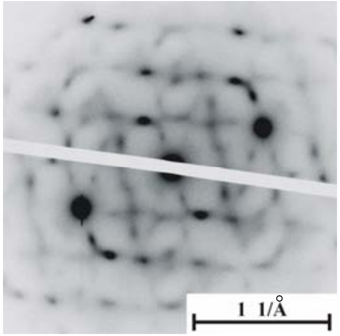
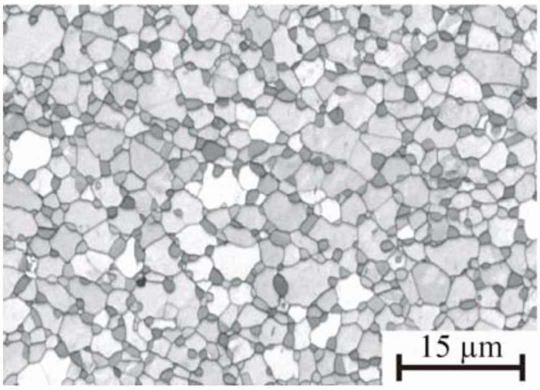


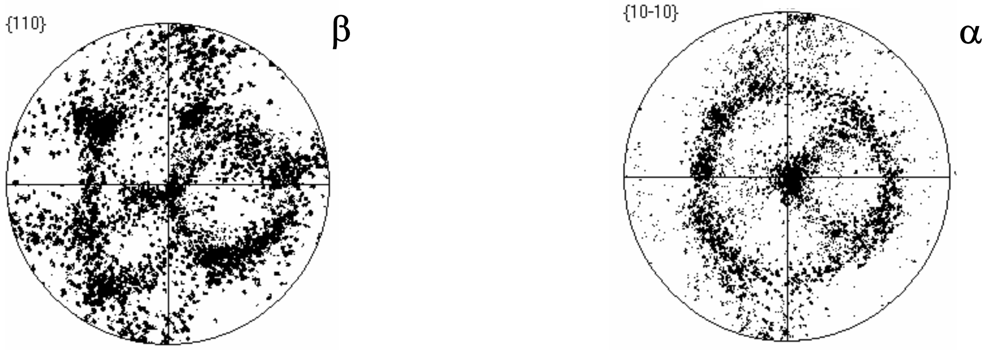
FIGURE. 4 TEM diffraction pattern of the nanometric ω phase present within the β phase of the Ti LCB (zone axis $[012]_{\beta}$)

Orientation Image Microscopy (OIM) based on the diffraction of back-scattered electron allowed to quantify both the crystallography and the morphology of the microstructure of the Ti LCB. Fig.5 (a) corresponds to the EBSD band contrast map (i.e. the quality of the Kikuchi patterns). Both α and β phases are clearly revealed by this type of contrast so that quantitative image analysis can be carried out. As determined by image analysis, the grain size of the β and α grains is around 8 µm and 1.5 µm, respectively. The proportion of the two phases is 80% of β and 20% of α.

This technique also reveals the presence of a crystallographic texture as shown by the pole figures of Fig.5 (b). For the β phase, the main texture component is {110} // RD while it is $\{10\bar{1}0\}$ // RD for the α phase.



(a)

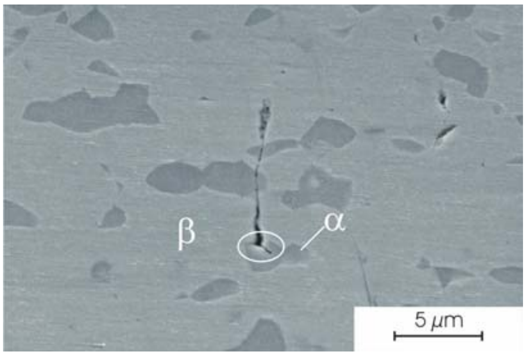


(b)

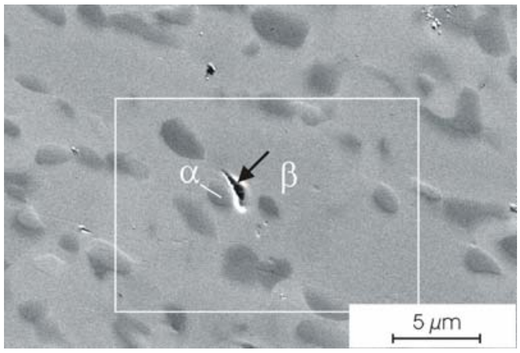
FIGURE.5. (a) : EBSD band contrast map of the Ti LCB ; (b) : EBSD pole figures of the β and α phases, respectively

Damage initiation

The present microstructure seems to exhibit very good fatigue properties since more than 6.10^5 cycles were necessary to observe the first damage sites for a stress amplitude of $\sigma_Y/2$. As shown in Fig.6, it seems that in the major cases, cracks initiate at the interface between the two phases α and β. However, the propagation does not necessarily follow these interfaces. Indeed, Fig.6 (a) demonstrates that the crack propagates throughout several α and β grains.



(a)



(b)

FIGURE.6. Damage sites after $6.6.10^5$ cycles

EBSD analysis was carried out on the surrounding area of the damage site of Fig.6 (b). The resulting map is shown in Fig.7. No particular systematic misorientation has been found up to now between the α and β grains bringing about the first damaging processes. However, more observations are necessary.

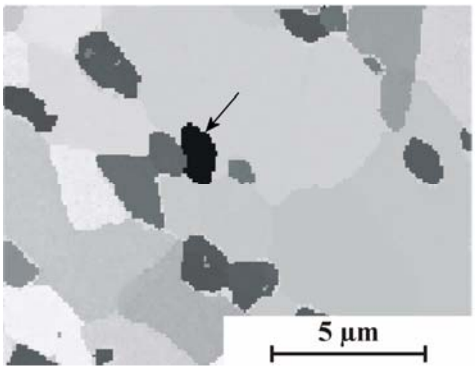


FIGURE.7. EBSD analysis of the grains surrounding the damage site of Fig.6 (b)

It also seems that local plasticity accompanies the appearance of the first damage sites. Fig.8 compares the topographic FEG-SEM micrographs of several damage sites with the EBSD contrast and crystallographic maps of the same area. While only separated damage sites can be seen on the SEM micrograph, EBSD reveals the presence of a continuous band joining these sites where it was impossible to index the Kikuchi patterns due to disturbance of the crystallographic lattice. This area could correspond to a zone where local plasticity occurred. Future observations will try to correlate the crack propagation with this local plasticity.

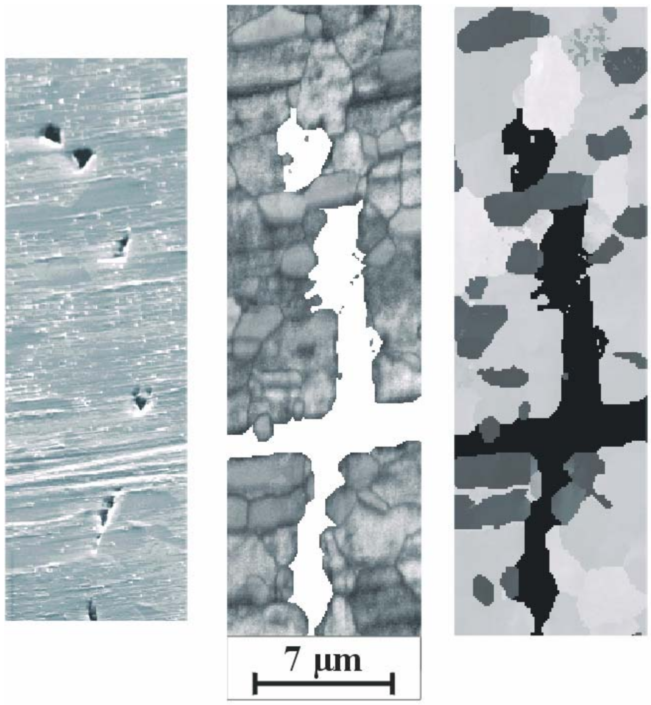


FIGURE.8. SEM micrograph of the damage sites and corresponding EBSD maps

Conclusion

This present work aimed at studying the fatigue crack initiation in a α/β titanium alloy. In the first part, it was thus necessary to characterise precisely the microstructure in order to correlate the relevant microstructural parameters for the resistance to crack initiation under cyclic loading.

The present microstructure is very fine and shows an important texture of the two phases. The first fatigue results showed that the damage sites seem to initiate at the interface between α and β grains and that local plasticity accompanies the appearance of these first sites. Complementary results will be necessary in order to ensure the possible effect of systematic misorientations on the damaging process.

References

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