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Development of Sharp Local α Microtextures during α/β Thermo-mechanical Processing of TIMETAL 834

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TIMETAL 834 is a near-α titanium alloy with excellent mechanical properties at temperatures up to 600°C. However, it shows a decrease in fatigue resistance when large regions with sharp local textures are present in the material. The present work reports some of the results on the development of sharp α microtextures during deformation in the α/β field. Samples with a coarse lamellar microstructure were deformed in α/β to produce a bimodal microstructure with equiaxed primary α grains and secondary lamellar colonies. It is shown that the deformation and recrystallisation steps create sharp local microtextures in the bimodal microstructure. Their development is *analysed in detail using to orientation maps measured on samples at the end of the processing route.*

Keywords: *TIMETAL 834, microtexture, macrozones, α/β deformation, forging*

1. Introduction

TIMETAL 834 is a high strength near-α titanium alloy used to manufacture high pressure compressors for aero-engines. The optimal creep and fatigue properties are achieved with a bi-modal microstructure composed of 15% of equiaxed primary α grains (α_p) in a matrix of secondary α colonies (α_s) [1)]. The billets processed to obtain this microstructure, are manufactured with a route that includes successive compressions in the β and α/β domain[2)]. Specifically β forging in the β region produces a coarse lamellar microstructure and deformation of lamellae in the α/β domain results in the bi-modal microstructure.

Process window optimisation during the last decade has been focused on obtaining an homogeneous α_p/α_s microstructure. However, recent works have shown that such billets contain millimetre long regions with grains having at least one close crystallographic axis[3)]. Such regions, hereafter called 'macrozones' can remain in the forged components thereby reducing their fatigue performance. In fact, regions presenting a large fraction of grains having their basal plane perpendicular to the applied stress, have been observed as preferential sites for crack initiation, especially in forged disks submitted to dwell fatigue tests[4,5)]. The presence of macrozones is thus assumed to be at the origin of the dwell fatigue life debit of forged disks.

Consequently, to improve the material properties, it is important to reduce the macrozones in the forged disks or even better, to prevent their development during billet forging. To achieve this goal, it is first necessary to develop a fundamental understanding of the formation mechanisms of the macrozones in the billet.

This contribution presents some results on the influence of α/β deformation steps in the development of sharp local textures in the billet. Series of compression/annealing tests were carried out. Large EBSD maps were acquired on the tested samples in order to characterise their local textures. Moreover, advanced EBSD data processing were applied to characterise the high temperature α_p/β and the room temperature α_p/α_s microtextures.

This paper presents the results obtained on one sample, after compression and annealing. The microtextures observed for intermediate deformation steps will be proposed in a coming paper with a detailed analysis of the deformation mechanisms leading to the formation of sharp local textures[6)].

2. Experimental

TIMETAL 834 cylindrical compression samples of dimensions (d=7.6mm, h=11.4mm) were cut off parallel to the billet axis. Each sample was heat treated in the β field at 1060° for 15min followed by furnace cooling at a rate of 1°/s. Thus, before compression, the samples are characterized by a typical 'β-transformed' microstructure with coarse lamellae. The prior β grains are easily recognisable by the α layers that decorate their boundaries. They are equiaxe with an average diameter of about 1 mm. Within the prior β grains, one observes colonies of 20μm thick α laths separated by thin β layers. EBSD analysis revealed that in most prior β grains, at least five colonies of different crystallographic orientations are observed, two or three being significantly larger than the others. It was also observed that the orientations were random on the section analysed by EBSD (a 10x7mm longitudinal section) and that no crystallographic domain significantly exceeded the colony size.

Once at the test temperature, the samples were hold for 15 minutes for temperature homogenization and were then compression tested in a MTS-810 machine[7)] equipped with a high temperature deformation furnace with controlled atmosphere. The testing conditions for the sample presented here, are schematically given in Fig. 1. The forging temperature was set to 1000°C to stabilise approximately 30% of the α phase. A strain ratio of ε=-1,4 and a strain rate of $\dot{\varepsilon}$ =1s^{-1} were applied. The deformation was followed by lh annealing at 1000°C.

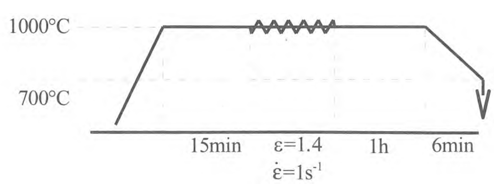

Figure 1. Thermo-mechanical processing route

The sample was cut in a longitudinal section, containing the compression direction (CD) and one radial direction (RD). This section was prepared for EBSD analysis by mechanical polishing followed by electropolishing[3]. Orientation maps were acquired on the JEOL 6500F FEG SEM equipped with the HKL technology EBSD attachment. A (10x7)mm^2 map was measured with a step size of 15µm. An additional map was acquired in a sharp textured region, with a step size of 3 µm. This higher spatial resolution allows the correlation between the local texture and the microstructure. The α_p grain orientations were identified by correlating Backscattered images and EBSD maps[8]. Moreover, the high temperature β microtexture was evaluated from the inherited α_s microtexture (room temperature) using the reconstruction method detailed in [9]. This original EBSD data processing gives information otherwise not available with any conventional measurement techniques. Using this technique, it is possible to characterise both room (α_p/α_s) and high (α_p/β) temperature microtextures. In this contribution, the EBSD data are mainly represented by means of inverse pole figure (IPF) maps and corresponding pole figures (PFs) with CD in the centre.

3. Results

The core microstructure of the sample is illustrated in Fig. 2. Deformation and annealing in the β/α field has produced necklaces of equiaxed α_p grains. This results from the progressive formation of sub-grain boundaries within initially coarse lamellae. The latter are aligned perpendicular to CD and are surrounded by α_s colonies. The α_p grain diameter is of the same order as the width of the initial α_p lamellae. Thus the thermo-mechanical treatment has initiated the transformation of coarse lamellae into equiaxed grains. Of course, to produce a homogeneous bi-modal microstructure with full equiaxed α_p grains, additional deformation/annealing steps are necessary.

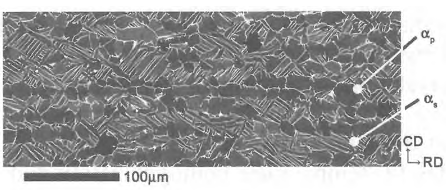

Figure 2. Microstructure of the thermo-mechanically tested sample.

The large scale IPF map of the tested sample is shown in Fig. 3 with the corresponding IPF colour key. The macroscopic direction considered in the standard triangle is perpendicular to the observed section and is referred as Tangential Direction. The grains having their c-axis close to TD appear in black. The grey level continuously changes from black to white when the c-axis is progressively tilted from TD. In the core of the sample, one can clearly observe band like regions, with significantly different grey levels, elongated over a few hundreds of µm. Each region presents a main texture component, different from that observed in adjacent regions. Thus the β/α thermo-mechanical treatment aimed to transform the coarse lamellae into equiaxed grains, also produces sharp textured regions, one order of magnitude larger than the expected grain size of 20 µm.

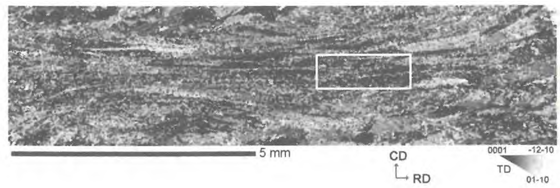

Figure 3. EBSD map of the compressed and annealed sample.

A local scale EBSD map was acquired in the region boxed in Fig. 3, covering (1.5x0.5)mm^2. This region has a sharp texture and is characterized by a large fraction of grains with c-axes in TD (in black in Fig.3). The higher resolution of the local map (3µm) allows distinguishing the individual α_p/α_s orientations. Therefore, the contribution of each type of grain to the sharp local texture, can be estimated.

Fig. 4 presents the microstructure of this region (4a), the corresponding α_p (4b) and α_s (4c) IPF maps together with the corresponding PFs. The same colour key as in Fig. 3 has been used. The white colour is used for the phases not considered in the representation as well as for the low fraction (4%) of grains having the c-axis perpendicular to TD.

Figures 4a-b mainly show elongated α_p lamellae and necklaces of equiaxed α_p grains, coloured in black and dark grey. Their orientations belong to the same texture component, characterized by c-axis and a <11-20> direction parallel to TD and CD respectively, as seen on the PFs. However, a spread of about 20° is observed around this main texture component. The α_p lamellae that exhibit no or few sub-structure are often sharp textured, with less spread around their main texture component. In areas with necklaces of equiaxed α_p grains, the spread around this texture component is larger and a limited number of differently orientated grains can also be found.

Figures 4a/c also reveal a large fraction of α_s colonies coloured in black and dark grey. Their c-axis are close to TD and have a <11-20> direction close to CD. So the α_s colonies are also strongly textured around the same texture component as the α_p grains. Comparing α_p/α_s orientation densities in the PFs, one can notice a slight increase of c-axis density around TD for the α_s colonies. At a local scale, Fig. 4b-c highlight that neighbouring α_p and α_s grains have often very close orientations.

Thus within the sharp textured region of Fig. 4, α_p grains and α_s colonies exhibit close orientations and contribute both to the sharp local texture. This result is rather surprising because the formation of each type of grains results from completely different mechanisms. The α_p grains are deformed/annealed at high temperature, whereas the α_s colonies are inherited from the transformation of the β phase by cooling.

To understand the formation of the α_s texture, it is

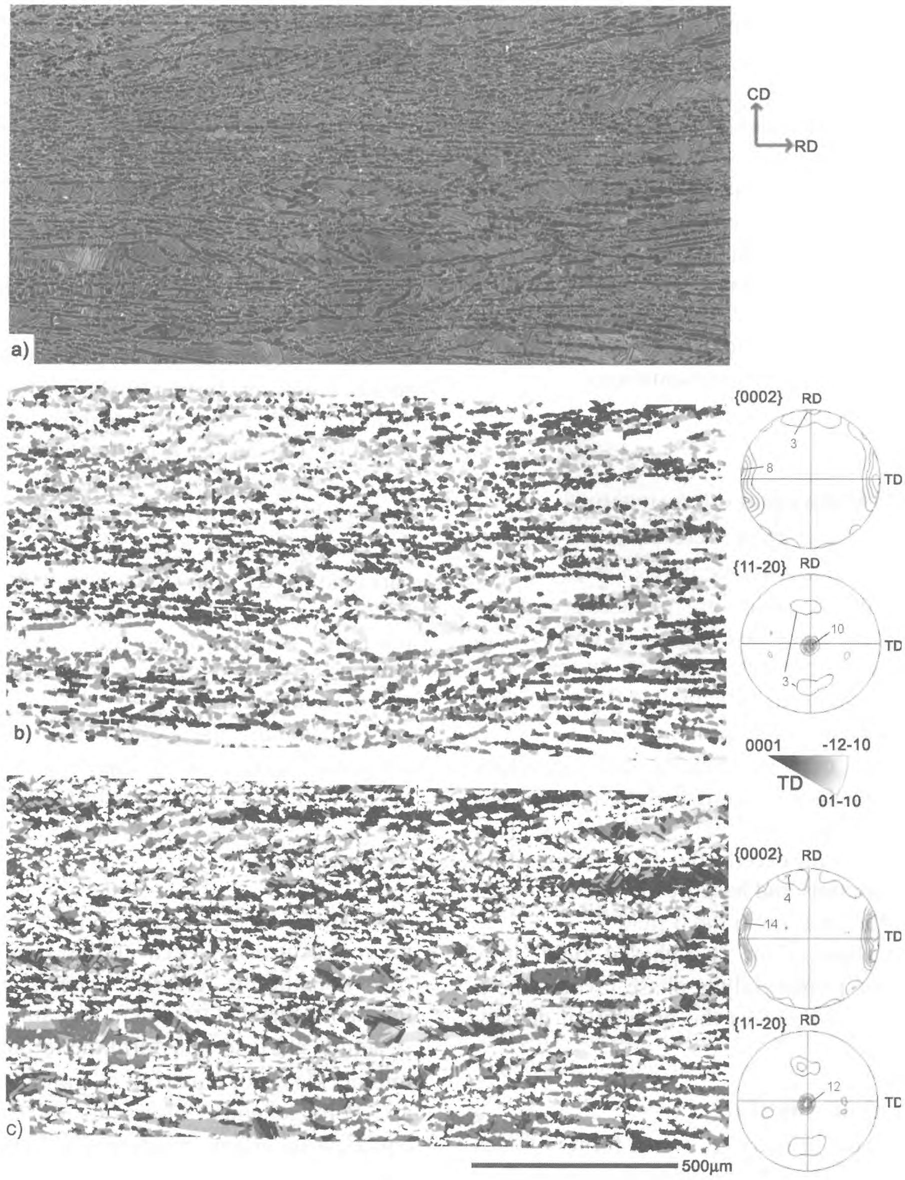

Figure 4. a) Microstructure of the analysed region. Orientation maps and corresponding pole figures b) α_p grains and c) α_s colonies.

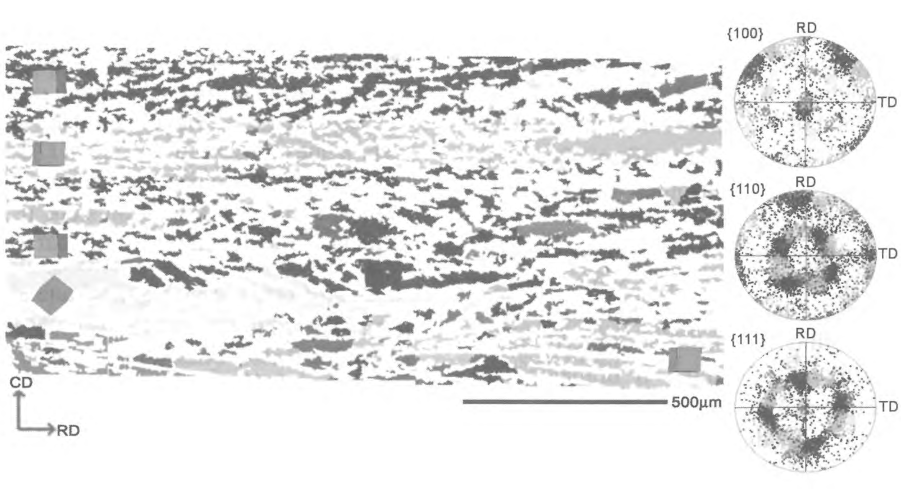

Figure 5. Orientation map of the reconstructed β microtexture with the corresponding discrete PFs.

necessary to analyse the high temperature β microtexture. The parent β orientation map, reconstructed from the α_s one (Fig. 4c), is presented in Fig. 5 with the corresponding discrete PFs. The colours reveal different β grain orientations, according to the PFs colour key. The corresponding lattice orientation is also displayed in the map. The α_p grains are not represented and correspond to the white regions. Four differently oriented β domains, elongated perpendicular to CD, can been observed. They have either their <100> or <111> axis parallel to CD. Despite their various orientations, they preferentially transform into α_s colonies with close orientations.

4. Discussion

4.1 Evolution of the β texture and microstructure

Before compression, the β grain were equiaxed with an average grain size of 1 mm. After compression in the α/β field and annealing, the β grains are clustered in large crystallographic domains elongated in RD, as observed in Fig. 5. Further studies not presented here, show that these domains correspond to the initially equiaxed β grains, then flattened and fragmented by the deformation[6].

Regarding the texture evolution, the β phase develops during deformation/annealing in the α/β field, orientations belonging to the <100>//CD and <111>//CD fibres. This texture evolution is often observed after high temperature compression of bcc materials and has already been reported for the β phase after deformation in the β field[10].

In case of compression in the two-phased field, it is highly probable that the primary alpha phase favours the β grain fragmentation and influences the orientation density around each fibre.

4.2 Evolution of the α_p microtexture

Before deformation, the primary α_p grains form colonies of coarse lamellae in Burgers relation with the surrounding β phase. During the deformation and annealing, these lamellae progressively transform to necklaces of equiaxed α_p grains. As seen in Fig. 2,4, this globularisation process is not homogeneous. In fact, the deformation mechanisms and consequently the annealing mechanisms of these α_p lamellae strongly depend on their morphological and crystallographical orientations with respects to the applied strain[9]. The neighbourhood of the α_p lamellae, in particular the surrounding β phase may also affect the local deformation mechanisms and contribute to make the globularisation process heterogeneous.

Regarding the texture evolution, the α_p grains develop during deformation a sharp texture with several components. However, these main texture components are not randomly located within the material. Indeed, large regions, containing differently oriented β domains, are characterised by α_p grains mainly oriented around a same texture component. From one adjacent region to the other, this component significantly changes. The size of these regions suggests that each of them is wider than several initial α_p colonies possibly related to different prior β grains before deformation. The globularisation mainly contribute to spread the α_p orientations around the main texture component observed after deformation.

4.3 Evolution of the α_s microtexture

The α_s colonies result from the transformation of the deformed and annealed β phase. As seen in Fig. 4 and 5, the α_s colonies that develop within sharp textured α_p regions have often orientations close to the main α_p orientations.

Before deformation, at high temperature, the α_p grains and the surrounding β phase were in Burgers relation. During deformation, the crystal lattices of α_p and β grains rotate. However, further analysis of the EBSD map in Fig. 4 and 5, shows that they mainly have held their Burgers relations (or at least common crystallographic planes). Consequently, the β grains of a sharp textured α_p region, even if they have different orientations, can transform into α_s colonies with orientations close to those of the surrounding α_p grains. Further, it is of clear evidence in Fig. 5 that the inherited orientations were less numerous than the Burgers orientation relations allow and that colonies were preferentially selected during the transformation. Consequently, the regions with a sharp α_p texture, are reinforced after cooling, due to a strong variant selection occurring in the β to α transformation.

5. Conclusions

A TIMETAL 834 sample with a typical 'β-transformed' microstructure has been compressed and annealed in the α/β domain. It clearly appears that the considered thermo-mechanical treatment that aims to break the lamellar structure, starts to transform the initially coarse α_p lamellae into necklaces of equiaxed α_p grains. Of course, to produce an homogeneous bi-modal microstructure with full equiaxed α_p grains, additional deformation/annealing steps are necessary.

Moreover, large regions with sharp α_p and as textures develop within the material. These regions are of one order of magnitude larger than the expected average size of the α grains. These regions result from complex 'coupled' deformation mechanisms of β/α_p grains at high temperature and from a strong variant selection in the β to α transformation during subsequent cooling.

These regions have similar characteristics as the macrozones observed in TIMETAL 834 billets with bi-modal microstructures. By analogy, the results of this study suggest that the deformation steps in the α/β field strongly influences the development of sharp textured regions in the billet.

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