	Experiment title: Elucidating the tension-compression twinning asymmetry in $\alpha_2+\gamma$ based TiAl alloys	**Experiment number**: MA192
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Shifts: 18	**Local contact(s)**: Dr. Gabriela González Avilés	

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Report:

TiAl based alloys are very promising materials for use in aerospace engines because of their excellent properties, such as low density, high specific yield strength, oxidation resistance and good creep properties at high temperature [1]. However, they exhibit very poor ductility at room temperature as well as low fracture toughness, which have prevented their widespread use. Several efforts have been carried out over the last years to overcome this major drawback in these alloys, using both alloy additions and microstructural design. Among the several microstructural variants developed, two-phase $\alpha_2+\gamma$ microstructures, both fine fully lamellar (FFL) and duplex (DP), have the most promising mechanical properties.

The TiAl-γ phase has a $L1_0$ type face-centered microstructure, with a tetragonal distortion which gives rise to six crystallographic variants. In contrast, the Ti_3Al-α_2 phase presents a $D0_{19}$ type close-packed hexagonal structure. In the lamellar colonies, the $\{111\}_\gamma$ planes are parallel to the basal planes $(0001)_{\alpha2}$

Deformation of the TiAl-γ phase occurs on {111) planes by glide of ordinary dislocations with Burgers vector b=<110] (the mixed notation {hkl) and <uvw] is used to show the tetragonality of the γ-phase), superdislocations with burgers vector b=<101] and b=<11-2] as well as mechanical twinning associated with 1/6<11-2>{111) shear.

Recently, carefully designed lamellar and nearly-fully lamellar microstructures of selected alloys (such as Ti44Al8Nb1B) having highly reproducible properties have been successfully developed [2]. However, a clear deviation from the expected elastic behavior when tested in tension has been reported in the fully lamellar microstructure of the aforementioned alloy. Acoustic events have been recorded using an acoustic emission technique. This phenomenon has been attributed to pre-yield cracking [2] and/or twinning of the γ phase [3].

Since twinning does not change the crystal structure, but merely reorients it, twinning is expected to be evidenced by changes in the integrated diffraction intensity in a particular direction. For instance, if twinning increases the level of texture in the material, the integrated intensity of certain types of crystal planes will increase in particular direction, while the integrated intensity of other reflections measured in the same direction will decrease.

During the beamtime granted, a number of in-situ loading experiments using several microstructural variants of Ti44Al8Nb1B alloy were carried out. Flat dog-bone tensile specimens with a cross-sectional area of $1.75mm^2$ and 6 mm gauge length were prepared by electro-discharge machining. A Deben screw-driven microtester with a load cell of 2KN was used for the testing. The specimens were irradiated using a monochromatic high energy (~90keV) X-ray beam with a spot size of 250x250 μm. Debye-Scherrer rings were captured [4] using a CCD FRELON (fast read-out low noise) camera with a resolution of 2048x2048 pixels, located at a distance of 2415mm from the sample.

The samples were loaded to 600 MPa, held at this load for 20 s, unloaded to 10 Mpa, held for 20 s and loaded again to failure. The strain rate was fixed at $8.33x10^{-3}$/s. The high flux on beam line ID15 allowed 5s exposure times. The exposures were taken continuously during the whole experiment. Recorded images of the diffraction rings were integrated over a +/-15º arc segment along the longitudinal direction. The obtained diffractograms were later fitted to a pseudo-Voigt curve, using a MatLab script. The fitting routine yielded important peak characteristics, in terms of peak center (2-theta values), as well as peak intensity and FWHM.
Figure 1 depicts the stress dependent normalised integrated intensity response of the (113)γ peak along the longitudinal loading direction. The (113) peak was selected for this analysis for several reasons: it showed the highest intensity change and it is not a composite peak such as the $(001)_\gamma$+$\{010\}_\gamma$ The contrast between the dramatic increase of the integrated intensity for the FFL microstructure and the unvaried behaviour of the DP microstructure can be clearly seen.

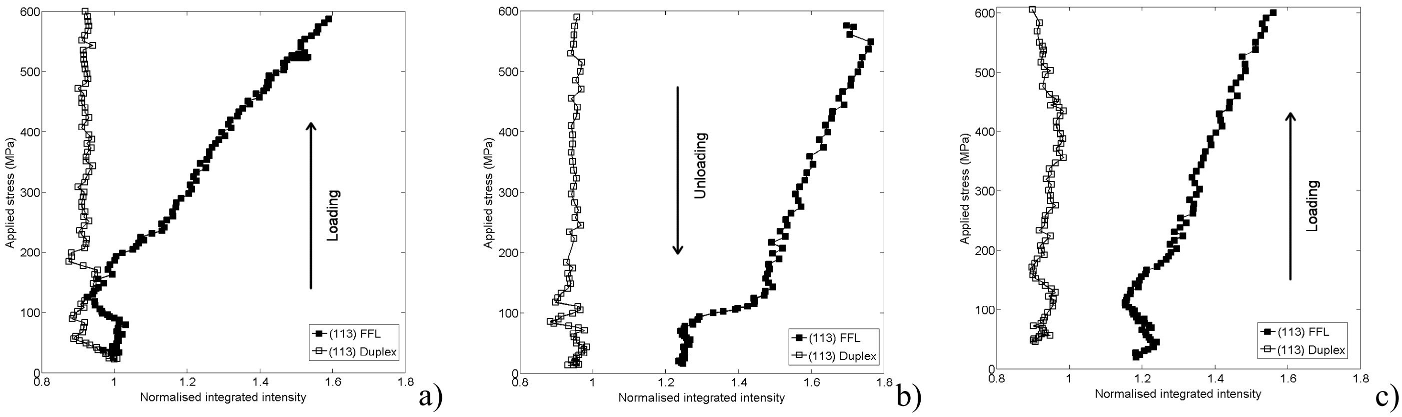

Figure 1. Stress-normalised integrated intensity plots of the $(113)_\gamma$ reflection for both FFL and DP microstructures during the first load (left), unloading (centre) and final load (right). It is remarkable that the normalized integrated intensity of the DP microstructure remain constant during the load cycles, whereas the intensity of the FFL microstructure rises when the applied stress is increased and diminishes when the stress is reduced.

During the 1st load cycle (Fig. 3a), the integrated intensity increased significantly when the level of applied stress exceeded 150MPa. At 600MPa the integrated intensity of the (113) reflection has increased by 60%. During the unloading phase (Fig. 3b), the intensity is reduced, but does not reach its original level, remaining at roughly 20% above it. Subsequently, during the 2nd and final load cycle (Fig 3c), the integrated intensity again increases to 60% with respect to the original reading.
In order to analyze the changes in the normalized integrated intensity during the loading cycle it is necessary to take an integral approach which takes into account the six crystallographic variants of the γ phase, the four twinning systems which can be activated and the conformity of the Bragg condition of the twinned planes. This analysis showed that, when all the aforementioned parameters are taken into account, twinning of the γ phase will give rise to additional (113)γ planes in the longitudinal direction. These twinned planes will effectively increase the integrated intensity of the (113)γ peak.
The dramatic increase of the integrated intensity for the $(113)_\gamma$ peak in the longitudinal direction during tensile loading of a Ti4481FFL sample has been recorded by means of high energy synchrotron X-ray diffraction during the MA192 beamtime on ID15b. This increase contrasts sharply with the unchanging integrated intensity of the same peak for a DP specimen. Our analysis suggest that the increase in integrated intensity is related to twinning and that twinning is initiating at relatively low stresses. Furthermore, the decrease in intensity during unloading would indicate that some twinning planes are reverting to their original planes when the applied load is reduced, which has an important impact on post mortem analysis of deformed samples.
These results have been presented in a paper submitted to the Titanium 2007 conference earlier this year and a journal paper is currently in the process of being written.

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