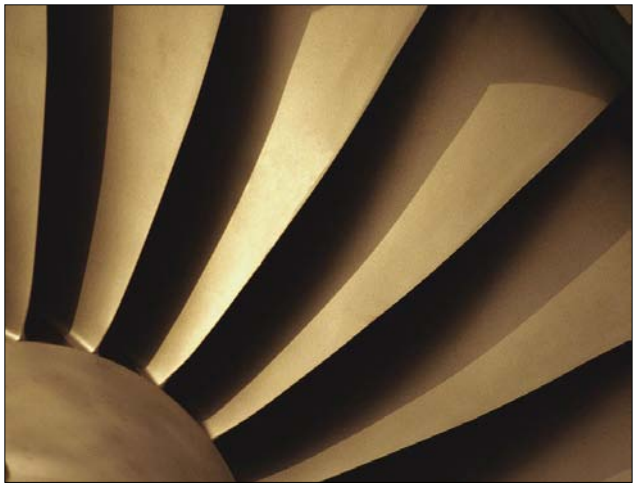
APPLICATION NOTE

EBSD analysis of TiAl alloys for texture and interphase boundary analysis

Introduction

γ-TiAl based alloys are considered as high temperature structural materials for aero-engine and automotive industry. Duplex and near γ -microstructures show good ductility at room and elevated temperatures [1]. The crystal structures of the common phases found in AlTi alloys are shown in Table 1.



Phases	Crystal structure	Lattice parameters (Å)
γ −TiAl	$L1_0$ ordered tetragonal (4/mmm)	a=b=4.00, c=4.07
α_2-Ti_3Al	DO_{19} ordered Hexagonal (6/mmm)	a=5.78, c=4.65

Table 1:
The crystal structure of the phases analysed in this study.

The structure of γ -TiAl and the EBSP indexing challenge

Accurate measurement of the orientation of γ -TiAl crystals during automatic EBSD mapping is one of the most challenging problems in EBSD today. Although γ-TiAl has a tetragonal crystal structure, the structure is 'pseudocubic' or extremely close to cubic, with the [001] axis of the crystal being only 2% longer than the [100] and [010] axes (see Figure 1). Consequently, virtually identical EBSPs are generated by any particular orientation and by the two orientations related to it by 90°[100] and 90°[010] rotations, because of the 'pseudo-symmetry'. The ability of an EBSD system to select the correct orientation from the three possibilities depends on its ability to determine which of the three almost identical simulated patterns best match the acquired EBSP (Figure 2).

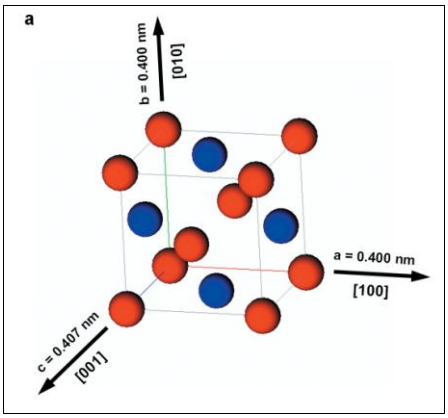


Figure 1:
Crystal structure of γ -TiAl with [001],[010] and [001] axes marked.

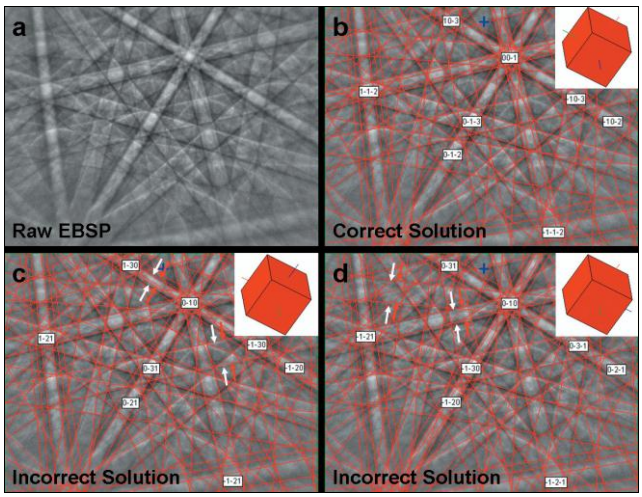


Figure 2:
(a) γ -TiAl EBSP, overlaid with (b) the correct solution and (c, d) two incorrect solutions.

EBSP band detection and indexing methods

Most commercial EBSD systems use a method based on the Hough transform for detecting bands in an EBSP. The Hough transform is used to convert the EBSP image into a different kind of image in which the bands of the EBSPs are represented by bright spots in the transformed image. It is a very fast (and for most cases, sufficiently accurate) way of identifying bands in an EBSP and allows mapping on certain samples to be carried out at rates of more than 100 patterns per second. However, there are alternative methods that are more sensitive to small changes in band position and consequently provide better results on

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samples where the ability to detect small band shifts is critical for correct orientation determination.

Oxford Instrument's HKL CHANNEL5 software allows the user to select between using only the Hough transform based method and using a second method, called "Advanced Fit" which uses the Hough transform based method to generate a short-list of possible solutions very quickly, and then compares the simulated EBSP for each possible solution in the short-list very accurately against the actual acquired EBSP. This method takes some extra time, but is well worth it for difficult phases, such as ɣ -TiAl, where Hough transform based methods are not able to produce accurate results.

Experimental procedure

The EBSD analysis in this study was carried out on a couple of hot-formed TiAl alloys, where table 2 shows the conditions used during the EBSD analysis.

Table 2:EBSD Conditions

Sample preparation: Mechanical polishing with Colloidal silica and electro-polished in a solution of methanol, butanol and perchloride, uncoated.
SEM type: FEG SEM
EBSD system: HKL Channel5 and NordlysII
Accelerating voltage: 20kV
Probe current: 4nA

Alloy 1: This sample was used for texture analysis. The alloy had a composition of Ti-48Al, with only γ-phase, which was isothermally forged. The sample shape and method of compression were such that the strain state in the middle section of the sample closely approximated plane strain. A small (100 x 100 µm) map was taken at a fine (1 µm) step size to check the consistency of indexing within individual grains and a much larger (3.5 x 2.4 mm) map was taken at a larger step size (20 µm) in order to measure the texture of the sample and allow comparison with a bulk texture measurement made using X-ray diffraction (XRD).

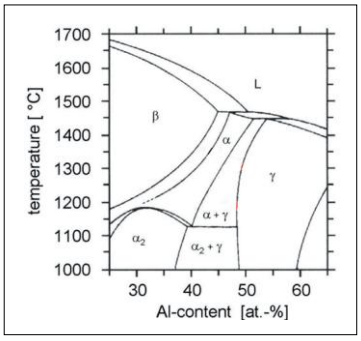

Figure 3:
Phase diagram for Ti-Al.

Alloy 2: This sample was used for interphase boundary analysis. This Ti-Al alloy with the composition of Ti-45Al-4.6Nb-0.2B-0.2C was hot formed into sheet form. This composition is in a two phase stability region of α_2 and γ, as shown in the phase diagram in figure 3 [1]. The EBSD analysis was done on this alloy at a fine resolution of 200nm step size.

Results

Texture analysis

The small map taken at a fine step size is shown in figure 4 in three different forms from the alloy 1. Figure 4a shows the raw map with the EBSPs indexed using the Hough transform method only. While this method provides consistent results for some grain orientations, there are other grains where this method is clearly unable to consistently determine the correct orientation of the grain. However the 'Advanced Fit' method allows acquiring of the correct data during acquisition, although the Channel5 software has the capability to remove the 'pseudosymmetry' points during post-processing too. Figure 4b shows the raw indexed data of the same map indexed using the Advanced Fit method. The indexing within all grains is virtually perfect. There are only a very few points within a few of the grains where the software has chosen a different solution to that chosen for the rest of the grain, and these points are concentrated along grain boundaries, where the quality of the EBSP may have been lower, due to part of the interaction volume being located in the adjacent grain. Figure 4c shows the same map, indexed using the Advanced Fit method, after data cleaning has been carried out using CHANNEL5 processing software. The non-indexed points around the grain boundaries have been filled in, creating a "cleaner" looking map, but it is clear that the cleaning procedures have not substantially changed the map.

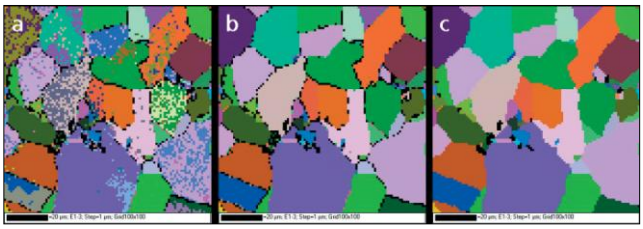

Figure 4:
The small (100 x 100 µm) map taken at a fine (1 µm) step size, (a) indexed using the Hough Transform method only (raw data), (b) indexed using the Hough Transform plus Advanced Fit method (raw data), (c) indexed using the Hough Transform plus Advanced Fit method (after data cleaning) in alloy 1.

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Figure 5 shows the texture of the plane strain region of the sample measured using EBSD (Figure 5a) and XRD (Figure 5b). Since the φ2 = 0° section of the orientation distribution function (ODF) shows the main features of the texture, this section, rather than multiple sections or the 3D ODF, has been shown in each case. Both the texture measured using EBSD and the texture measured using XRD show a strong peak near the {010}<100> orientation (φ1 = 0°, Φ = 90°, φ2 = 0°). It should be noted that the EBSD texture was measured over a relatively small (3.5 x 2.4 mm) area of the specimen, whereas the XRD texture was measured over a much larger (15 x 15 mm) area. The much smaller number of grains sampled using EBSD compared with XRD explains the small difference in peak position and less consistent intensity contouring towards the {010}<100> orientation in the EBSD data compared with the XRD data.

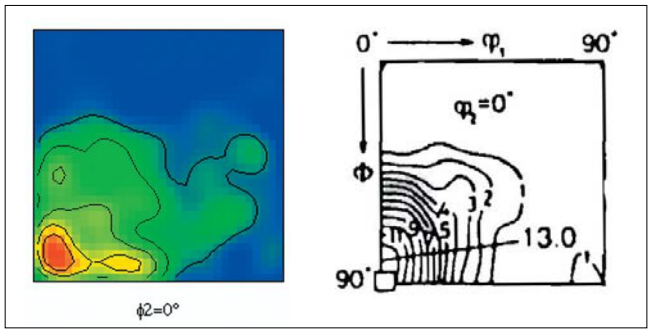

Figure 5:
φ2 = 0° ODF sections showing bulk textures measured by (a) EBSD, (b) XRD [2] in alloy 1.

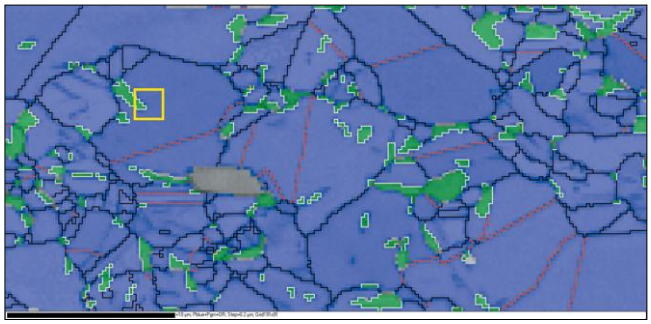

Figure 6:
EBSD maps showing phases γ (blue) and α_2 (green) and interphase boundary component {111} γ \\{0001}α_2 and <110> γ \\<11-20>α_2 as white lines and boundary components, where the high angle (>10°) are shown as dark and twin {110}70° as red lines in alloy 2.

Interphase boundary analysis

Figure 6 shows the EBSD map from this sheet, where the phase map shows that this area consists of 91% area fraction of the γ -phase and 7% α_2-phase. The γ -phase is found to have a larger average grain size (ECD=4μm) with a large fraction (20%) of twin boundaries {110}70°, whereas the α_2-phase is finer (ECD=0.8μm).

Figure 7 shows the pole figures from adjacent γ and α_2 phases highlighted in figure 6. The orientation relationship {111} γ ||{0001}α_2 and <110> γ ||<11-20>α_2 between the two phases is evident in the pole figures. In figure 6, this 'complete relationship' is shown using the interphase boundary component, 'orientation relationship', where the interphase boundaries with less than 5° deviation from this particular relationship, also known as the Blackburn orientation relationship [3], are highlighted as white lines.

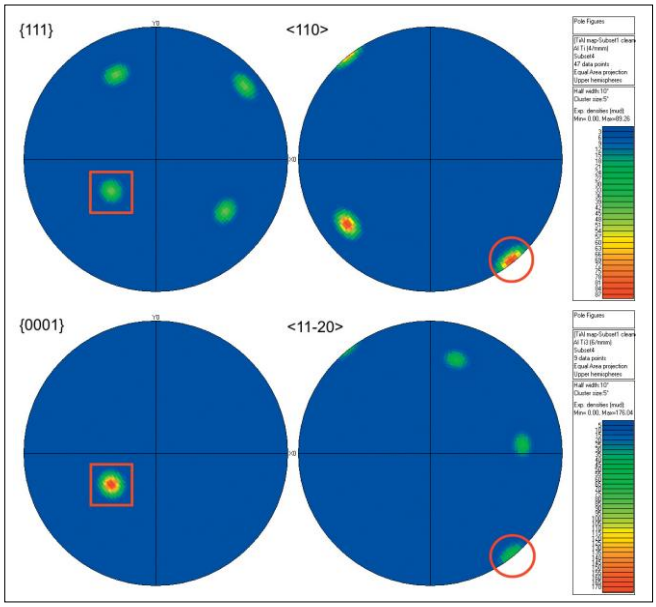

Figure 7:
Pole figures from the highlighted region in figure 6 for the a) γ and b) α2 phases in alloy 2.

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Conclusion

Using its unique Advanced Fit band detection and indexing algorithm, the HKL CHANNEL5 EBSD system can consistently and correctly measure the orientation of tetragonal γ-TiAl crystals, which have only a 2% difference between a and c lattice parameters. The quality of the indexing is nearly perfect, such that very little, if any, subsequent cleaning of the data is needed.
Additionally the EBSD can be used to analyse the phases, orientations and interphase boundary relationships of γ and α2 phases.

Acknowledgements

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References

[1] S. Gebhard, F. Pyczak and M. Göken, The influence of heat treatment parameters on the microstructure of TiAl alloys with and without Nb additions, to be published.

[2] H.Inoue and N.Inakazu, 'Hot deformation Textures of Intermetallic Compound TiAl', Proceedings ICOTOM 11, 1996, p.1495-1500.

[3] S. Bystrzanowski et al., Intermetallics 13 (2005) 515-524.