Interactive Orientation Imaging Microscopy (OIM™) Analysis of Fatigue Cracks

Introduction

Fatigue cracking is a well known problem in structural materials. Understanding the role of crystallographic orientation (and misorientation at grain boundaries) in crack formation and propagation is critical to optimizing microstructure in order to prevent fatigue cracking. OIM™ is an ideal tool for gaining insight into the role crystallography plays in fatigue cracking. It is sometimes assumed that twin boundaries are more resistant to intergranular degradation processes such as corrosion or void formation. However, in the nickel superalloy sample shown in Figure 1, the fatigue crack appears to follow the twin boundaries. OIM™ can be used to identify boundaries which satisfy twin orientation relationships.

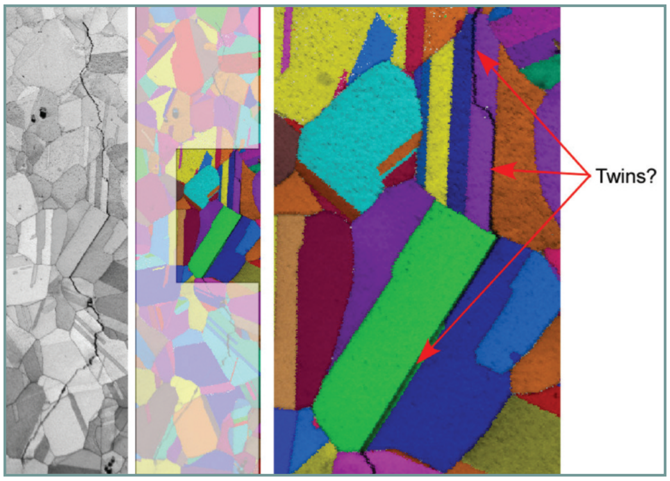

Figure 1. OIM™ IQ map and colored grain maps of a fatigued nickel super alloy sample.

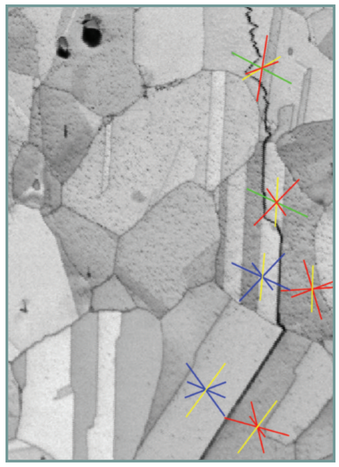

Figure 3. {111} plane traces overlaid on an IQ map.

Grain Boundary Analysis

Figure 2 shows a map, where boundaries meeting the twin misorientation criterion are highlighted. In this map it is clearly evident that the crack preferentially follows these boundaries. Since the grains on either side of a twin have (111) planes in common, the crack may be aligning itself with (111) planes as opposed to twins per se. So, the plane trace highlighting tool in OIM™ was used to confirm this assumption as shown in Figure 3. This tool shows the traces a specific family of planes make with the sample surface. The length of the traces is a function of the inclination angle – the more it is inclined the longer the trace drawn. The plane trace parallel to the twin boundary trace is highlighted in yellow. In some cases, we even see the crack switching from one {111} plane trace to a second {111} plane trace - highlighted in green.

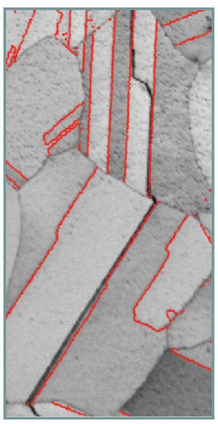

Figure 2. Red twin boundaries overlaid on an IQ map.

Statistical Analysis

However, one should be skeptical of the {111} assumption based on plane trace analysis. If a plane with more multiplicity (like a {211} type, where there are 12 symmetrical variants) is used then it may appear to be a match. In the 2D section only the traces of the crack can be observed. Without 3D analysis it is not possible to ascertain whether the crack planes are truly aligned with the {111} planes. However, a statistical approach can be employed. The idea is to first identify the crack trace, and then rotate about the trace from 0° to 180° in 1° increments representing all potential inclinations of the crack face. Since the orientation of the grain in which the crack resides is known, the plane in the grain parallel to each of the crack face inclinations can be determined. This can be shown as a path through an inverse pole figure as shown in Figure 4a. The colors indicate the inclination, blue is 0° and red is 180°. In the example, the green color of the path at {111} indicates that if the crack face is inclined at 52°, then it is aligned with the {111} plane.

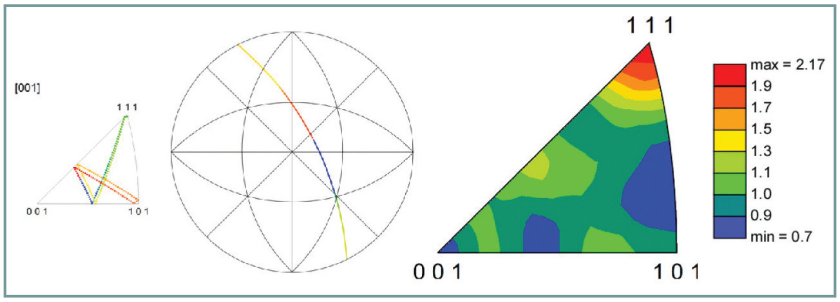

Figure 4. (a) Inverse pole figure showing the crystal orientation of potential crack planes for a given segment of the crack. (b) Inverse pole figure showing propensity of the potential crack planes to be aligned with the {111} crystal planes.

If this analysis were applied to each crack trace segment, then the tendency toward {111} would be evidenced by many of the paths intersecting at {111}. However, with so many paths (data on 54 segments were collected) it would be too confusing to interpret. Thus, a texture calculation is used where each segment is weighted by the segment length. This results in the inverse pole figure shown in Figure 4b. There is a peak at (111) which is weaker than expected, but, nonetheless, it does show a tendency towards (111).

Figure 5 shows a summary of the analysis of the individual crack segments. The deviation of the plane trace from the closest {111} is overlaid on the map. These results convince us that the crack does indeed follow a path coinciding with {111} planes. There are many instances where the crack path changes directions within a grain or at a grain boundary and follows a new {111} plane trace. Some of the deviation comes from how well the crack segment is drawn, manually with the endpoints snapping to the scan grid. It should be noted that the plane trace analysis of the crack segment labeled >15° shows that it appears to be aligned with {001}.

Conclusions

The suite of tools for interactive analysis in OIM™ Analysis allows users to gain critical insight into materials problems, such as fatigue cracking. The ability of users to manually interact with the data enables very complex analyses to be performed.

Bibliography

1. D. L. Davidson, R. G. Tryon, M. Oja, R. Matthews and K. S. R. Chandran (2007). "Fatigue Crack Initiation In WASPALOY at 20 °C " *Metallurgical and Materials Transactions A* **38**: 2214-2225.
2. S. I. Wright (2006). "Random thoughts on non-random misorientation distributions." *Materials Science and Technology* **22**: 1287-1296

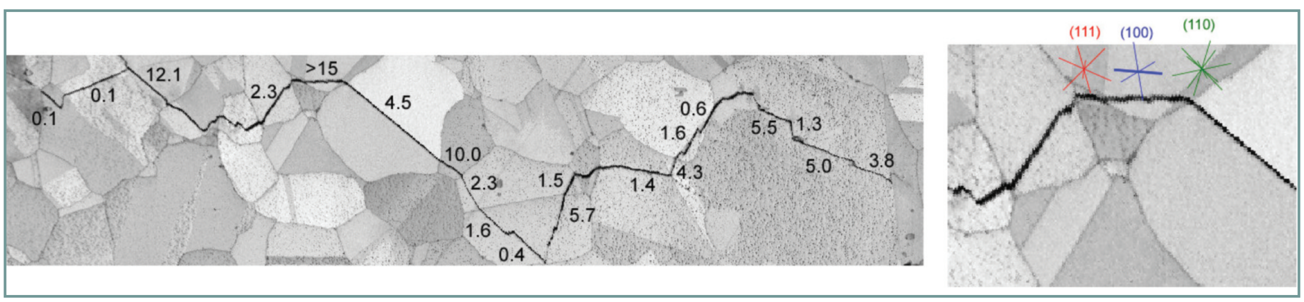

Figure 5. OIM™ Deviation between crack segment traces and {111} plane traces.