EBSD Analysis of Crack Propagation: A Case Study

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Introduction

The following is a summary of a presentation given by Dr. Wright at ICOTOM[18] held November 5-10, 2017 in St. George, UT. Thanks go to those in attendance whose comments have helped refine some of our original interpretations of the results presented.

The ability of automated Electron Backscatter Diffraction (EBSD) to rapidly measure lattice orientations makes it well suited for statistical analyses of the distribution of crystallographic orientation in polycrystalline materials – analyses such as the study of preferred orientation (i.e. texture) or misorientations at grain boundaries. The desire to link texture analysis with microstructure motivated the automation of the EBSD technique (B.L. Adams, S.I. Wright and K.Kunze (1993). "Orientation Imaging: The Emergence of a New Microscopy." *Metallurgical Transactions A* **24**: 819-831.) Materials scientists have since not only found EBSD useful for statistical analyses but also for linking lattice orientation with specific microstructural features through direct interactive analysis of orientation maps. As an example, consider the following investigation into the propagation of a fatigue crack in a nickel superalloy (thanks to Ravi Chandran of the University of Utah for the sample).

Figure 1 shows an Orientation Imaging Microscopy (OIM) scan of one crack in the sample. The scan contains 3.26 million points collected on a hexagonal grid with a 0.25 µm step size. The sample exhibited a high population of twin boundaries. Our initial assumption was that twin boundaries would be resistant to cracking. The first step towards confirming or refuting this assumption was to identify point pairs across the crack. This is done using the mouse in the boundary highlighting mode (icon to the right) in the OIM Analysis™ software as shown by the pairs of red dots in Figure 1. An effort was also made to maintain an equidistant spacing between the point pairs.

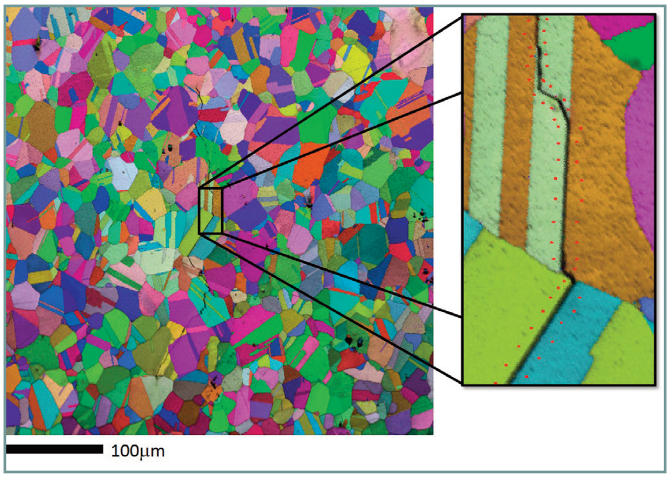

Figure 1. OIM scan of one crack in the sample.

In the process of manually clicking the point pairs, it was immediately apparent that the crack propagates both along the boundaries between grains (intergranular) as well as through grains (transgranular). The crack showed no aversion to propagating along twin boundaries. A misorientation angle distribution calculated for each of the point pairs shows two major peaks (Figure 2a). The one on the left is associated with transgranular cracking (near 0° misorientation) and the one on the right with the primary recrystallization twins (60° rotations about <111>). To confirm this, a Misorientation Distribution Function (MDF) was calculated. The results are shown in Figure 2b for the 60° section of Axis-Angle space. There is clearly a strong peak at 60° at <111>.

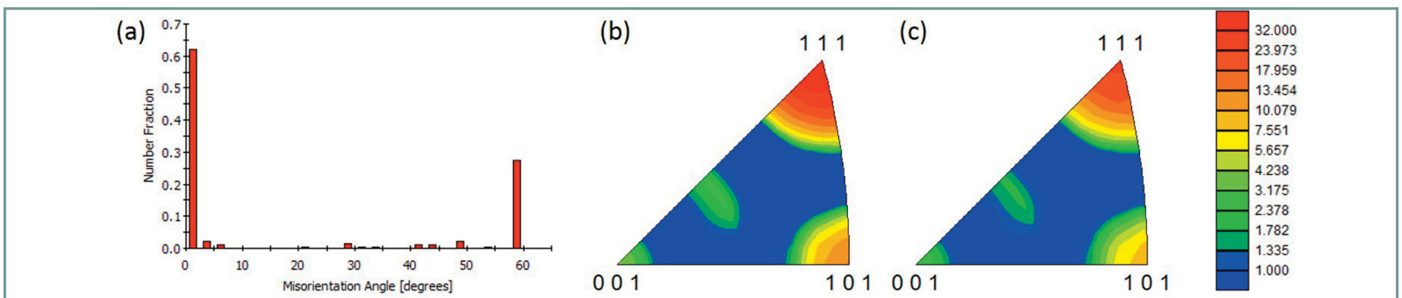

Figure 2. a) Misorientation angle distribution calculated for each fo the point pairs show two major peaks. b) Misorientation Distibution Function (MDF) calculated for the 60° section of Axis-Angle space. c) MDF calculated for the entire scan.

The peak is even stronger than the corresponding peak for an MDF calculated for the entire scan as shown in Figure 2c. While results from a single crack do not provide statistical certainty to the observation of preferential propagation along twin boundaries, results from a second crack in the same material exhibited the same trend. One caveat to this analysis is that our observations are obtained solely on two-dimensional surfaces. It is possible that a crack appearing to propagate on a boundary plane in a 2D section could be on some other plane in the crystal, not coincident with the boundary plane, but with the same plane trace – this can only be ascertained through 3D analysis of the boundary/crack structure.

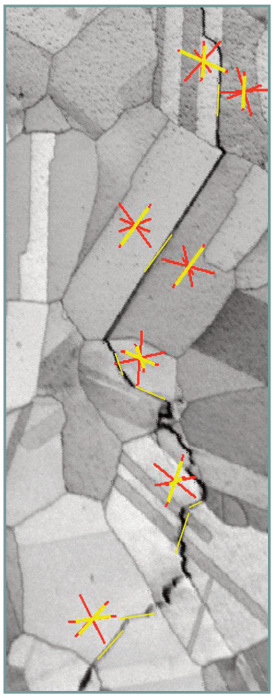

Figure 3. OIM Analysis™ software was used to draw the (111) slip traces in red. The traces that appear to be aligned with crack plane are highlighted in yellow.

Analysis of the slip traces in grains adjacent to the crack shows that the crack wants to follow (111) planes (Figure 3). The tendency of the crack to follow the (111) planes explains why it often follows twin boundaries in this material. In some grains, the crack path is very jagged as shown in Figure 4. Almost as though the crack is a hiker trying to ascend a steep hill via a series of switch backs. It is assumed the jagged path minimizes the energy required to propagate the path in a direction generally normal to the tensile axis (horizontal in this case) as the crack interacts with the local stress state. In some grains the crack does not appear to follow a (111) plane and is not jagged. However, in such areas the crack appears less distinct in the IQ map. It is possible at higher resolution we would see a jagged path as well but with shorter segments between the direction changes.

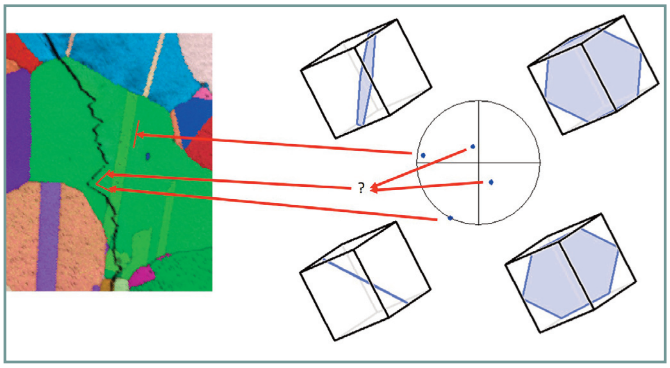

Figure 4. Schematic of (111) planes associated with jagged transgranular path.

Kernel Average Misorientation (KAM) maps provide an indication dislocation density within the microstructure. An example at higher resolution than the original scans is shown in Figure 5. Note that areas with high KAM values appear to be associated with direction changes. While it may be possible that the dislocation density builds up, forcing a change in the crack path direction, it may also be possible that the cracks confront some other obstacle forcing the direction change and that the higher dislocation density is associated with dislocations behind the crack front after the change in direction.

While only a portion of the case study presented here is statistical in nature, such analyses provide insight into physical processes such as those underlying crack propagation and can also provide direction for further statistical investigation.

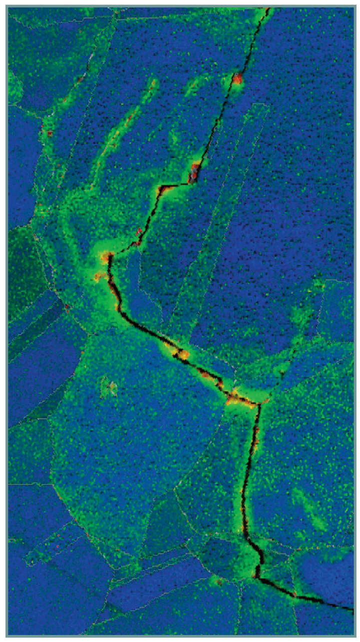

Figure 5. KAM/IQ map showing high dislocation densities at directional changes in the crack path.

Conclusion

We often focus on all the automated tools OIM has to offer to analyze EBSD data. However, sometimes, user interaction with the orientation maps is required to analyze certain phenomena. In this example of crack propagation in a nickel super alloy, analysis of the interactive data shows that while crack paths in this material do sometimes follow grain boundaries, particularly twin boundaries, the overwhelming tendency is for cracks to propagate along {111} planes. In fact, it was observed that a crack will jump back-and-forth between different {111} planes to continue propagating in a general direction consistent with the imposed global stress state.