Electron Backscatter Diffraction (EBSD) Analysis of Cracking in Polycrystalline Materials

Introduction

It is not always apparent from a standard Scanning Electron Microscope (SEM) micrograph whether a particular boundary path follows grain boundaries in the structure or has a transgranular component. Orientation Imaging Microscopy (OIM™) has the unique capability of differentiating grains from one another based on crystallographic orientation instead of relying on etching or other contrast enhancement approaches. The improved capability of OIM™ to differentiate grains enables an unambiguous determination of whether a given crack segment is transgranular or intergranular. In addition, the crack path is particularly evident in Image Quality (IQ) maps. This is because in the crack the diffraction patterns are generally non-existent or at best very weak.

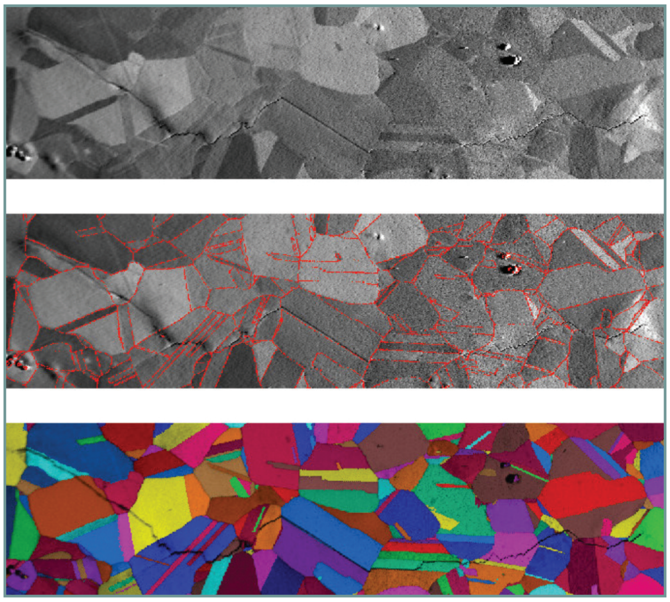

Figure 1. Image from the Secondary Electron Detector (SED) of a fatigue crack in a nickel superalloy (top). SED image overlaid with grain boundaries as determined by OIM™ (middle). Grains as determined by OIM™ delineated by random colors overlaid on a gray scale map based on a parameter describing the Image Quality (IQ) of the individual diffraction patterns (bottom).

Grain Boundary Distributions

For cracks propagating along grain boundaries, it may be helpful to identify whether there is a unique character shared by the cracked boundaries versus the overall distribution of boundaries. Consider the example shown in Figure 2 from copper interconnect lines undergoing thermal stress. Misorientations were measured across both the voided and unvoided grain boundaries using OIM™. From the two distributions it is evident that low angle boundaries are resistant to void formation. There is also a spike in the distribution of voided boundaries at 52° indicating that these boundaries are susceptible to void formation. Similar types of analysis have been applied to fractures in lead free solder alloys.

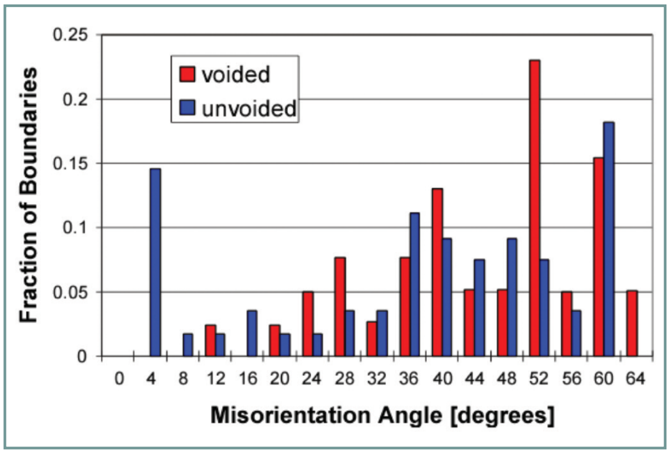

*Figure 2. Distribution of voided and unvoided grain boundaries in copper interconnect lines. Nucci, J. A., R. R. Keller, D. P. Field and Y. Shacham-Diamand (1997). "Grain boundary misorientation angles and stress-induced voiding in oxide passivated copper interconnects." Applied Physics Letters **70**: 1242-1244.*

Taylor Factor Mapping

OIM™ can be used for even more complex analysis of the microstructure. For example, a Taylor factor map can be constructed. The Taylor factor shows the predicted yield response of a grain relative to the stress state and grain orientation. In Figure 3, the grains in blue are oriented for relatively easy slip, whereas the grains shaded red tend to be resistant to yielding. Boundaries separating grains with a high degree of mismatch in Taylor factor may be more susceptible to intergranular fracture. Grains with high Taylor factors will be less likely to yield and may be susceptible to transgranular fracture. Note the crack path in Figure 3 – there appears to be some evidence that the path is intergranular where there is a strong mismatch in Taylor factor. The challenge of applying such analysis to lead free solders is properly identifying the stress state. In this example, the stress state is uniaxial tension in the horizontal direction, aligned with the experimental testing axis.

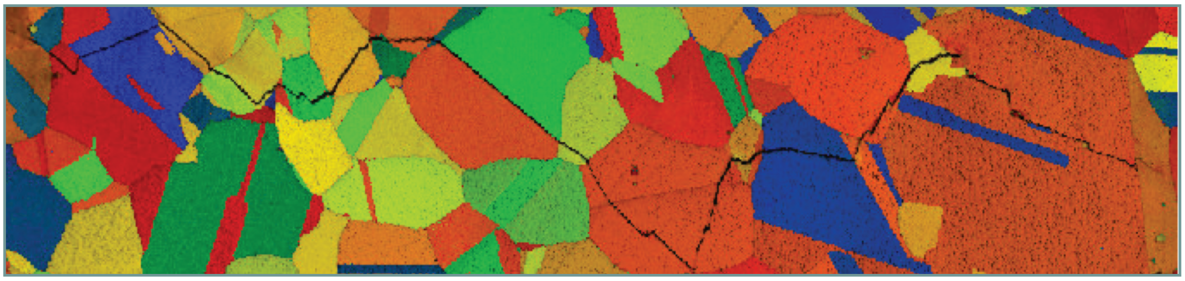

Figure 3. Taylor factor map overlaid on an IQ map. The map area contains a fatigue crack in a nickel superalloy.

Local Orientation Variations

Local orientation variations that can be observed in OIM™ can impact crack propagation. Local orientation variations are indicative of built up residual strain in the material. These may be areas where crack initiation may occur. Figure 4 shows local orientation variations emanating from a fatigue crack tip in a nickel alloy. The variations are quite large within individual grains – as high as 60°. OIM™ is well suited for studying these local orientation gradients because of its angular resolution.

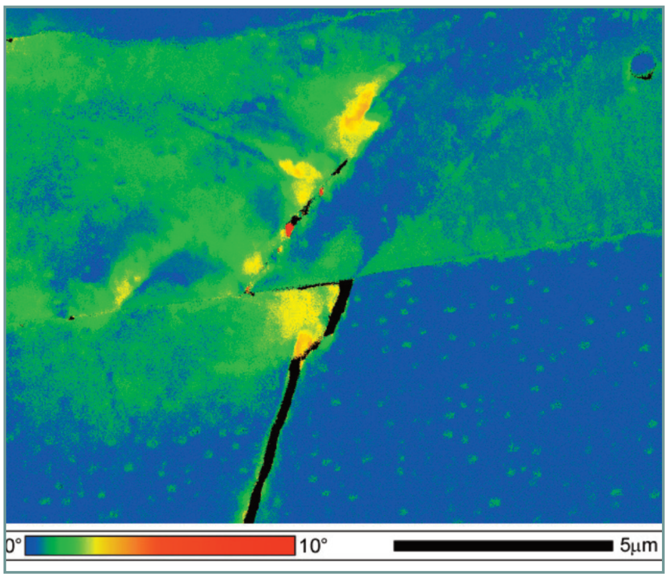

Figure 4. Local misorientation map near a crack tip in steel. The small ovals are associated with second phase particles.

Note

It is important to remember that the OIM™ results shown here are all performed on two-dimensional planar surfaces. Of course, cracking is a three-dimensional phenomenon and thus three-dimensional analyses would need to be performed in order to get a complete picture of crack propagation and/or the strain fields surrounding a crack tip.

Conclusion

As cracking often appears to propagate along specific crystallographic planes in crystalline materials, OIM™ is well suited to the study of the many different aspect of cracking.

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