DOI: 10.1017/S1431927603440993
Microsc Microanal 9(Suppl 2), 2003

Analysis of Grain Fragmentation in Deformed Materials

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Deformation of polycrystalline metals results in the fragmentation of crystallites dependent upon their orientation with respect to the imposed strain field. Automated electron back-scatter diffraction (EBSD) allows lattice orientations to be measured over a regular grid on the surface of a polished plane section, and thus directly obtain information on the lattice curvature of deformed crystallites. Measurement of local dislocation density by EBSD was first approached by quantifying the diffuse character of the diffraction patterns when imaging through a volume of crystallite containing many defects [1]. Another approach to quantifying the dislocation density distribution using EBSD measurements is to extract a measure of the curvature in the lattice from the orientation measurements, thereby obtaining the geometrically necessary component of the dislocation density. Nye [2] gives a direct relationship between the second-rank curvature tensor and the dislocation density tensor. The measurement of the curvature tensor requires some amount of tedious serial sectioning since the lattice rotation gradient in the direction of three mutually orthogonal vectors is required. The recent work of El-Dasher, et al [3] provides an application of this technique in connection with automated EBSD data. In addition, they have presented a discussion of deformation in an aluminum bicrystal using the dislocation density tensor approach as it can be measured from a plane section. Namely, three of the nine components of the dislocation density tensor were recovered from the measurements.

Since the work of Frank in 1988 [4] representation of orientations and misorientations in Rodrigues space has been adopted by various researchers. The Rodrigues vector, $\boldsymbol{R}$, is defined by the expression $\boldsymbol{R} = \boldsymbol{n}\tan(\omega/2)$, where $\boldsymbol{n}$ is the axis of rotation and ω is the rotation angle defining the lattice. Typically the misorientations are mapped into a fundamental zone that is an asymmetric domain. For cubic crystal symmetry, this region in misorientation space is chosen from the 48 symmetrically equivalent zones in the asymmetric domain of orientation space. Since misorientations are relative to the two orientations in question, and the fundamental zone is arbitrarily chosen, the flow field represented by a misorientation Rodrigues vector mapped into this zone would be limited in application. A vector defined over all of orientation space that represents the rotation from the grain average orientation to the orientation at any position is required to properly construct the flow field. This vector can be obtained as follows. The result of two successive rotations $\boldsymbol{R}_1$ and $\boldsymbol{R}_2$, is given by $\boldsymbol{R}_2 \circ \boldsymbol{R}_1 = \dfrac{\boldsymbol{R}_1 + \boldsymbol{R}_2 - \boldsymbol{R}_1 \times \boldsymbol{R}_2}{1 - \boldsymbol{R}_1 \cdot \boldsymbol{R}_2}$, so the rotation $\delta\boldsymbol{R}$ from $\boldsymbol{R}_{ave}$ to $\boldsymbol{R}(\boldsymbol{x})$ assumed to be near one another in orientation space, is obtained from $\boldsymbol{R}(x) = \delta\boldsymbol{R} \circ \boldsymbol{R}_{ave}$ or $\delta\boldsymbol{R} = \boldsymbol{R}(x) \circ \left(-\boldsymbol{R}_{ave}\right)$. Using $\boldsymbol{R}_{ave}$ and $\boldsymbol{R}(\boldsymbol{x})$ in the form given above leads to the result, where $\delta\boldsymbol{R}$ is a vector with a direction that can lie anywhere in space, but aligns with the misorientation axis as defined in Rodrigues space. This vector can be projected onto the orientation maps to obtain a graphical presentation of the misorientation flow field. This field is related to the dislocation distribution since the total dislocation density required to rotate the lattice from the average orientation to each given position is represented by the magnitude of the flow vector. The vectors are projected onto the plane of the specimen seen, so they might correspond to the total dislocation

content between the mean orientation and that of each position. The vector directions coincide with the dislocation lines seen in the TEM and their magnitudes correlate to the total geometrically necessary dislocation content.

Images shown in Figs 1-4 show the structure of deformed Al single crystals. Fig. 1 shows the misorientation angle from the average orientation of the crystallite. Fig. 2 indicates the axis of rotation in a color-coded scheme. Figs 3 and 4 show Rodrigues vector flow fields as described above for two deformed single crystals. One exhibits a cellular structure, and the other contains a continuously curving lattice.

References

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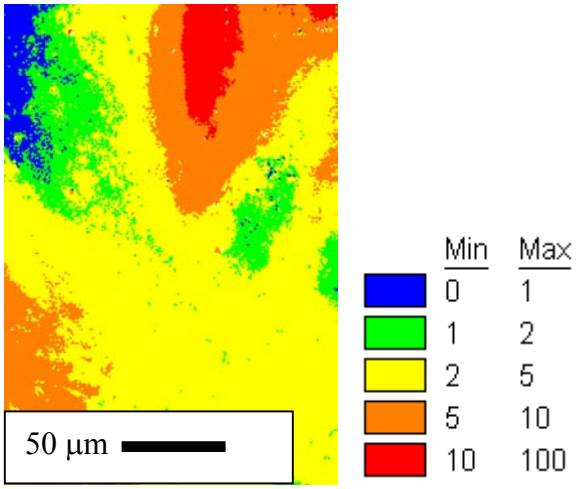

Fig. 1 – Orientation angle deviation plot (degrees).

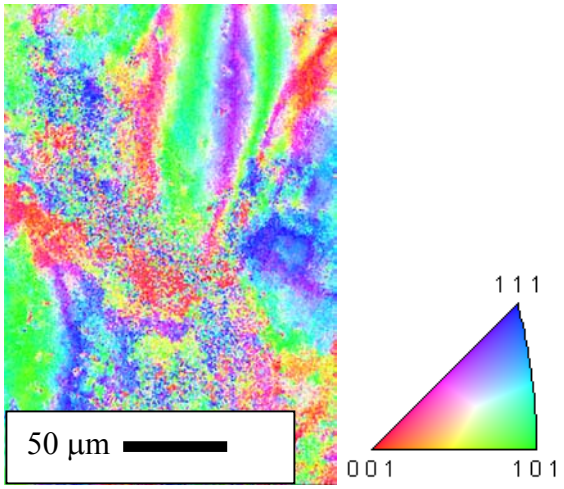

Fig. 2 – Misorientation axis plot of Al crystallite.

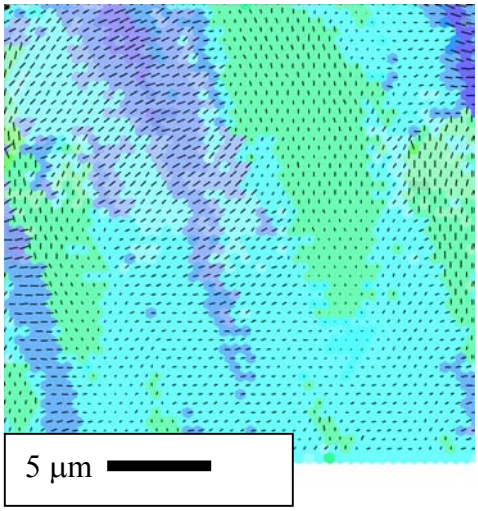

Fig. 3 – Rodrigues difference vectors in Al.

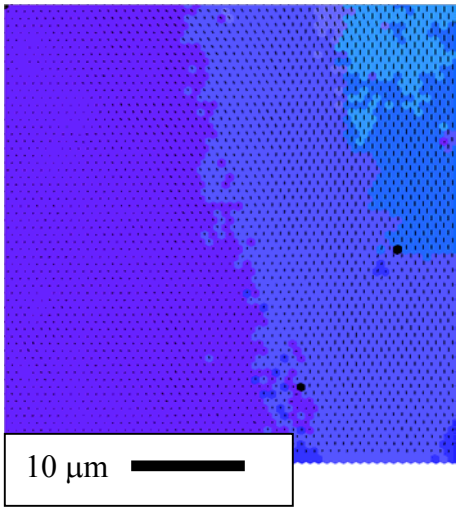

Fig. 4 – Rodrigues difference vectors in Al.

https://doi.org/10.1017/S1431927603440993 Published online by Cambridge University Press