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TEXTURE-DEPENDENT MEASUREMENT OF RECRYSTALLIZATION KINETICS USING ELECTRON BACKSCATTER DIFFRACTION

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ABSTRACT- Partially recrystallized samples of 5352 aluminum alloy and pure titanium were sectioned and characterized with automated electron backscatter diffraction (EBSD) in a scanning electron microscope. Pixels were partitioned into recrystallized (annealed state) and unrecrystallized (deformed state) using a criterion based on the confidence index (*CI*) and the diffraction pattern quality (*IQ*). Unrecrystallized pixels were linked to Low *CI* and *IQ*. Errors in indexing were minimized by incorporating isolated unrecrystallized pixels into surrounding recrystallized regions. Good agreement was obtained with conventional methods of determining fraction recrystallized.

INTRODUCTION: The traditional method of measuring the fraction recrystallized, in deformed and partially annealed metals, uses optical micrographs and the operator's judgment based on the appearance of each region. Uniform gray level is typically associated with recrystallized and speckle is associated with unrecrystallized. These qualitative criteria suggest that local perfection of the lattice should lead to a quantitative criterion using EBSD maps. In recent years, this has been attempted with digital imaging using a grayscale threshold on the image quality (*IQ*) values, which is a measure of the diffraction quality at any point (Wright[2000]). Given a suitable choice of threshold, the fraction recrystallized is then equal to the area fraction of high *IQ* points.

Also of interest is observation of the evolution of any preferred orientation (or texture) in the material as annealing proceeds. This is typically measured in a separate step using X-ray diffraction. While this procedure remains useful as a measure of the average texture, it cannot be used to obtain detailed information on individual components. In addition to the need for information on spatial and texture-dependent information on the kinetics of recrystallization, it is evident that the cutoff threshold used to determine the recrystallization state is very subjective as it is heavily operator dependent. These considerations motivated a desire to create and test a new approach to this problem. This work is allied to other efforts to characterize the deformed state at a smaller scale in which the geometrically necessary remnant dislocation structure is derived from the orientation field.

PROCEDURE, RESULTS AND DISCUSSION: Our approach is based on TexSEM Labs' Orientation Imaging Microscopy (OIM) system. In this technique, a focused electron beam is used to interrogate a sample surface on a regular grid of points (see

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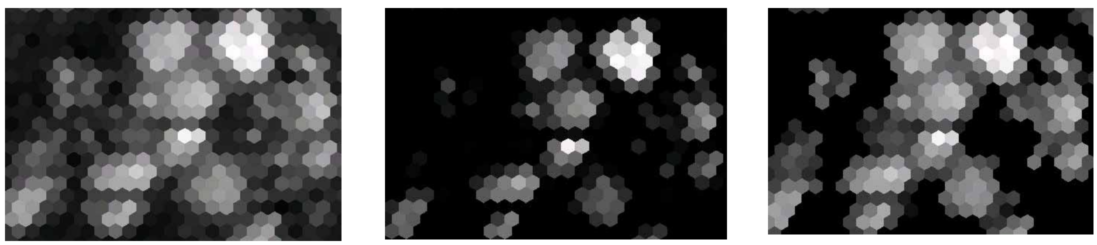
Adams[1993]). An Electron Backscatter Diffraction Pattern (EBSP) is captured for each point, and this pattern is subsequently indexed to determine the orientation of the crystal at that grid position. The *IQ* value, which represents the contrast present in the pattern, and the *CI* value, representing how certain the software is of the indexing are also recorded. However, despite an observed relationship between the unrecrystallized portions and low *IQ* and *CI* values, testing with thresholds on the *IQ* or *CI* yielded inadequate results. Specifically, it was found to be too aggressive and yielded unrealistic microstructures, as it eliminated too many points around recrystallized grains (including grain boundaries), while occasionally leaving points surrounded on all sides by unrecrystallized material, as can be seen in the change from Figure 1(a) to 1(b).



(a) **(b)** **(c)**

Figure 1. (a) As scanned IQ map, (b) map modified using an IQ threshold, and (c) map modified using Eqn. (1). Black points represent those considered unrecrystallized.

In order to create a more physically based and justifiable algorithm, we set a *CI* threshold of 0.1. This was justified since experience indicated that, in general, the transition between well- and poorly-indexed points occurred at this value. Next, an *IQ* threshold was chosen to be the average *IQ* of all points with a *CI* value less than 0.1. This value was not only found to be in many cases, surprisingly, close to the cutoff that would have been chosen by the operator, it also completely eliminated the need for a subjective operator decision. Lastly, a neighbor correlation was applied in order to ensure that the final microstructure was physically reasonable. This allowed a point to be considered recrystallized if it has at least four recrystallized nearest neighbors, or three of its nearest neighbors are within 3° of the same orientation. We can represent all of this as follows:

$$\forall p \in S, p \in U \text{ iff } \begin{cases} IQ_p < IQ_{thres} \\ CI_p < 0.1 \\ n_p < 4 \end{cases} \tag{1}$$

where p is any data point in set S of all OIM data points, U is the set of all unrecrystallized points, IQ_p is the image quality value of point p, IQ_{thres} is the average *IQ* of all points with a CI<0.1, CI_p is the Confidence Index value of point p and n_p is the number of neighbors of p whose *CI* and *IQ* values are larger than 0.1 and IQ_{thres} respectively.

As can be seen in Figure 1 (c), this algorithm not only eliminates the unrecrystallized portion, but also yields a reasonably realistic microstructure by considering the orientation and the physical relation of each point with its neighbors. In the pole figures in Figure 2, we can readily see the effect of this algorithm on the computed texture in an aluminum sample, essentially providing a filter of data obtained from only those points that were considered to be recrystallized ($p \notin U$), and in this case increasing texture strength.

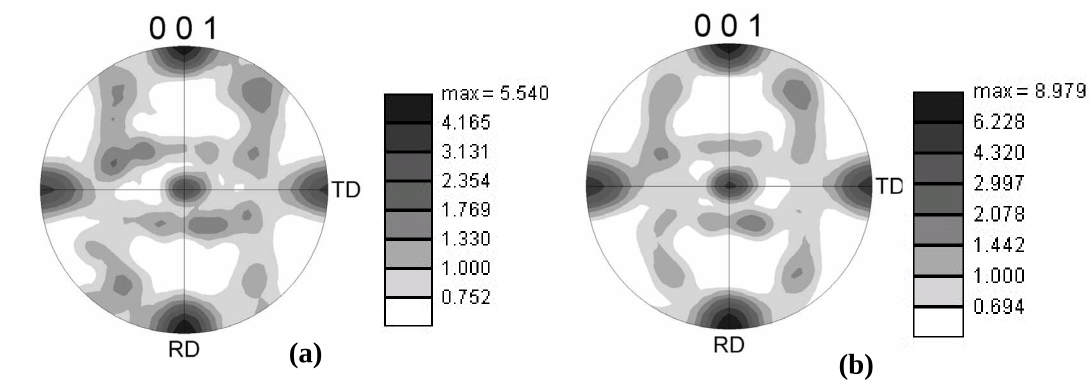


Figure 2. [001] Pole figure of an (a) as scanned and (b) Eqn. 1 filtered to include only recrystallized points in a 5352 Al OIM dataset

In terms of the recrystallization estimates, the algorithm compared well with the traditional characterization method, yielding results within 3% of that estimated by the traditional optical method. There were only two cases in which the discrepancy was quite large. In the first case, the amount of recrystallization was small at 5%, and the algorithm estimated it at 27%. This was because the chosen scan area was insufficiently large to represent the sample as a whole. In the second case, the algorithm estimated a recrystallization of 83% when it was actually closer to 95%. This discrepancy was attributed to the over-etched nature of the sample in question, as the stepped topography generated many points with unrealistically low *IQ* and *CI* values.

CONCLUSIONS: A mechanism was successfully developed to estimate the percentage recrystallization present in samples using Orientation Imaging Microscopy datasets. The criteria developed are not sample dependent, eliminating any subjective operator decisions. Further, both recrystallization and texture information can now be obtained simultaneously, significantly decreasing the time required of the operator.

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