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Post processing effects on GND calculations from EBSD-based orientation measurements

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Abstract. Electron Backscatter Diffraction (EBSD) has shown great utility in characterizing the aspects of microstructure related to crystallographic orientation. Such information is critical to understanding deformation in crystalline materials as well as the impact of deformation induced structural variations on recrystallization. Small angle rotations induced by the production of dislocations and their movement through the structure can be well captured by EBSD. Geometrically Necessary Dislocations (GND) can be derived from the measurement of these local variations in orientation. However, these local orientation variations are often right at the limit of angular precision that can be achieved by EBSD. Various post-processing tools have been developed to improve the angular precision. However, this is generally achieved through point-to-point smoothing of the orientation data within the measurement grid. The impact of such various filtering method are explored in terms of their impact on GND calculations. A new post processing approach which improves the EBSD indexing rate will also be presented along with results on its influence on local orientation variations. Fortunately, the general conclusion drawn from the reduction results is that these approaches generally improve the overall GND measurements.

1. Introduction

Electron Backscatter Diffraction (EBSD) in the Scanning Electron Microscope has become one of the preferred tools for the study of microstructural evolution particularly for deformation based metal forming processes. We have surveyed the EBSD literature using various online search tools and found that deformation is the most common application area for EBSD based analysis. Two EBSD analytical tools frequently used in the study of deformation by EBSD are first Kernel Average Misorientation (KAM) [1] and second Geometrically Necessary Dislocations (GND) [2-4]. The KAM measurement is the average misorientation between a point in the EBSD scan grid and its neighbors (usually just the nearest neighbors). The movement of dislocations through the material results in small angle rotations which can be captured by the KAM measurement. However, this measurement is very much sensitive to the step size used in the original scan data. A more quantitative measure of the dislocations is provided by the GND calculation. The GND calculation takes into account the slip systems in the material and provides some compensation for the step size. However, studies have shown that the GND measurements are still sensitive to the step size [5-6]. These measurements are not only sensitive to step size but are also sensitive to the precision of the orientations measured by EBSD. Various "filtering" approaches have been developed to mitigate the effects of orientation "noise" [7-10] in the EBSD measurements. The impact of these approaches on the GND measurements are characterized by adding

artificial noise to high-fidelity EBSD measurements and then comparing the original results with those obtained after applying the noise reduction filters..

2. Step size

In order to confirm the step size dependence of EBSD measurements, we have done some studies on the step size dependence of GND calculations on deformed brass materials used in a study of the orientation precision of EBSD measurements [11]. In this study, orientations were measured by EBSD on grids with a fine step (20 nm) and a coarse step (250 nm). Four samples were investigated with four different levels of cold-rolling reduction – 4.5, 11, 20 and 30%. These scans were then coarsened by removing every other point in the scan grid. The average GND density was then calculated. The results, shown in Fig. 1, clearly demonstrate a dependence on the step size used with the exception of the one anomalous point for the 4.5% 20 nm original step size.
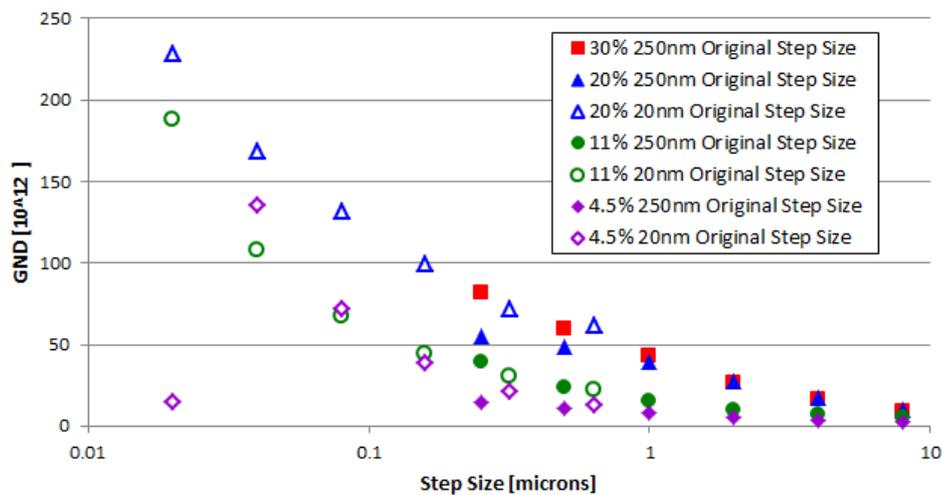

Figure 1. GND measurements of deformed brass showing general decrease in measured GND density with increasing step size.

One of the challenges of measuring local orientations using EBSD on deformed materials is that the deformation generally results in lower-quality diffraction patterns than would be observed in the recrystallized material. It is assumed that the effects of noise in the deformed would manifest itself by higher KAM and GND values but that this effect would decrease with increasing step size. In order to verify this, Gaussian noise was added to EBSD patterns collected on a rolled copper sample. 4.35 million measurements were collected on a hexagonal scan grid with 50 nm spacing. An example of an as-collected pattern and a pattern after adding noise is shown in Fig. 2.

The noisy patterns were then re-indexed, the indexing success rate [12] prior to the addition of the noise was found to be 99.7% and 94.7% after. As expected, the GNDs measured from the noisy data are higher for the smaller step sizes but then drop to match those of the original data at 200 nm. These results are shown in Fig. 3. It should be noted that adding more noise to the patterns lead to much lower indexing success rates and then data did not follow the expected trend likely due to so many missing points.
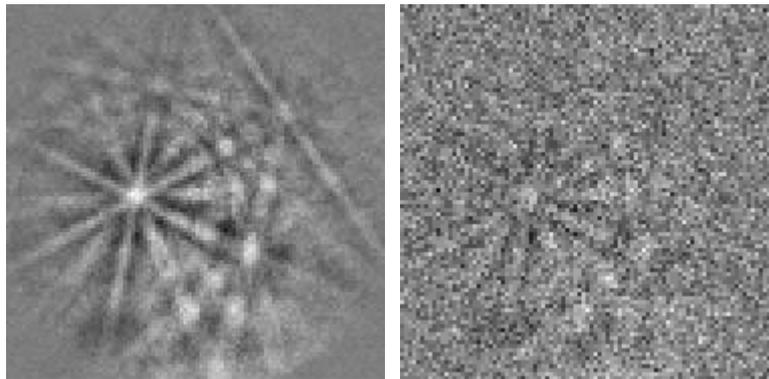
**Figure 2**. Pattern from a rolled copper sample before and after the addition of Gaussian noise.
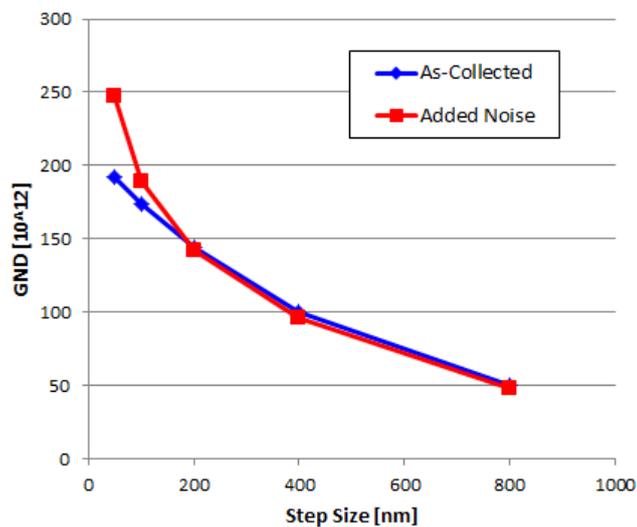
Figure 3. GND measurements from rolled copper before and after the addition of Gaussian noise to the patterns.

3. Noise reduction

Four different orientation noise reduction methods were investigated: (1) the Kuwahara filter [8], (2) a Bilateral smoothing filter [9], (3) a Gaussian smoothing filter and (4) a neighbor pattern averaging filter followed by re-indexing (NPAR) [10].

The Kuwahara is an edge retention filter where, in this application, the edges are essentially sub-grain boundaries. The Bilateral and Gaussian filters are smoothing filters. The pattern averaging filter averages the pattern at each point on the scan grid with the patterns of the neighboring points. These neighbor averaged patterns are then re-indexed in the standard manner. It requires that patterns be recorded during the original scanning process at the SEM. The four noise reduction schemes were all applied to the rolled copper data obtained after adding Gaussian noise to the as-collected EBSD patterns. Fig. 4 shows the results.

The Kuwahara filter produced an average GND value which most closely matches that of the original scan data while the NPAR approach most closely matches the original GND distribution. However, all four filtering approaches brought the GND distribution generally closer to that calculated on the original scan data. Corresponding KAM maps are shown in Fig. 5. The many points colored red in the Kuwahara and Bilateral filtered maps are primarily points which are either unindexed or points without any neighbors within 5° in orientation.
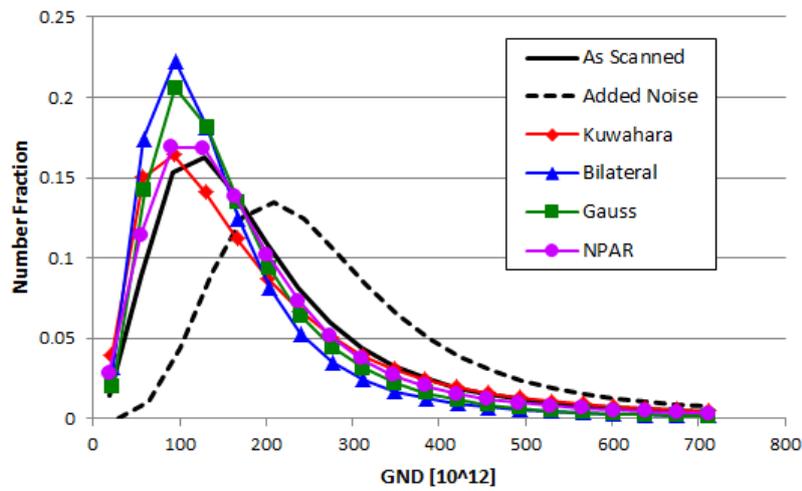
Figure 4. GND measurements from rolled copper with orientation noise reduction filters applied.
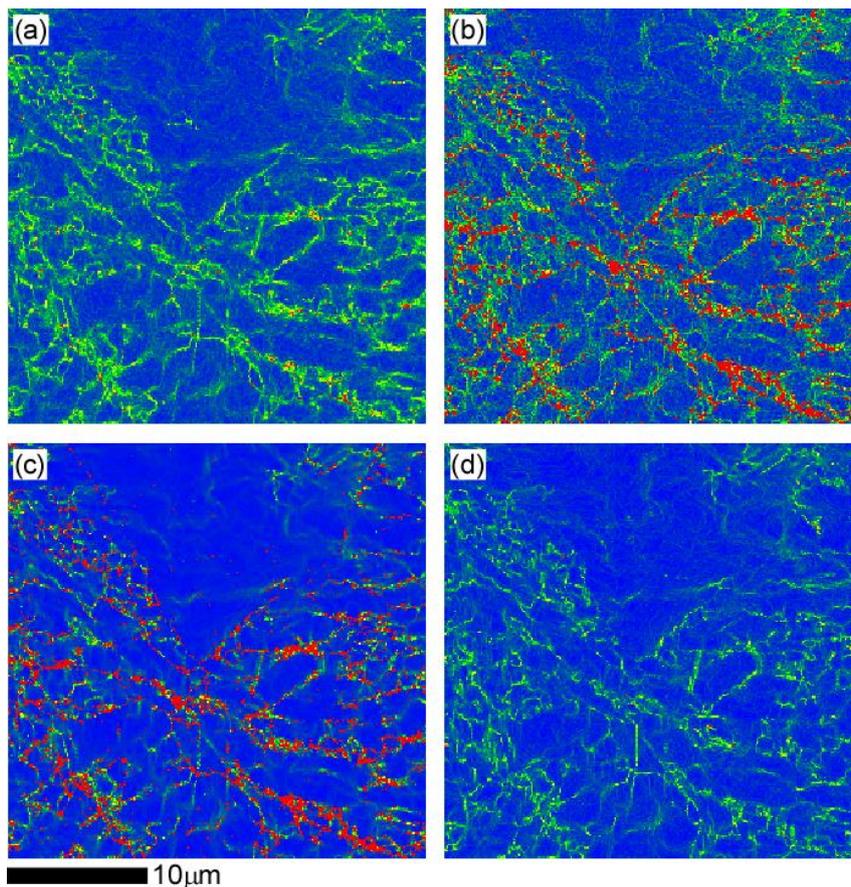
Figure 5. KAM maps for a 30 m square sub-region of the full copper scan data for the (a) original scan and the following filters applied to the noisy data - (b) the Kuwahara filter, (c) the Bilaterial smoothing filter and (d) NPAR.

It should be noted that cursory results on data from other materials, at different strain levels and step sizes relative to the visible structure suggest that the different noise reduction filters may not always be as successful as those shown here and warrant further investigation.

4. Conclusions

The results presented confirm the step size dependence of the GND calculations from EBSD scan data. The results also demonstrate that GND values tend to increase with decreasing orientation precision but that this effect is most apparent at the smaller step sizes as expected. Furthermore, the effects of reduced orientation precision can be mitigated through the application of noise reduction methodologies at least in terms of overall GND distributions.

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