

Microstructural Analysis of Forged Aluminum Carabiners

Introduction

The performance of a material can be enhanced by optimizing its microstructure. This is done by carefully controlling the material processing to achieve a desired microstructure. Carabiners are a critical part of the safety system for rock climbing and mountaineering. For carabiners, strength-to-weight ratio is a crucial performance parameter. Orientation Imaging Microscopy (OIM™) has been used to study the microstructure in rockclimbing carabiners purchased at a local retail store. The carabiners were made of Aluminum 7075, an aluminum alloy best known as “aircraft aluminum”. It is typically used in applications where a high-strength, low-density material is needed at relatively low cost. Because the material is utilized in a high-stress environment, cracking behavior is of particular interest to engineers. The goal is to maximize strength and minimize weight, but the way in which that is accomplished is unique to each manufacturer. Because there is no variation in the material selection and the material itself is homogeneous, OIM™ is ideal for evaluating microstructures introduced by the processing.

OIM™ Results

Four carabiners were investigated. While the exact processing history is unknown we do know that carabiner A was cold forged and then from the OIM™ results we assume this was followed by an anneal. Carabiners B, C and D were formed by forging at high temperature. The scans were all collected from the interior of the carabiners’ nose bend (Figure 1). It is at this point on the carabiner that 85% of all failures originate. Using OIM™, grain orientation and deformation can be quantified. Figure 2 shows the orientation maps of three different carabiners. These maps are colored according to the crystal direction normal to the sample surface according to the color-coded unit triangle. The microstructures of the three carabiners are quite different due to the different processing used to form them. Carabiner A shows a relatively equiaxed microstructure with random colors indicating random

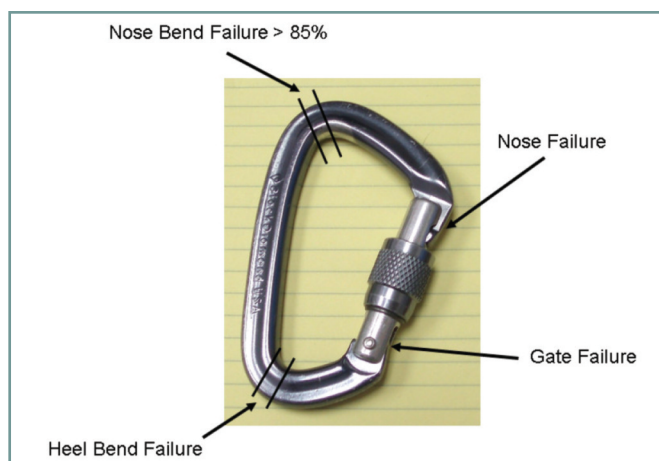


Figure 1. Carabiner and potential failure areas.

orientation, carabiner B exhibits an elongated structure, also with random colors and carabiner C shows a more pronounced elongated structure dominated by blue colored points, which indicate a tendency towards a (111) texture.

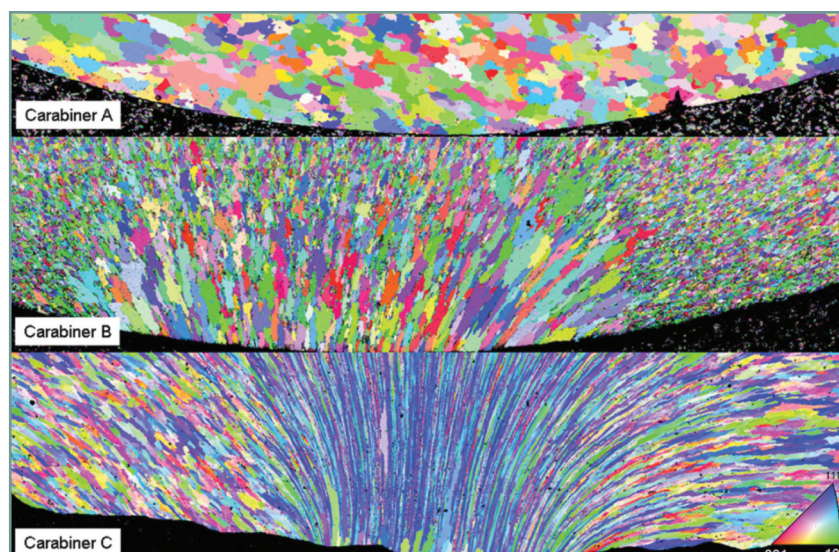


Figure 2. Orientation maps of carabiners A, B and C.

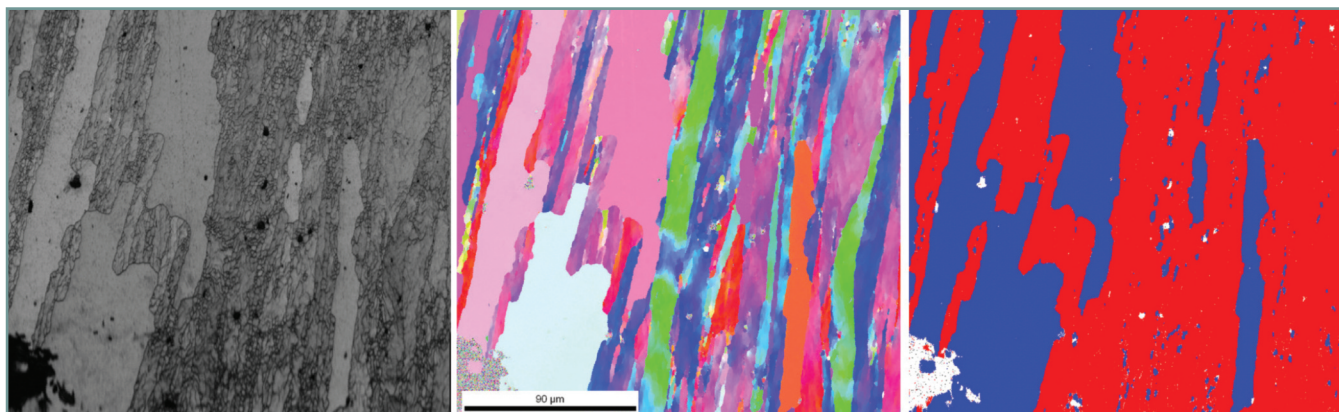


Figure 3. OIM™ IQ (left) and orientation (center) maps and a map delineating deformed (red) and recrystallized regions (blue) (right) in a partially recrystallized Al 7075 sample.

Deformation and Recrystallization

As OIM™ measures orientations on a point-by-point basis, it is well suited for the characterization of local variations in orientations. These local small angle misorientations are characteristic of a deformed material. One sign of the presence of dislocations in the crystal lattice is local small angle misorientations. Thus a grain that exhibits small angle misorientations from point-to-point within the grain signifies a deformed grain, whereas a grain with very little point-to-point variance in orientation signifies a recrystallized material. This is evident in Figure 3, which shows an OIM™ image quality (IQ) map and an orientation map. The orientation map depicts the subtle variation in color indicative of small angle misorientations. These are regions of deformed material. If a tolerance value on the local misorientations is set then the deformed material can be differentiated from the recrystallized material in the OIM™ measurements.

Figure 4 shows a map where a tolerance value for the local misorientation has been selected. The points in red represent deformed material, whereas the points in blue represent recrystallized material. Carabiner A is clearly mostly recrystallized due to the post-forging anneal, whereas carabiner B is primarily still in a deformed state. However, some recrystallization has occurred during the hot-forging, primarily in the region of very elongated grains, which are those with enough stored energy to initiate dynamic recrystallization.

Material Flow

The elongated grain structures in carabiners B and C are indicative of the flow of material during the forging process. In order to understand this flow structure better, a statistical study

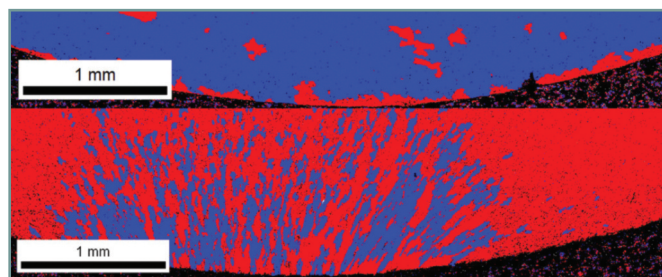


Figure 4. Deformed (red) and recrystallized (blue) grains as measured by OIM™ for carabiners A and B.

of the crystal direction aligned with the grain elongation was performed for carabiner C. The results are shown in the form of an inverse pole figure, where the sample direction is the elongation direction of the individual grains (Figure 5). While there is a tendency for the elongation axis of the grains to be aligned with the $\langle 110 \rangle$ crystal direction, it is a weak correlation. The alignment of $\langle 111 \rangle$ crystal directions with the normal direction of the sample is much more pronounced.

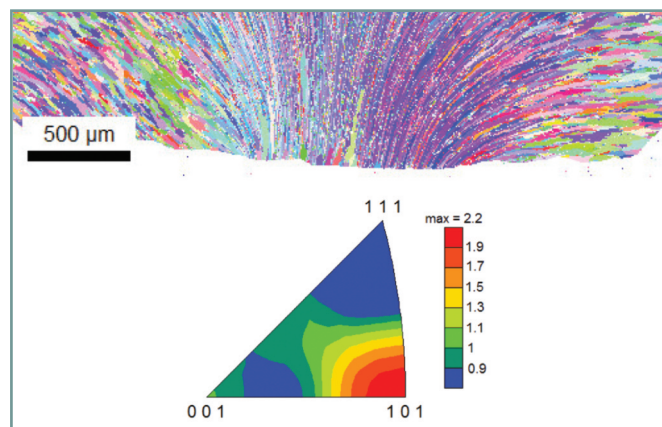


Figure 5. Grain elongation axis orientation map and accompanying inverse pole figure.

The flow field over the entire carabiner cross-section is shown in Figure 6 for carabiner D. This map is a montage of 1600 beam scans stitched together. The total number of orientation measurements in the scan is 3.2 million points.

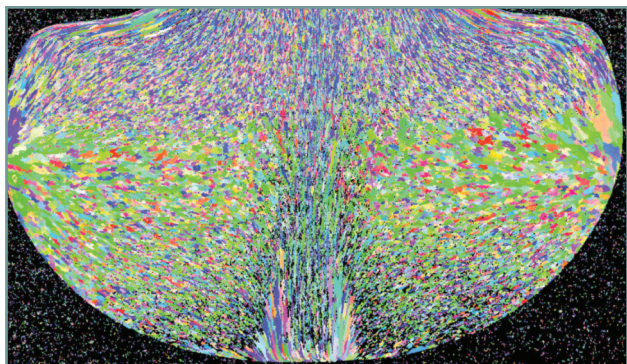


Figure 6. Orientation map of carabiner D.

Conclusions

OIM™ is an excellent tool for characterizing polycrystalline microstructures. It is well suited for exploring the deformation/recrystallization state of the material. Examining the spatial distribution of orientation also gives helpful information that can be used to understand the flow of material during the forging process.