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# Experimental Investigation of Sub-Surface Deformation using EBSD in Single Crystal Aluminum during Orthogonal Micromachining

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Single crystal metals are used in a variety of industries including aerospace, medical technology and optics. In many situations, machining is required to form the crystal into desired dimensions. Numerous studies have confirmed that machining response such as machining forces [1-5] and surface roughness [4,6] strongly depend on the crystallographic orientation. These operations deform the surface beneath the cut, thereby altering the mechanical properties of the material at the surface. Therefore, the subsurface damage created by the machining of single crystals requires thorough analysis.

Recently, Kota et al. [2] used electron backscatter diffraction (EBSD) to show that the deformation depth was approximately equal to the cutting depth for aluminum single crystal. To gain a thorough understanding of this sub-surface damage, we machine a single crystal sample at the micro-scale along multiple crystallographic orientations and compare the extent of damage caused by it. This fundamental knowledge from single crystal experiments can be used to understand/predict the behavior of coarse-grained crystals while micromachining.

The work-piece used in these experiments is a [111] zone axis, single crystal aluminum in the form of a disk with 25.4 mm diameter and 1.8 mm thickness. A microtome was modified to create an orthogonal planning setup which was used to cut the sample along eight different crystallographic orientations as shown in Figure 1. The sample was machined with a 0° rake single crystal diamond tool at a cutting speed of 40 mm/s with 40 μm depth-of-cut. A Kistler 9256C2 3-axis dynamometer was used to record forces in three mutually perpendicular directions. Figure 2 displays the forces encountered while machining along one of the orientations. We can observe that all three force components are fairly consistent over the cutting length of the sample.

After machining, the sample was mounted in a conductive epoxy to facilitate mechanical polishing for EBSD analysis. Orientation imaging microscopy (OIM) was used to analyze sub-surface damage caused by machining. Figure 3 shows the result from the OIM analysis for one of the orientations. To start with, the out-of-plane orientation of the sample was [111], depicted in blue color. We can see the gradual change in the color from blue to green as we move towards the edge (from top to bottom of the image). This color change implies the extent of lattice rotation. Based on measured distortions by OIM, a quantified depth-of-deformation is estimated around 25 μm from the edge (bottom of the image) of the sample. Different cut orientations exhibit different machining forces as well as different extents of subsurface damage. These trends are described with respect to the aluminum single crystal orientation, in particular slip planes and anisotropic elastic properties.

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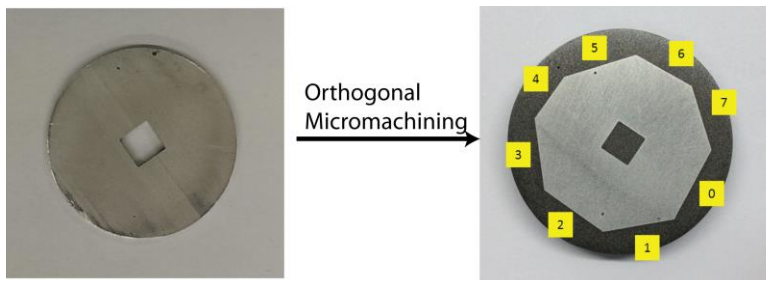


**Figure 1.** Aluminum single crystal: raw sample (left) and micro-machined sample (right) along eight different crystallographic orientations

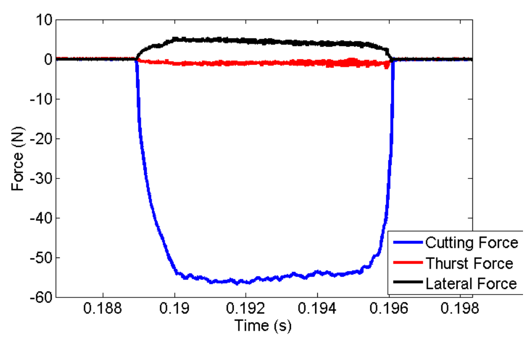


**Figure 2.** Cutting forces shown along three mutually perpendicular directions while machining single crystal aluminum for one of the eight crystallographic orientations

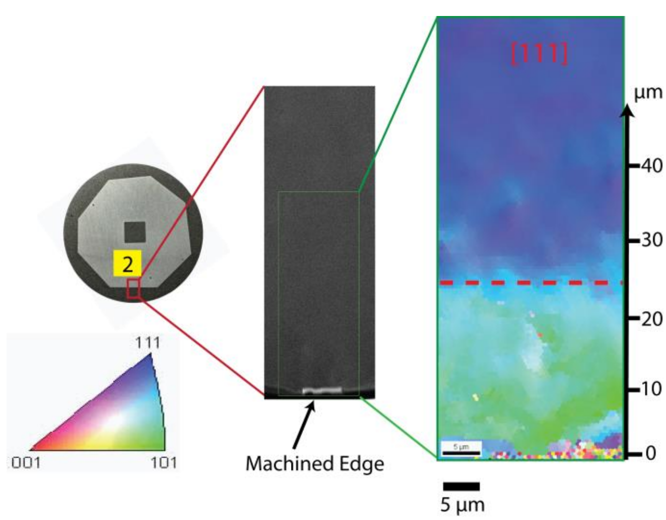


**Figure 3.** OIM map for one of the machined edges depicting the depth of sub-surface deformation and lattice rotation

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