Corrosion of Anodized Aluminum on a Precision Saw
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INTRODUCTION
Shortly after the opening of the college, the Olin College Materials Science lab purchased an Allied Techcut 5 Precision Sectioning machine. After several years of use, the saw was taken out of service and replaced due to an extraordinary amount of corrosion on a number of the surfaces of the saw.

The saw is primarily constructed of black anodized aluminum, machined and sheet parts. Steel fasteners and a stainless steel coolant reservoir are also present. From specifications, the coolant used in the machine is known to be very slightly basic.

Severe corrosion was observed on two aluminum support blocks which hold the screen in the coolant reservoir (Figure 1). These blocks lost almost half of their mass due to corrosion during the saw’s lifetime (Figure 2). Furthermore, there was a significant quantity of buildup of corrosion products in the reservoir (Figure 3).

Figure 1: Buildup of corrosion products in stainless steel coolant reservoir
Less severe degradation of the anodized layer was observed on many of the sheet surfaces (Figure 4) and machined parts, especially in the vicinity of holes near the heads of fasteners (Figure 5).
Figure 4: Corrosion on anodized aluminum surface

Figure 5: Corrosion in vicinity of a threaded hole
METHODS & RESULTS
A variety of experimental techniques were used to analyze the saw corrosion.

Composition Analysis
Energy dispersive x-ray spectrometry (EDS) was used to determine the chemical composition of the base aluminum alloy and the corroded specimen. Multiple tests were taken and the results were processed to ignore carbon and the noble gases. Results (Table 1) show an unusual amount of copper in the corroded region and the presence of small quantities of additional elements. Furthermore, the percentages of aluminum and magnesium were greatly reduced in the corroded region.
An x-ray map was generated across a corroded region of the anodized specimen (Figure 7). The map highlights increases in aluminum, magnesium and silicon in the corroded region and decreases in nickel and sulfur. This makes sense because as the anodize layer is dissolved, the elements below poke through. Notable however is the substantial increase in copper, which is not an alloying element, in the corroded region.

Table 1: Chemical composition of base metal and corroded region (% mass)

<table>
<thead>
<tr>
<th></th>
<th>Base Metal</th>
<th>Anodize Layer</th>
<th>Corroded Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>98.02%</td>
<td>78.25%</td>
<td>76.06%</td>
</tr>
<tr>
<td>Mg</td>
<td>0.39%</td>
<td>0.06%</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>1.29%</td>
<td>3.02%</td>
<td>5.14%</td>
</tr>
<tr>
<td>Fe</td>
<td>0.30%</td>
<td>1.21%</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td></td>
<td>1.07%</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td></td>
<td>0.75%</td>
<td>1.33%</td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td></td>
<td>13.15%</td>
</tr>
<tr>
<td>Zn</td>
<td></td>
<td></td>
<td>1.10%</td>
</tr>
<tr>
<td>S</td>
<td>2.27%</td>
<td>0.87%</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
<td>15.70%</td>
<td></td>
</tr>
</tbody>
</table>
Anodize Layer Consistency
Using scanning electron microscopy (SEM), we compared the anodize layer from the saw sample to a control sample from an anodized bicycle part (AVID BB7 Disk Brake Caliper) in order to determine whether the anodize layer failed due to it’s thickness or other fault. It was observed that the anodize layer on the saw’s parts was approximately twice as thick as that on the bicycle part (20 um vs 10um). Both layers exhibited numerous small cracks, voids and inconsistencies in the layer (Figure 8).
Furthermore, energy dispersive x-ray spectrometry of the cross-section of the anodize layer showed incredible consistency across samples. The section features an increased concentration in oxygen and sulfur and a decreased concentration of magnesium and aluminum (Figure 9).

DISCUSSION
While tests were inconclusive, it is expected that cutting fluid, when mixed with remnants from cut materials, produced an electrolytic environment. Initial tests of the pH of the cutting fluid placed it at a slightly basic pH of 8, but this was clean cutting fluid not diluted in water and without any contaminant in it. Testing the pH of the water used to dilute the cutting fluid showed it to be slightly basic with a pH of 7.7. Research indicated that machine coolant typically has a pH of 8.5 to 9, making it slightly basic. Note that the cutting fluid tested was similar but was not actually taken from the saw.

In general, an aluminum oxide film is effective at protecting aluminum from corrosion over a pH range of about 4 to 9 but there are exceptions and solutions outside this range can attack the coating. One exception can be where the surface of the material is mostly protected by the anodize but localized damaged spots in the anodize layer start localized corrosion. Once the corrosion begins, it can easily spread.

**Around Fasteners**
Corrosion was seen around almost all of the aluminum areas touched by the steel fastener heads. Scrape marks at each fastener head site suggest that the anodize layer was scraped off or otherwise physically damaged by the tightening of the screw against the layer. One corrosion site is shown in Figure 3.

It is suspected that galvanic corrosion occurred at these sites. Galvanic corrosion occurs when two dissimilar metals are placed in contact with one another and the potential difference produces electron flow between them. In galvanic corrosion, the more reactive metal loses electrons to the solution through the less reactive metal.

In the case of the saw, the reactive aluminum acted as an anode and was eaten by the more cathodic steel at regions where the two were in contact. The magnesium in the aluminum alloy likely also was eaten by the cathodic steel. This was enabled by the scratches in the anodize layer around the head of the bolt.

**Presence of Copper**
The composition analysis of the sample revealed strikingly high concentrations of copper in the heavily corroded regions of the part. Because copper is much more cathodic than aluminum, it is possible that copper particles from materials cut on the saw came in contact with the aluminum and caused severe galvanic corrosion by metal deposition. This was likely enabled by cracks in the anodize layer around sharp curvature or due to scratches and external damage.

Another possibility is that the copper observed was originally present in the aluminum alloy of the saw and was left behind as the aluminum and magnesium were dissolved. This would also
explain the slightly increased concentration of silicon in the corroded region. However, because no copper was measured in the base metal and due to the extremely high concentrations in the corroded regions, this is unlikely.

Anodize Layer Porosity
The anodized aluminum cutting bed was severely damaged by corrosion, showing splotchy craters across its surface (Figure 6). Meant to provide additional durability and protection from corrosion, the anodize layer quickly failed, presumably developing many small nicks and cracks which allowed the corrosive environment to work on the aluminum beneath. Corrosion quickly spread from these faults in the anodize layer, exacerbated by the galvanic influence of steel parts and fasteners strewn across the cutting bed. This failure led us to inspect the anodize layer to determine whether it was poorly applied or otherwise weak.

Microscopy of the anodize layer of the saw part showed a number of small cracks, voids and inconsistencies which could have potentially allowed the coolant solution and caused corrosive effects. However, it is notable that the porosity of the anodize layer on the saw was similar to that of the reference part and the thickness was greater.

Although it is possible that the harsh environment combined with the porosity of the layer could have significantly contributed to the corrosion, it is more likely that the corrosion began at areas where the layer was compromised by scratches or external damage.

Coolant Reservoir
Rapid corrosion of aluminum parts holding the screen in the coolant reservoir was likely caused by the electrolytic environment and the extremely high cathode to anode area ratio. The failing parts lost almost half their initial mass and are shown in their final state in Figure 2.

Once the conductive environment was established, the large surface area of the cathodic stainless steel drastically increased the corrosion reaction’s surface area, and caused the rapid degradation of the aluminum parts. The aluminum parts were likely anodized to reduce the rate of corrosive damage, but the protective layer was either damaged or otherwise ineffective.

This behavior is reminiscent of the strategy of anodic protection in which a relatively small anode can be used to protect a larger cathode from corrosion. This approach may have been employed here to protect the more expensive stainless steel tray with a small amount of sacrificial aluminum.

CONCLUSIONS
We attribute the saw’s failure to three sources: basic cutting fluid, an insufficiently tough anodize layer, and poor material choice. The cutting fluid mixed with the slightly basic water produced an environment conducive to corrosion of the aluminum, which wouldn’t have been an issue had the anodize layer not been too fragile. Unfortunately, the anodize allowed the aluminum beneath to contact the electrolytic environment through nicks and around fasteners, producing corrosion. In a redesign, a thicker hard anodize layer may have more effectively protected the aluminum. Once started, the corrosion was hurried along by galvanic interactions with steel components and the copper remains of materials cut. Had the fasteners used been coated to mask their cathodic presence or been made of a material with a similar galvanic potential to aluminum, the corrosion would likely have proceeded at a much reduced rate. All in all, no individual flaw was enough to render the saw unusable so quickly but the combination present did so handily.

References


