Preparation of Cast Aluminum-Silicon Alloys

By: George Vander Voort

Introduction

Aluminum and its alloys are characterized by light weight, a good strength-to-weight ratio, excellent corrosion resistance, ease of fabrication, and reasonable cost. Their strength can be increased by alloying, cold working and by precipitation hardening. Cast and wrought aluminum alloys are produced in a wide range of forms. This TECH-NOTES describes preparation procedures for cast aluminum-silicon alloys which are experiencing increased usage by the automotive industry.

Three Al-Si alloys were chosen for this study. They contained 7.15, 11.82 and 19.85% Si plus minor levels of Cu, Fe, Mg, Ti and Zn (the Al-7.15% Si alloy contained 0.32% Mg, all other elements were at incidental levels). They were taken from relatively thin-walled castings, none being more than 12mm (0.5 inch) thick. These three alloys represent hypoeutectic (7.15% Si), near eutectic (11.82% Si), and hypereutectic (19.85% Si) compositions and present a variety of preparation problems for the metallographer. The Al-7.15% silicon alloy contained a noticeable amount of shrinkage cavities, while the other two contained only a negligible amount. The large primary Si particles in the hypereutectic alloy can be fractured during cutting and grinding and presented a relief control problem.

Traditional Approach

Thirty years ago, when I was a novice metallographer, I would have prepared aluminum specimens using a procedure very similar to that shown in Table 1. The specimens would be ground through the usual sequence of silicon carbide (SiC) papers, polished with one or two diamond abrasive steps, and final polished with a magnesium oxide slurry. Although this procedure was performed manually, “by hand”, it can be automated.

A series of five SiC papers, 120 to 600grit (ANSI/CAMI), were used to grind the specimens [six 1¼in (30mm) diameter specimens placed in a holder] using water as the coolant/lubricant. Next, two steps of polishing using diamond paste were employed followed by 1μm magnesium oxide (MgO) in a thick aqueous slurry on a RAYVEL® cloth. “Kitten Ear” cloths were popular 30 years ago for preparing aluminum alloys but is no longer available.

Wet MgO forms carbonates which produce scratches. After use, the polishing cloth must be thoroughly washed, treated with a dilute (1:1) aqueous HCl solution, and stored in this solution, so that magnesium carbonate does not form on the cloth. If it did form, the contaminated cloth would scratch specimens. For most metals and alloys, 0.3μm alpha alumina and 0.05μm gamma alumina aqueous suspensions were used for final polishing; but, these are considered less useful for aluminum and its alloys. Vibratory polishing devices are also commonly used for final polishing aluminum alloys. Samuels [1] advocated adding a sodium hydrogen phosphate-citric acid buffer solution or a solution of (2 parts) propylene glycol and (1 part) water to the MgO abrasive to prevent carbonation when using a vibratory polisher. These additions provided a complexing action which prevents carbonate formation. Copper or copper-based alloys, such as bronze, should not be used for polishing wheel platens, as an undesirable galvanic reaction occurs with Cu plating out on the specimens. Hence, aluminum alloys or stainless steel alloys are generally used for the platens.

Figures 1a, b and c show the microstructures of the three alloys after traditional preparation (Table 1) followed by etching with aqueous 0.5% HF. While the microstructure is clearly visible, and is probably of adequate quality for production evaluations, they certainly are far from perfect. First, SiC particles can be observed embedded in the matrix, particularly in the Al-19.85% Si specimen, Figure 1c. Also, it is clear that damage from some of the preparation steps is still present. Relief around the primary Si particles (Figure 1c) is
evident but not too excessive. This experiment showed that SiC particles can become embedded in aluminum alloys. In general, this problem varies with alloy composition and usually arises with the finer grit size papers.

Contemporary Methods

Fortunately, alternate procedures and materials are available to correctly prepare aluminum alloys, and with fewer steps. The first five-step procedures which produce excellent, publication-quality results. Four and three-step procedures will be illustrated later. But, as the procedure is shortened, preparation quality will be compromised.

Table 1. Traditional Preparation Procedures

<table>
<thead>
<tr>
<th>Step</th>
<th>Surface/ Abrasive</th>
<th>RPM</th>
<th>Direction</th>
<th>Load</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120grit SiC*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>U.P.</td>
</tr>
<tr>
<td>2</td>
<td>240grit SiC*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>1 min.</td>
</tr>
<tr>
<td>3</td>
<td>320grit SiC*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>1 min.</td>
</tr>
<tr>
<td>4</td>
<td>400grit SiC*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>1 min.</td>
</tr>
<tr>
<td>5</td>
<td>600grit SiC*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>1 min.</td>
</tr>
<tr>
<td>6</td>
<td>6μm METADI Diamond Paste on Billiard**</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>2 min.</td>
</tr>
<tr>
<td>7</td>
<td>1μm METADI Diamond Paste on MICROCL CLOTH**</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>2 min.</td>
</tr>
<tr>
<td>8</td>
<td>MgO on a RAYVEL Cloth</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>2 min.</td>
</tr>
</tbody>
</table>

Notes: Load – per specimen
Comp. – Specimen holder and platen rotate in same direction
U.P. – until plane
* Water used as coolant
** METADI Fluid used as coolant/lubricant

Table 2. Five-Step Contemporary Procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Surface/ Abrasive</th>
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<th>Direction</th>
<th>Load</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30μm Resinbonded ULTRA-PREP Diamond Disc*</td>
<td>300</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>U.P.</td>
</tr>
<tr>
<td>2</td>
<td>9μm METADI Paste on ULTRA-PAD Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>5 min.</td>
</tr>
<tr>
<td>3</td>
<td>3μm METADI Paste on TRIDENT Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>3 min.</td>
</tr>
<tr>
<td>4</td>
<td>1μm METADI Paste on TRIDENT Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>5 lb [22N]</td>
<td>2 min.</td>
</tr>
<tr>
<td>5</td>
<td>MASTERMET on CHEMOMET I Cloth</td>
<td>150</td>
<td>Contra</td>
<td>5 lb [22N]</td>
<td>1.5 min.</td>
</tr>
</tbody>
</table>

Notes: Load – per specimen
Comp. – Specimen holder and platen rotate in same direction
Contra – Specimen holder and platen rotate in opposite direction
U.P. – until plane
* Water used as coolant
** METADI Fluid used as coolant/lubricant

Figure 2. Results from a five-step practice (Table 2) with contra rotation for steps 2-5 showing good results for the (a) Al - 7.15% Si and the (b) Al - 11.82% Si specimens but poorer results for (c and d) the Al - 19.85% Si specimen (200x, 0.5% HF etch, d as-polished).

Figure 3. Excellent relief control and freedom from damage to the primary Si particles (Al-19.85% Si) when complementary rotation is used for step 2 (200x, 0.5% HF etch).

It is possible to substitute other surfaces for the planar grinding step (step 1). For example, PLANARMET™ AL 120grit Al2O3 waterproof paper can be used in Step 1 with excellent results. Likewise, it is possible to use SiC paper for step 1. For step 5, both MASTERTEX® and MICROCL CLOTH® polishing pads were substituted for the CHEMOMET® cloth and results remained excellent.

Four-Step Practices

Developing a four-step procedure that produces publication-quality micrographs is more difficult, but it can be done for these alloys. The approach used is to minimize damage in sectioning and at the planar grinding step. The simplest procedure is to use 240grit SiC...
Table 3. Four-Step Contemporary Procedure

<table>
<thead>
<tr>
<th>Step</th>
<th>Surface/ Abrasive</th>
<th>RPM</th>
<th>Direction</th>
<th>Load</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>240-grit CARBIMET SiC paper*</td>
<td>300</td>
<td>Comp.</td>
<td>5lb [22N]</td>
<td>U.P.</td>
</tr>
<tr>
<td>2</td>
<td>9μm METADI Paste on ULTRA-PAD Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>9lb [40N]</td>
<td>5min.</td>
</tr>
<tr>
<td>3</td>
<td>3μm METADI Paste on TRIDENT Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>8lb [36N]</td>
<td>3min.</td>
</tr>
<tr>
<td>4</td>
<td>MASTERMET on CHEMOMET I Cloth</td>
<td>150</td>
<td>Contra</td>
<td>7lb [31N]</td>
<td>2min.</td>
</tr>
</tbody>
</table>

Notes: Load – per specimen  
Comp. – Specimen holder and platen rotate in same direction  
Contra – Specimen holder and platen rotate in opposite direction  
U.P. – until plane  
* Water used as coolant  
** METADI Fluid used as coolant/lubricant

Table 3 presents a four-step procedure for these alloys. While ULTRA-POL™ (silk) is listed as the preferred cloth for step 2, ULTRA-PAD™ and Nylon cloth may also be used with equal success. In a four-step procedure, it is even more important to use complementary rotation in step 2, otherwise relief around the primary Si particles in the Al-19.85% hypereutectic alloy will be excessive, Figure 4. This is not a problem for the other two lower silicon alloys, and may not be a problem for most aluminum alloys. In this example, an ULTRA-POL cloth was used for step 2. When complementary rotation is used for step 2, with the ULTRAPOL cloth, results are excellent, as shown in Figures 5a-c. Results with the ULTRA-PAD cloth were also excellent. Nylon also produced equivalent results and can be used for either steps 2 or 3. For step 4, MASTERTEX or MICROCLOTH surfaces were tried and found to yield similar quality results.

Three-Step Practices

In a three-step process, steps 1 and 2 will be basically the same as for the four-step process. Again, cutting damage must be kept to an absolute minimum if such a short procedure is to be successful. Extra thin abrasive blades, such as the ACU-THIN™ blades, or wafering blades on a precision saw, may be the best choice for cutting to minimize damage. If possible, use 320grit SiC for step 1. Step 2, as shown before, must use complementary rotation for the hypereutectic alloy. For other alloys, either rotation direction can be used. This is a variable the user must evaluate for the alloy compositions being prepared. Step 3 is the most difficult one in a three-step process. The logical choice is to use 1μm diamond, as it would be too big a step to use colloidal silica (which has a low removal rate). The surface choice for the 1μm diamond is critical. A napless cloth will give good flatness and a good removal rate but the surface will exhibit scratches and pull outs. A medium-nap cloth is needed to reduce the scratch level, minimize pull outs and other damage, yet not create excessive relief.

Because three-step procedures using diamond suspensions to prepare Al-Si alloys have been published, an experiment was tried using this procedure. Due to our experience with embedding of diamond abrasive particles in aluminum alloys, especially relatively pure aluminum alloys using suspensions, only paste had been used in the initial experiments.

The specimens were prepared using 240grit SiC for the first step and 9- and 1-μm diamond suspensions for the second and third steps. While the quality of the preparation was acceptable, the specimen surfaces were heavily embedded with diamond abrasive, see Figures 6a-c. The diamond particles are actually easier to see in the unetched condition. However, they are still clearly visible after etching and generally observed in the primary alpha. They are also present in the alpha-Si eutectic, but less noticeable after etching. This experiment was performed using competitive materials and it was repeated using our diamond suspensions and cloths with similar results. However, when a 9μm polycrystalline diamond slurry, METADI® SUPREME, was used for step 2 of the procedure shown in Table 4, with 1μm METADI paste for step 3, diamond embedment was not observed. This suggests that embedment is mainly a problem with fine diamond particles. Consequently, diamond paste rather than a suspension is recommended, especially for the 1μm diamond step, for these alloys and for pure aluminum and dilute alloys.

Table 4 shows the three-step procedure that we developed for these alloys. Our initial results, using only 1μm diamond paste in step 3, produced surfaces of lesser quality than obtained with either 4- or 5-step practices, as might be expected. The shrinkage cavities in the Al-7.15% Si alloy were not developed as clearly and crisply as with larger practices. Scratches were visible but were not excessive. Some smearing of the alpha phase could be observed in the dendrites and some “comet-tail” like streaks could be seen in the eutectic in
Figure 7. But, for production work, these results may be satisfactory. Consequently, we decided to charge the cloth with 1μm diamond paste, wet it with METADI Fluid, and then add MASTERMET® colloidal silica to the cloth during polishing. This dual-abrasive procedure, which we have used successfully in the past on certain materials, worked superbly, yielding the results shown in Figures 8a-c.

Table 3. Four-Step Contemporary Procedure

<table>
<thead>
<tr>
<th>Step</th>
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<th>RPM</th>
<th>Direction</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>240-grit CARBIMET SiC paper*</td>
<td>300</td>
<td>Comp.</td>
<td>5lb [22N]</td>
<td>U.P.</td>
</tr>
<tr>
<td>2</td>
<td>9μm METADI Paste on ULTRA-PAD Cloth**</td>
<td>150</td>
<td>Comp.</td>
<td>9lb [40N]</td>
<td>5min.</td>
</tr>
<tr>
<td>3</td>
<td>1μm METADI Diamond Paste and MASTERMET 2 on MICRO-CLOTH Pad</td>
<td>150</td>
<td>Comp. or Contra</td>
<td>7lb [31N]</td>
<td>3min.</td>
</tr>
</tbody>
</table>

Notes: Load – per specimen
Comp. – Specimen holder and platen rotate in same direction
Contra – Specimen holder and platen rotate in opposite direction
U.P. – until plane
* Water used as coolant
** METADI Fluid used as coolant/lubricant

Other surfaces were tried for steps 2 and 3. Nylon, ULTRA-PAD and TRIDENT™ cloths were tried for step 2 but produced relief around the primary silicon particles in the hypereutectic alloy. This may not be a problem for routine work. The other lower silicon content alloys were prepared acceptably. TEXMET® 1000 was also tried for step 2 and yielded superb flatness with the primary silicon particles but the surfaces were a bit scratchy. This would not be excessive for production work. Both 6- and 3μm diamond abrasives were tried for step 2 but neither produced results as good as with 9μm for step 2. MASTERTEX and CHEMOMET® cloths were tried and both produced excellent results (Figure 9 shows the use of a MASTERTEX cloth in step 3) using the dual abrasive approach.

Conclusions

Cast Al-Si alloys present some interesting challenges for the metallographer. It is necessary to minimize damage during the cutting phase, especially if 3- or 4-step preparation procedures are used. Fine SiC grinding papers should be avoided due to embedding problems. This is not a problem with coarse grit papers. Several different surfaces can be used for planar grinding. Traditional 240grit SiC paper, PLANARMET AL 120grit aluminum oxide paper and 30μm diameter resin-bonded diamond discs all gave excellent results. The 240grit SiC paper has the least life, while the resin-bonded diamond disc gives the longest life. 5-, 4- and 3- step preparation procedures were demonstrated using a variety of surfaces. These contemporary procedures were shown to produce much better results than can be achieved by the traditional 8-step method. Diamond slurries were shown to be prone to embedding problems, chiefly with fine particle sizes. Colloidal silica was shown to be much more effective for final polishing than magnesium oxide. A dual-abrasive procedure was shown to yield superior results as the final step of the 3-step procedure.

Figure 6. Results of a 3-step procedure using competitive 9- and 1-μm diamond suspensions and cloths: a) Al-7.15% Si; b) Al-11.82% Si; and c) Al-19.85% Si (500x, 0.5% HF etch).

Figure 7. Results from a three-step practice using 240-grit SiC paper, 9- and 1-μm diamond pastes showing (a) scratches and smearing around a shrinkage cavity in the Al - 7.15% Si alloy, (b) smearing of alpha dendrites in the Al - 11.82% Si alloy; and, (c) comet-tail like damage on the Al - 19.85% Si alloy (200x, 0.5% HF)

Figure 8. Results of a 3-step procedure using 1μm diamond paste and MASTERMET 2 colloidal silica on a MICRO-CLOTH pad for step 3: a) Al-7.15% Si; b) Al-11.82% Si; and c) Al-19.85% Si (200x, 0.5% HF etch).
**Tech-Tips**

**Question:** I have used colloidal silica and, while it works well, it is difficult to fully clean my specimens. What do you suggest?

**Answer:** To minimize cleaning problems, I stop adding colloidal silica to the cloth about 20 seconds before the end of the cycle. With 10 seconds left, I turn on the water and direct it onto the cloth. Then, it is easy to get the surface clean using running water and cotton.

**Question:** Fine alumina abrasives are widely used for final polishing many metals and alloys. Can they be used for aluminum and its alloys?

**Answer:** MASTERPREP suspension, a 0.05μm gamma-alumina abrasive suspension, was substituted for colloidal silica in the 5-step procedure. The results were quite acceptable for production metallography (see below). Fine polishing scratches could be observed at high magnification. Colloidal silica, however, is clearly superior to alumina for final polishing aluminum and its alloys.

**Question:** Are color etchants useful for studying the microstructure of Al-Si alloys?

**Answer:** These are relatively simple alloys and color is not needed to identify the Si particles. But color etchants will reveal matrix segregation, which decreases as you approach the eutectic composition. Following are micrographs of the hypoeutectic Al-7.15% Si and the hypereutectic Al-19.85% Si specimens etched with Weck’s reagent (100mL water, 4g KMnO4 and 1g NaOH). Color etching did not reveal anything of interest in the near-eutectic Al-11.82% Si alloy.

![Figure 9. Results from a three-step practice using 1μm diamond paste and MASTERMET 2 colloidal silica on a MASTERTEX cloth for step 3: (a) Al - 7.15% Si; (b) Al - 11.82% Si; and, (c) Al - 19.85% Si alloys (200x, 0.5% HF etch).](image1)

**Reference**


![Results from a five-step procedure using MASTERPREP™ alumina suspension on a CHEMOMET cloth for step 5 revealing quite acceptable results: (a) Al-7.15% Si; (b) Al-11.82% Si; and, (c) Al-19.85% Si (200x, 0.5% HF etch).](image2)

A). Al-7.15% Si revealing dendritic structure and associated segregation; B). Al-19.85% Si, note the segregation in the matrix around the primary Si crystals (both at 200x. Weck’s color reagent for aluminum).