Welding A356 Sand Castings

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SCOPE

The intent of this paper is to demonstrate the viability of welding A356 sand castings both before and after heat treatment while maintaining the integrity of the casting.

INTRODUCTION

During production of castings, welding is sometimes used as a cosmetic or structural repair process, or to attach features to the parent casting that could not be cast into the part. The integrity of these welds is often questioned especially if the castings are used in high vacuum or other critical applications. The most prevalent questions posed to the foundry are: is the weld leak proof, does the weld contain porosity, and is the weld material homogenous with the parent casting? To answer these questions, a casting was produced at Palmer Foundry. This casting was then sectioned and machined into weld test plates. The welded areas were then sectioned, polished and analyzed using optical microscopy. The microstructures show that the weld material is as sound as the parent material, the bond between the parent metal and weld is fully fused, and porosities in both welding and interface areas are smaller and less than in the casting substrates.

PROCEDURE

A356.2 alloy was used to cast a 300 lb. vacuum chamber with a 25.4 mm (1") nominal wall thickness (Fig.1). The walls of the casting were sectioned into four sample plates, which were then machined into weld capability test plates per AMS 2694C (Fig. 2). Per the specification, each thickness of the plate had two features milled into it to represent a controlled casting discontinuity. Plates 1 through 4 were solution heat treated. Plate 4 was heat treated “T77” after welding. Plate 5 was prepared without heat treatment in order to see the virgin state of the weld. The order of welding and heat treating operations were varied to simulate a typical casting operation, see Table 1. Welding was performed by an AWS D17.1 certified welder at a Nadcap/FAA certified weld repair facility. The weld was made using the TIG process with an A356 filler rod.

<table>
<thead>
<tr>
<th>Sample Plate</th>
<th>Cast</th>
<th>Welded</th>
<th>Heat Treated (T77 Temper)</th>
<th>Welded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample Preparation and Coding

For each of the six features welded on each test plate, a transverse and a longitudinal cross section was analyzed, see Fig. 3 and 4. The samples (and subsequent images) are coded per Table 2:

<table>
<thead>
<tr>
<th>Digit</th>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sample plate</td>
<td>1-5</td>
</tr>
<tr>
<td>2</td>
<td>Location on sample plate</td>
<td>1 Edge in 1.5 mm section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Slot in 1.5 mm section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 Round depression in 8 mm section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 Trough in 8 mm section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 Trough in 16 mm section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 Edge in 16 mm section</td>
</tr>
<tr>
<td>3</td>
<td>Sample direction</td>
<td>1 Transverse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Longitudinal</td>
</tr>
</tbody>
</table>

Example: Sample 5-5-1 is from plate 5, trough feature in 5/8” section, transverse direction.

Example: Fig. 5: Weld Regions Legend 242 is sample from plate 2, sample plate location 4, sample direction longitudinal.

All samples were mounted in Bakelite, ground, and polished. These samples were all analyzed under optical microscope and stereomicroscope in an as-polished condition. Some selected samples were then slightly etched in 5% HF water solution and analyzed again.
ANALYSIS

When analyzing the samples using an optical microscope under low magnification (50x), it was observed that all welds contained 3 distinct regions. These regions are the substrate or parent material, weld body (filling material), and weld interface or heat affected zone (filling material and substrate) (Fig. 5).

Figure 6 shows complete fusion between the substrate and weld body. This was typical for all weld features prepared on all five plates.

The substrate area (parent A356 alloy), consists mainly of Al dendrites, eutectic Si particles, and small amounts of Fe, Mg, and Cu rich particles.

The weld body consists mostly of fine columnar structures with different sizes and directions. These structures are composed of small Si particles, some small Fe-rich phase (needles), and some other small particles from the A356 filler rod. In the welding body areas one can observe the welding lines and fine columnar structures with different sizes and directions. Discrete porosity can be seen dispersed in the weld body. The observed pores are all less than 0.00254 mm in diameter.

The interface contains large (coarse) Al dendrites with small Si particles in the interdendritical areas. When etched, these particles have a different color from those in the welding body indicating that their compositions are probably slightly different.

The images presented below are from the 8 mm (3/8") and 16 mm (5/8") thick sections of the test plates. These are representative of typical wall thicknesses used in vacuum chambers.

Figures 7 through 9 show the sample plates that were cast, heat treated and welded. They show excellent fusion between the weld and the substrate. Particles seen in Fig. 8 are ostensibly silicon from the parent alloy or weld rod. These particles are fully encapsulated by the weld material, and the weld is seamlessly integrated with the substrate.

Differences in microstructures apparent in Fig. 6, 8, 9, 12, 13, 16 and 17 are due to the compositional difference, cooling rate (differences in the solidification conditions), or both, of the substrate and filler body. While notable, the reasons for the microstructure differences among the substrate, weld body, and interface were not the focus of this paper.

CONCLUSION

The sample welded castings were sectioned and machined into optical specimens at Worcester Polytechnic Institute’s Advanced Casting Research Center (ACRC) where they were prepared and metallographically examined by Libo Wang, Research Professor. This study clearly demonstrates the effectiveness of welding A356 before and after heat treatment. The microstructures examined and studied confirm complete fusion between the weld body and substrate in all of the conditions, thicknesses, and configurations present in the sample castings. This study demonstrates the principle that welding within the process parameters used in this study is a viable method for repairing, filling or modifying sand cast components.

ACKNOWLEDGEMENT

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REFERENCES

AMS 2694C Repair Welding of Aerospace Castings

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The figures presented in this paper are a sample of over one thousand images recorded by WPI while conducting this study. Contact Palmer Foundry for further information about images or the study.
Figure 1: A356.2 Aluminum Casting for Weld Study
Figure 2: A356.2 Aluminum Casting for Weld Study
Dimensions are in millimeters; thickness of plate left to right 16, 8, and 1.5
Figure 3: Welded Features on Test Plates

Figure 4: Coding; 1 - Transverse; 2 - Longitudinal
Figure 5: 242 (see Table 2)
Sample from plate 2, feature location 4, sample direction 2
Sample from plate 2, 4 - trough in 8 mm section, 2 - longitudinal direction
Etched

Figure 6: 542
Sample from plate 5, feature location 4, sample direction 2
Etched
Figure 7: 261
Sample from plate 2, feature location 6, sample direction 1
Etched

Figure 8: 251
Sample from plate 2, feature location 5, sample direction 1
Non-etched
Figure 9: 252
Sample from plate 2, feature location 5, sample direction 2
Non-etched

Figure 10: 461
Sample from plate 4, feature location 6, sample direction 1
Etched
Figure 11: 461
Sample from plate 4, feature location 6, sample direction 1
Etched

Figure 12: 451
Sample from plate 4, feature location 5, sample direction 1
Non-etched
Figure 13: 451
Sample from plate 4, feature location 5, sample direction 1
Non-etched

Figure 14: 561
Sample from plate 5, feature location 6, sample direction 1
Etched
Figure 15: 561
Sample from plate 5, feature location 6, sample direction 1
Etched

Figure 16: 551
Sample from plate 5, feature location 5, sample direction 1
Non-etched
Figure 17: 551
Sample from plate 5, feature location 5, sample direction 1
Non-etched