Busting the Myth

The Corrosion Resistance of Cast vs. Wrought Aluminum for Use in Ocean Engineering

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Abstract— **The pitting and intergranular corrosion of cast aluminum alloy A356 were compared to that of aluminum alloy 6061 to test whether cast aluminum alloys can be used as a substitute for 6061 in select ocean engineering applications. Accelerated corrosion tests were conducted in a salt water and hydrogen peroxide environment at elevated temperature for over six hours. Metallographic samples were then examined for evidence of corrosion. While both aluminum samples showed some evidence of corrosion, there was no substantial difference between the corrosion of the two samples. We conclude that the viable use of certain heat-treatable cast aluminum alloys in a seawater environment has been experimentally verified.**

Keywords-corrosion; aluminum alloys; aluminum casting; marine technology; hull material

I. INTRODUCTION

Aluminum, isolated less than 200 years ago, has a very short history of commercial manufacture [1]. Nonetheless, within this short time frame, aluminum has become prized for use in applications where a high strength to weight ratio is important [2]. It has also come into popular use because of its corrosion resistance due to the protective oxide layer that instantly forms on its surface [3]. However, possibly because of its short lifetime, there are still some misconceptions about its usefulness. While the corrosion resistant wrought aluminum alloy 6061 has become widely used in specific marine applications, such as in seawater piping and the hulls of submerged vehicles, an equivalent cast alloy, A356, has not.

While in general aluminum is extremely corrosion resistant due to its protective oxide, it is still susceptible to galvanic corrosion. Since most aluminum alloys have alloying elements that form multiple phases in the alloy, galvanic corrosion can happen on a micro-scale. This micro-galvanic coupling is the root cause of both main types of corrosion that aluminum alloys are susceptible to: pitting corrosion and intergranular corrosion [3,1].

Pitting corrosion, the simpler of the two systems, is extremely localized corrosion that occurs in the presence of chlorine ions. The presence of these ions in salt water makes this type of corrosion extremely applicable in a marine environment. Pits are started at scratches or weaknesses in the oxide layer, such as an impurity in the alloy or an intermetallic phase with less of an oxide layer [1,3]. The reaction then proceeds as visualized in Fig. 1.

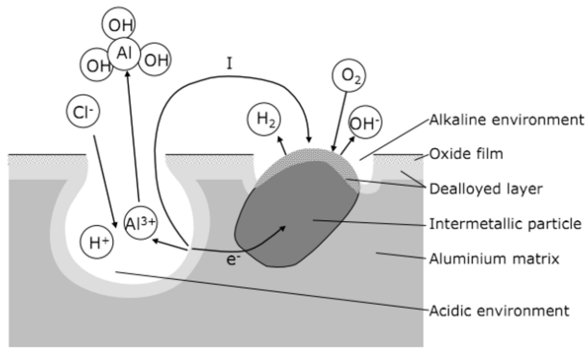

Figure 1. The process of pitting corrosion in aluminum alloys [3].

Intergranular corrosion is a similar process. Intergranular corrosion, selective corrosion of grain boundary regions, is caused by micro-galvanic reactions at grain boundaries. Since grain boundaries are often sites for precipitation, they are concentrations for intermetallic phases and impurities, making them vulnerable to corrosion [2,1].

Both the wrought alloy 6061 and cast alloy A356 are corrosion resistant alloys. However, fear of pitting corrosion in cast alloys has left A356 nearly nonexistent in current marine usage. The goal of this paper is to verify the viable use of this cast alloy in marine applications, especially for use in the hulls of autonomous underwater vehicles (AUVs). The acceptance of this alloy would have far-reaching consequences in terms of offering marine manufacturers a cheaper and easier way to create their products [2].

II. METHODS AND MATERIALS

The two aluminum alloys studied in this comparison were 6061 and A356. The 6061 was T6 plate stock from McMaster and the A356 was casting scrap with T61 heat treatment. Both samples were polished on one face to 600 grit. They were then analyzed following ASTM standard G110-92: Standard Practice for Evaluating Intergranular Corrosion Resistance of Heat-Treatable Aluminum Alloys by Immersion in Sodium Chloride + Hydrogen Peroxide Solution [4].

The samples were immersed for one minute in a heated etching cleaner solution composed of 189 ml of deionized water, 10 ml of 70% nitric acid, and 1 ml of 48% hydrofluoric acid. The samples were then rinsed and immersed for one minute in 70% nitric acid. Finally, both samples were immersed in the accelerated corrosion test solution— 11.4g of

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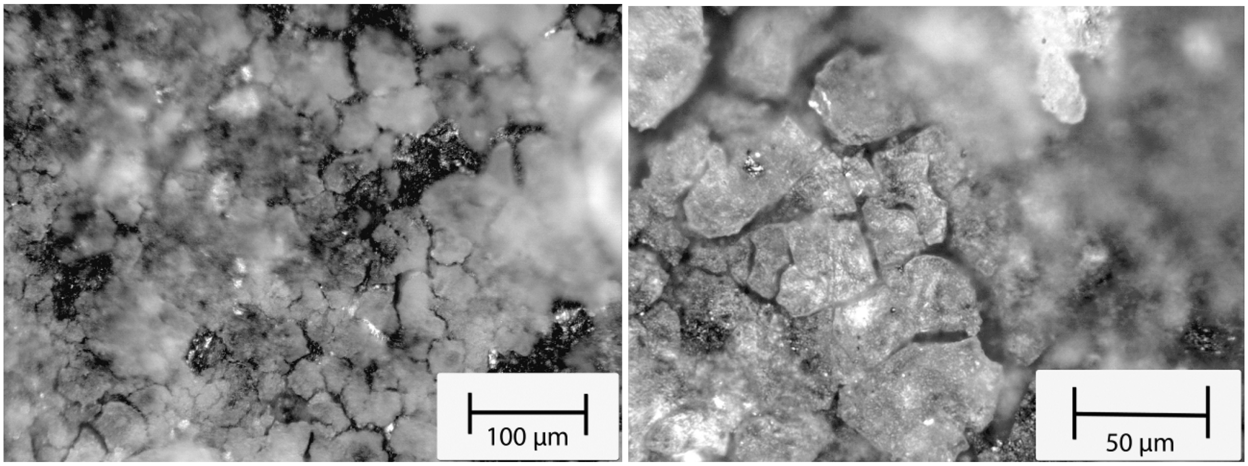

Figure 2. Two images of the nonstandard surface of the A356 test piece. The image on the left is taken at 200x magnification, while the right image is at 400x. In both images, areas of intergranular corrosion (cracking) can be seen, as well as collected aluminum oxide (out of focus).

sodium chloride and 2 ml of 30% hydrogen peroxide diluted with deionized water to 200 ml. The samples in solution were placed into a 30°C incubator for 11 hours. The samples were then rinsed again and the surfaces were preliminarily examined for obvious surface corrosion.

Each sample was then cross-sectioned and embedded in thermo-set resin and polished to a 0.05 micron grit polish before being etched with Keller's metallographic etchant. The samples were then imaged with an optical microscope to assess the degree of intergranular and pitting corrosion.

III. Results and Discussion

For each aluminum sample, three representative images were taken of the extent of corrosion. The first image was of the unmodified original surface of the test piece. This was not a standardized comparison image, as the two samples had quite different surface finishes. The second image was of the standardized surface of each piece that had been ground to a 600 grit for comparison. The final image was a cross section of the test sample used to check for the extent of intergranular corrosion.

A. Nonstandard Test Surfaces

The first images of the nonstandard surfaces showed the greatest extent of corrosion in both samples. In the A356 test piece, the nonstandard surface showed clear evidence of intergranular corrosion, as seen in Fig. 2. The nonstandard surface of the 6061 test piece also showed evidence of intergranular corrosion, though to a lesser extent, as seen in Fig. 3.

While these images provide a good approximation of the corrosion of the test pieces, they cannot be used for comparison, since both test pieces had different surface finishes. Thus, a surface of each test piece was ground to 600 grit and then studied.

B. Standardized Test Surfaces

The test surface of the A356 sample is shown in Fig. 4. The figure shows some evidence of pitting corrosion, but no intergranular corrosion was observed on the test surface.

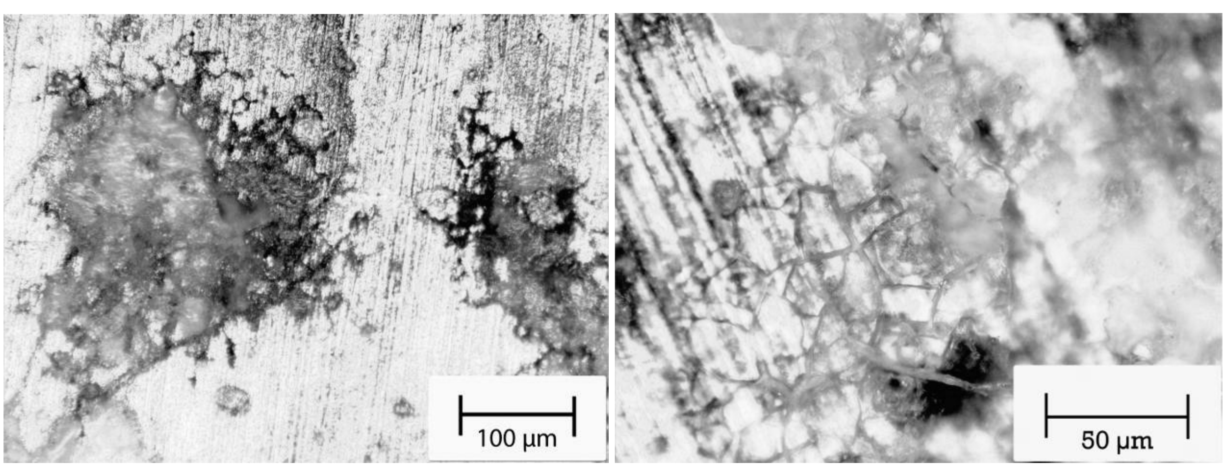

Figure 3. Nonstandard surface of the 6061 test piece. Intergranular corrosion and collected oxide can be seen in both the left (200x) and the right image (500x)

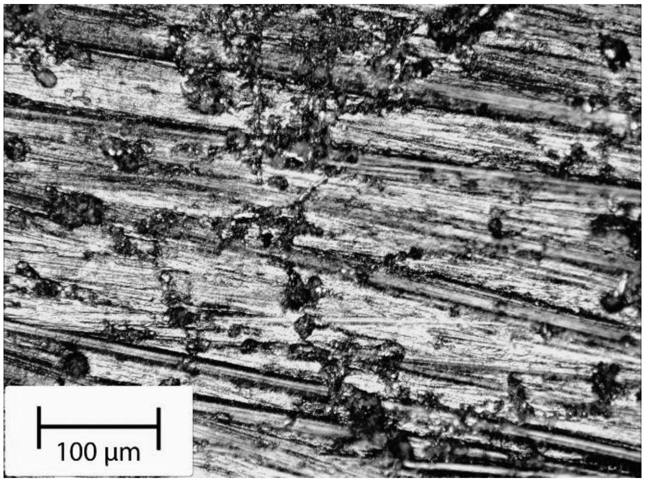

Figure 4. Test surface of A356 sample ground to 600 grit and magnified to 200x. Scratch marks from grinfing can clearly be seen. There is no evidence of intergranular corrosion. However, there are pits in the surface characteristic of pitting corrosion.

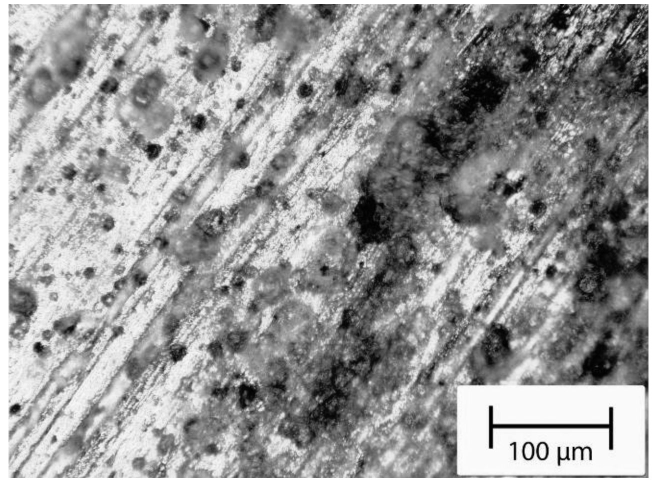

Figure 5. Test surface of 6061 aluminum ground to 600 grit and magnified to 200x. Similar pitting corrosion but lack of obvious intergranular corrosion is observed.

The ground test surface of the 6061 sample shows very similar results in Fig. 5. In the test surface of the 6061 sample, pitting corrosion is observed at a scale similar to that of the A356 test piece. The similarity of the pitting corrosion in the two alloys shows initial positive results that the two are functionally equivalent in terms of corrosion.

C. Cross-section analysis

Each test piece was then cross-sectioned and polished to observe the extent (if any) of intergranular and pitting corrosion in the corroded areas identified by the surface microscopy.

Fig. 6 shows the cross section of the comparison test surface of the A356 sample. No intergranular corrosion was observed in the cross section of the test surface. However, a small amount of pitting corrosion was observed, as seen in the figure. The figure also shows the microstructure of the cast A356 to be a dendritic structure, which is susceptible to pitting corrosion.

Fig. 7 shows the cross section of the comparison test surface of the 6061 alloy sample. While the 6061 sample shows considerably less pitting corrosion than the A356, it shows some intergranular corrosion.

Thus, there is a tradeoff in corrosion types between the two alloys. A356 shows no intergranular corrosion on the test surface, but has non-negligible pitting corrosion. 6061 has much less pitting corrosion, but also suffers from intergranular corrosion. It is helpful in this case to have a quantitative comparison of corrosion depth and breadth of both alloys, as offered in Table 1.

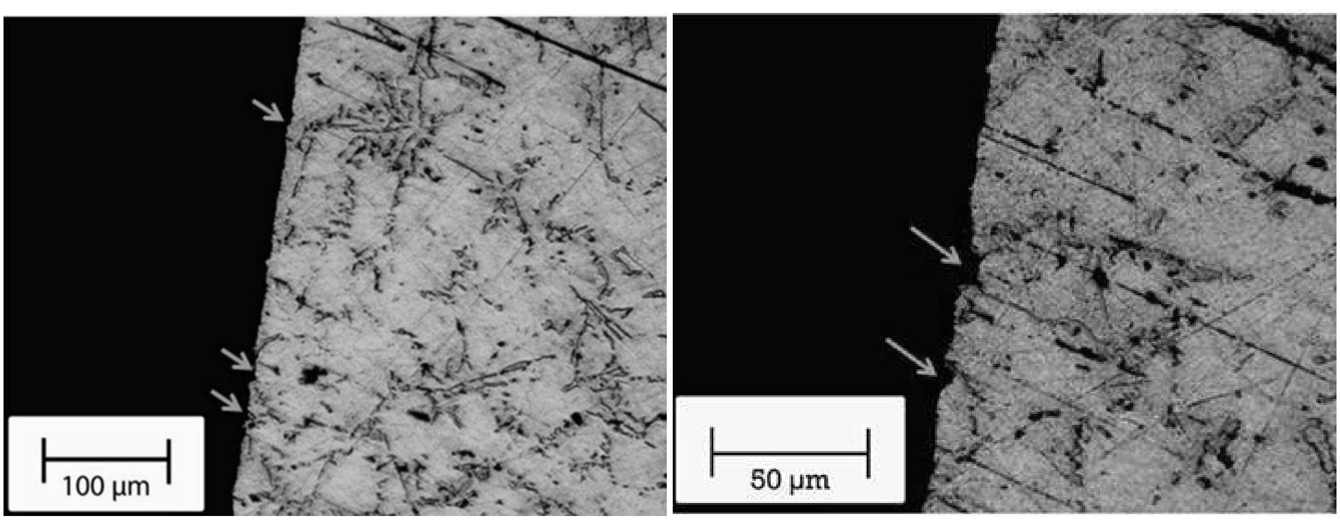

Figure 6. Cross-section of test surface of A356 sample. Image on the left is 200x magnification, and image on the right os 500x magnification. Arrows indicate areas of pitting corrosion on the surface of the aluminum.

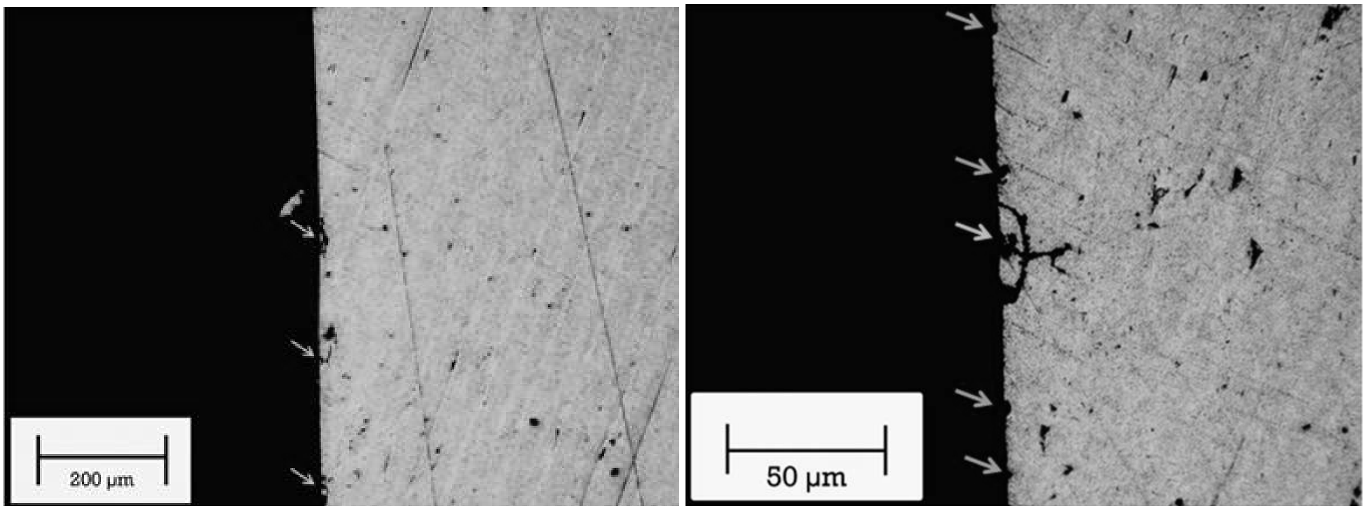

Figure 7. Cross-section of test surface of 6061 aluminum piece. Left image is 100x magnification, right image is 500x magnification. Minimal pitting corrosion is observed with some intergranular corrosion. Right image is a closer view of one of the areas of intergranular corrosion from the left-hand image. Arrows denote areas of both pitting and intergranular corrosion.

This table shows that while the qualitative type of corrosion occurring in the alloys is different, the relative amount is very similar. Thus, A356 is a suitable alloy for most applications where 6061 is used.

This experiment is limited in scope, however. While the findings presented are viable, it would be a useful extension to test the alloys for longer, possibly in an actual saltwater environment for months, rather than an accelerated environment. It is also important to note that while the two alloys are generally equivalent, in an application where the consequences of one type of corrosion are much higher than another, the qualitative difference becomes significant.

IV. Conclusion

The research presented here on the accelerated seawater corrosion of wrought and cast aluminum alloys shows that 6061 and A356 aluminum alloys are functionally equivalent in terms of corrosion. Both pitting and intergranular corrosion were compared with optical microscopy of both the surface and cross section of test faces. Both alloys showed evidence of corrosion after the testing. Alloy 6061 showed intergranular corrosion with very mild pitting, while alloy A356 showed no evidence of intergranular corrosion, but a moderate amount of pitting. Overall, the amount of corrosion of both samples was functionally equivalent. Thus, it was confirmed that there was no substantial difference between the corrosion of the two samples. We conclude that the viable use of certain heat-treatable cast aluminum alloys in a seawater environment has been experimentally verified.

TABLE I. Quantitative Corrosion Comparison

	A356		6061	
	Pitting	***Intergranular***	***Pitting***	***Intergranular***
Depth (μm)	3.5	0.0	2.2	19.6
Breadth (μm)	10.9	0.0	4.5	51.2
Distance Between (μm)	58.4	N/A	42.6	205.1

Acknowledgment

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