Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

Effect of Salt Solution Corrosion on Tensile Properties of Vacuum High Pressure Die Cast A356 Alloy Subjected to Heat Treatment

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Keywords: V-HPDC A356 T4, T6, Corrosion, Porosity

Abstract

Nowadays, vacuum high pressure die casting (V-HPDC) aluminum alloys are increasingly used because of the smooth surfaces and excellent dimensional accuracy of the products. In this study, the effect of corrosion on mechanical properties of V-HPDC Al alloys A356 was investigated. Prior to corrosion testing, the T4 and T6 thermal treatments were applied to the rectangular plates of A356 cast by V-HPDC. The treated V-HPDC plates were subjected to immersion corrosion in 3.5% NaCl solution. The corroded plates were tensile tested. The results of tensile testing indicated that for the T4 treated A356, corrosion had more effect on elongation than strength. However, compare to T4, corrosion has limited effect on tensile properties of T6 conditions. The microstructure analyses suggested that microstructure variation in T4 and T6 treatment should be responsible for the extent of corrosion effect on V-HPDC A356 tensile properties.

Introduction

High pressure die casting usually contains gas porosity mainly due to the entrapment of air or gas in the melt during the very high speed injection of the molten metal into the cavity [1]. The concept of vacuum high die casting (V-HPDC) generally evacuated the cavity during the mould filling process, in that case, the volume of gas porosity and the pore size are significantly reduced. It was pointed out that with the assistance of vacuum during the high pressure die casting process, the density and the mechanical properties are highly improved [1-4].

Alloy A356, like other aluminum alloys, is receiving much deserved attention within the automotive industry due to its high specific strength as a structural metal. These castings are generally heat treated (T4&T5) to obtain the desired combination of strength and ductility [3]. Applying the V-HPDC process on A356 alloys could further increase their industrial applications [1,3,5].

Meanwhile, corrosion is often problematic for aluminum alloys. Since aluminum is most likely to act as anodic during application, its alloys suffer corrosion attack in service environments. However, in the open literature, there is limited work focusing on the corrosion resistance of V-HPDC A356 alloy subjected to heat treatments. The primary microstructure difference between T4 and T6 A356 alloys is the existence of the strengthening precipitates Mg_2Si [3]. It has been pointed out that, the precipitating phase could become a barrier in Al-Mg alloys to prevent the corrosion attack [6]. Hence, the object of this work was to characterize the effect of the T4 and T6 treatments on the corrosion of V-HPDC A356 alloys and their resultant tensile properties.

Experimental Procedure

In order to fulfill the objective of this work, execution of the experiment proceeded in six steps. These include: casting preparation, immersion testing, tensile testing, potentiodynamic testing, microstructure analysis, and the porosity calculatings.

Casting Preparation

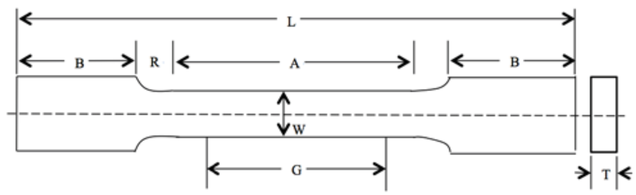
A356 rectangular plates (10 mm x 3 mm x 3mm) made with a vacuum high pressure die casting process were provided by an industrial supplier (Ryobi Die Casting, Inc.). T4 and T6 heat treatments were applied to different casting plates. The chemical composition for the alloy is presented in Table 1 [7].

Table 1: Chemical composition of the investigated alloy (wt. %) [5].

Alloy	Si	Mg	Cu	Fe	Mn	Others
A356	8.00	0.40	0.20	0.15	0.10	<0.15

Immersion Testing

Since it is inconvenient to immerse the whole casting plate into the corrosive liquid, prior to immersion testing, the rectangular plates were water cut into tensile test bars according to the ASTM B557 standard [8], as shown in Figure 1. The gauge length and width of the specimens were to 25mm and 5mm, respectively. Specimens were submerged in 3.5% NaCl solutions both T4 and T6 specimens. The NaCl solutions for immersion corrosion tests were prepared from road salt that is widely used for melting snow during winter season. The adoption of the road salt was intended to simulate the corrosive environment on road. A large volume (10 liters) of the solution was selected to achieve fully immerse of five specimens, and also avoid significantly the pH change during the corrosion process. Since the passive film could protect the surface of the specimen, the immersion system was placed in room temperature for six weeks to observe relatively severe corrosion damage.



G: gage length 25 ± 0.1 mm W: width 6 ± 0.1 mm
T: thickness 3 ± 0.1 mm R: radius of fillet 6 mm
L: overall length 100 mm A: reduced section 32 mm
B: length of grip section 30 mm

Figure 1: Schematic diagram showing a tensile specimen [6].

Tensile Testing

Tensile testing was carried out to evaluate the effect of salt solution corrosion on the mechanical properties of the alloy. After immersion testing, each specimen was polished by grinding paper of grit 320 to avoid stress concentration and cross-section dimensions were measured for tensile testing. The tensile tests were performed at room temperature with a strain rate of 2.00 mm/min. The outputting data, including displacement measured by extensometer and tensile load, were then analyzed. The average 0.2% offset yield (YS) as well as highest observed ultimate tensile strength (UTS) and % elongation (E_f) was also determined for each heat treatment condition.

Potentiodynamic Testing

Potentiodynamic polarization testing was carried out exposing 0.8cm^2 of sample surface area to the electrolytic media. In this case, each sample was tested using 3.5%wt NaCl solutions. Two electrodes were submerged in the electrolytic: a counter electrode, CE, near the sample surface, and a reference electrode, RE, elsewhere in the solution. The set-up shown in Figure 2 describes the system.

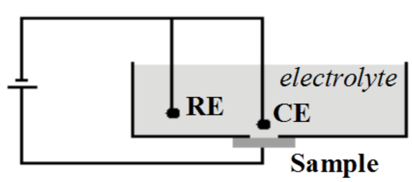


Figure 2: Potentiodynamic testing set-up.

The potentiodynamic polarization testing curves were plotted by EC-Lab® software. The corrosion current density, i_{corr}, which is equal to corrosion rate, was approximated from the curve. Meanwhile, the anodic and cathodic slopes: β_A and β_C were calculated. Equation 1 expresses the determination of the polarization resistance [4].

$$R = \frac{\beta_A \beta_C}{2.303 i_{corr} (\beta_A + \beta_C)} \quad (1)$$

Porosity Percentage Calculation

Casting defects would be the major factor such as porosity that affects the mechanical properties of V-HPDC A356 alloys since stress concentration could occur during tensile testing. To calculate the percentage of porosity inside specimens, an electronic balance and a beaker filled with water were used. The mass of the specimen M_1 was first measured by the balance in the air, then fully immerse the specimen into water and measure the new mass M_2. Equation 2 was used to calculate the density (ρ_1) of the specimens. Note that the density of water (ρ_2) used in this case is *1. 000 g/cm^3*.

$$\rho_1 = \frac{M_1 \rho_2}{M_1 - M_2} \quad (2)$$

With the density of the specimen, using Equation 3, the porosity percentage of specimens was calculated. Note that the standard density of A356 alloy using in this case is *2.685 g/cm^3* [9].

$$wt\% = \frac{\rho - \rho_1}{\rho_1} \quad (3)$$

Results and Discussion

Tensile Testing Result

Figure 3 and 4 show the representative stress-strain curves for each of the heat treatment condition studied. The curves show that under tensile loading, the alloy deformed elastically first. Then, once the yield point reached, plastic deformation of the alloy set in. It is obvious that the UTS, YS and E_f of the uncorroded specimens are slightly higher than the corrosion tested samples. The data shows the effect of corrosion on tensile properties of V-HPDC A356 alloy is shown in Table 2.

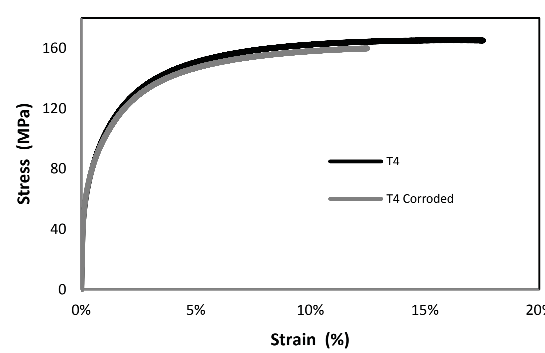


Figure 3: Engineering Stress-Strain curves for A356-T4 with/without corrosion test.

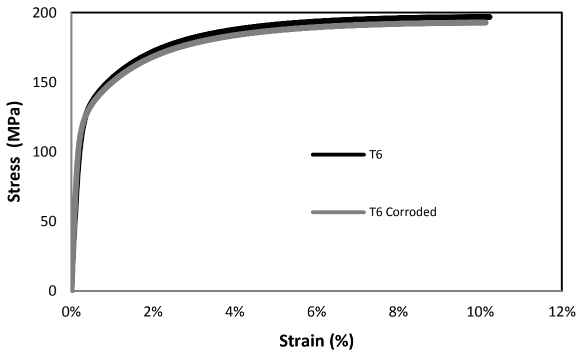


Figure 4: Engineering Stress-Strain curves for A356-T6 with/without corrosion test.

Table 2: Variation of Tensile Properties with Corrosion Testing

Condition	YS (MPa)	UTS (MPa)	E_f (%)
T4	82.4 ± 2.3	164.8 ± 0.7	17.55 ± 0.5
T4 Corroded	78.6 ± 0.3	159.1 ± 2.6	13.42 ± 1.5
T6	134.4 ± 1.7	198.6 ± 0.9	10.13 ± 0.5
T6 Corroded	128.0 ± 1.3	191.2 ± 1.7	9.90 ± 0.8

It can be seen from the data that the corrosion had relatively higher effect on the tensile properties of the T4 alloy than those under the T6 condition, especially on the elongation properties. The average elongation of T4 corroded specimens was 13.42%, which results a decrease of 30.8% over the uncorroded samples.

Meanwhile, in the T6 condition, the data shows that the corrosion had very limited affect on the tensile properties, the decrease of YS, UTS and E_f were only 5%, 4% and 2%, respectively comparing to the uncorroded samples. The difference in tensile properties from different heat treatment conditions should be attributed to the fine microstructure and massive well-dispersed intermetallics.

Potentiodynamic Polarization Result

The difference in corrosion behavior between the T4 and T6 A356 alloys are illustrated in Figure 5. The current density (i_{corr}) and polarization resistance (R_p) obtained by Tafel calculations are listed in Table 1. Comparing the results between the T4 and T6 alloys, the polarization curves for T6 alloys shifted to higher current densities. As shown in the table, the T6 alloy (1.38 uA/cm^2) has a lower current value comparing to T4 alloy (1.46uA/cm^2). Meanwhile T6 has a corrosion resistance R_p marginally higher than that of T4 specimen

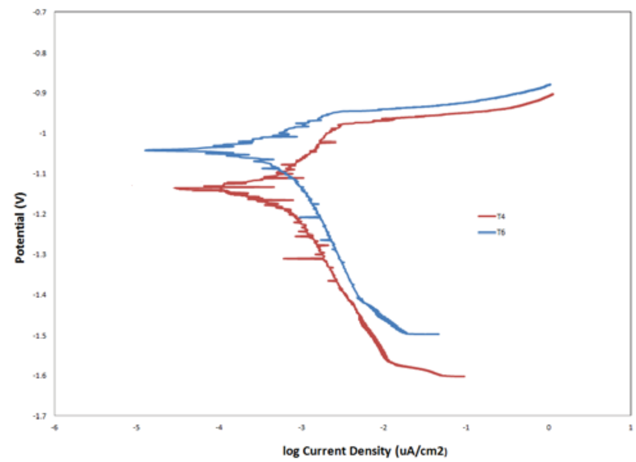


Figure 5: Potentiodynamic Polarization Curves for T4 and T6 alloys.

Table 3: Polarization curve characteristics and polarization resistance

Sample	E_{corr} (mV)	i_{corr} (uA/cm^2)	β_A (mV)	β_C (mV)	R ($k\Omega \cdot cm^2$)
T4	1040	1.38	76.5	99.3	13.6
T6	1142	1.46	72.3	98.5	12.4

The outcome of corrosion testing combining with the tensile testing results further suggest that salt solution corrosion has minor effect on the tensile properties of A356-T6 alloys than A356-T4 alloys.

It has been reported [6] that the fine microstructure and massive well-dispersed intermetallic should be responsible for the enhanced corrosion resistance. Further investigations in microstructure characteristics are to be carried out to reveal corrosion mechanism resulting from different heat treatment schemes.

Porosity Percentage Calculation

The porosity percentages of as-cast, T4 and T6 alloys before and after immersion testing are given in Table 4 and Figure 6. It can be seen that the as-cast alloy has the lowest porosity percentage, which is 0.34%. After the heat treatment processes, the porosity levels rose. The expansion of pores in the alloy due to the application of high temperatures during heat treatment should be responsible for an increase in porosity. The porosity percentages of T4 and T6 alloys increased to 0.60% and 0.63%, respectively. The porosity problem became more severe after the immersion testing. This might be attributed to the fact that the influx of salt solution into porous regions in the alloy could corrode pores for further damage during immersion testing. As a result, the porosity percentages increased to 0.81% and 0.82% for T4 and T6 conditions, respectively.

Table 4: Porosity Percentage of A356 Alloys

Condition	Avg. Density (g/cm^3)	Porosity Percentage
As Cast	2.683 ± 0.007	0.34% ± 0.14%
T4	2.669 ± 0.002	0.60% ± 0.32%
T6	2.668 ± 0.009	0.63% ± 0.45%
Corroded T4	2.663 ± 0.011	0.81% ± 0.27
Corroded T6	2.663 ± 0.009	0.82% ± 0.18

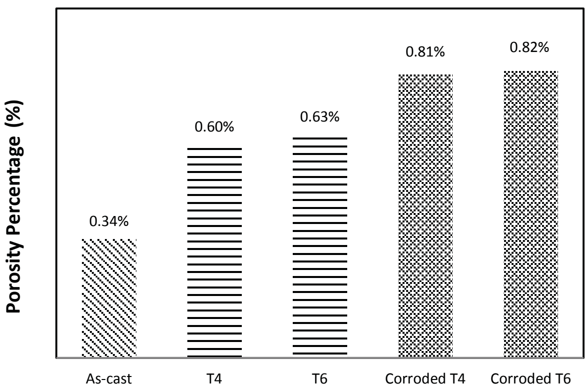


Figure 6: Porosity percentage of each heat treatment condition.

The porosity measurements indicate that the heat treatment process had certain effect on porosity level. But, there is no significant difference in porosity levels between T4 and T6 conditions despite of the porosity increase. This observation implies that the porosity might have limited influence on the corrosion resistance of T4 and T6 specimens.

Conclusions

1. The corrosion had relatively higher effect on the tensile properties of the T4 alloy than those under the T6 condition, especially on the elongation properties. The average elongation of T4 corroded specimens was 13.42%, which results a decrease of 30.8% over the uncorroded samples.
2. In the T6 condition, the data shows that the corrosion had very limited affect on the tensile properties, the decrease of YS, UTS and E_f were only 5%, 4% and 2%, respectively comparing to the uncorroded samples.
3. The difference in tensile properties from different heat treatment conditions should be attributed to the fine microstructure and massive well-dispersed intermetallics
4. T6 has a corrosion resistance R_p marginally higher than that of T4 specimen. Salt solution corrosion has minor effect on the tensile properties of A356-T6 alloys than A356-T4 alloys.
5. Porosity has limited influence on the difference of corrosion resistance for A356 T4 and T6 specimens.. .

Acknowledgements

The authors would like to thank the National Science and Engineering Research Council of Canada (NSERC), Ryobi Die Casting (USA) Inc, and University of Windsor for supporting this work.

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