

Fusion Welding of Vacuum High Pressure Die Cast Aluminum Alloy A356 and Wrought Alloy 6061

Meng Wang and Henry Hu
Univ. of Windsor

ABSTRACT

Recently, joining of cast aluminum components with wrought and/or cast similar metals becomes an urgent task for the auto industry to develop light-weight complex and large-scale chassis and body structures for further reduction in vehicle weight. In this study, fusion-joining of vacuum high pressure die cast (VHPDC) alloy A356 subjected to T5 heat treatment and wrought alloy 6061 with the Gas Metal Arc Welding (GMAW-MIG) process was experimented in an effort to understand the effect of the MIG process on the microstructure development and tensile behaviors of the base alloys (T5 A356 and 6061), Heat Affected Zone (HAZ) and Fusion Zone (filler metal ER4043). The results of tensile testing indicated that the ultimate tensile strength (UTS), yield strength (YS) and elongation (E_f) of VHPDC T5 A356 were relatively high, compared to both wrought alloy 6061 and the filler metal (ER 4043). The microstructure analysis showed that the improvement in the tensile properties of T5 A356 should be mainly attributed to the minimized porosity content, the presence of strengthening intermetallic phases and fine grain structure, which resulted from the combined effects of the applied manufacturing processes, i.e., the VHPDC, T5 heat treatment and MIG welding.

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INTRODUCTION

High pressure die casting as a new core of expertise in automotive development, becomes very popular and cost-effective for mass production of metal components. Among the 150 kg aluminum usage in each vehicle in 2009, almost 35% of automotive Al components were manufactured by conventional high pressure die-casting (C-HPDC), which is one of the most cost-effective processes compared to other casting processes (permanent mould and sand casting) [1, 2, 3]. Recently, joining of cast Al components with wrought and/or cast similar metals becomes a necessity for the auto industry to reduce the weight of vehicles. However, the process often produces casting defects, such as gas porosity in castings which is mainly caused by high velocity turbulence injection of molten and liquid metal into the die cavity. The presence of gas porosity adversely affects mechanical properties of the cast components, such as strengths and ductility. The entrapped defects limit cost-effective joining of C-HPDC Al components. A vacuum system in high pressure die casting is thus an essential technology to extract gases from die cavities and runner systems during casting. Therefore, new high vacuum (V-HPDC) process, advances the die casting process and makes it more competitive for mass production of structural

automotive components with enhanced properties and significantly reduced number of defects[2, 3].

To develop light-weight complex and large-scale chassis and body structures for automobiles, joining of cast Al components with wrought and/or cast similar metals is often considered a good strategy for design engineers, which enables them to take advantages of different manufacturing processes such as casting, extrusion and forming. Up to now, most studies on joining cast Al alloys [4,5] have been focused on friction stirring welding of the Al components made by relatively costly casting processes such as permanent mold, and squeeze casting, which contains low amount of porosity in materials. Relatively expensive friction stir welding has been attempted on joining C-HPDC Al alloy ADC 12 despite of its high cost. Meanwhile, fusion welding of C-HPDC Al alloys is difficult due to the formation of blowholes by entrapped gases and the presence of brittle intermetallic in the weld metal [6]. V-HPDC as an emerging technology minimizes the entrapment of porosity, which could improve mechanical properties and engineering performance of welded die cast aluminum alloys [7, 8, 9]. However, work on applying fusion welding processes to join vacuum high pressure die cast aluminum alloys is very limited.

The present study was carried out to investigate the mechanical properties of vacuum high pressure die cast aluminum alloy A356 subjected to a T5 treatment joined to wrought alloy 6061 by using the Gas Metal Arc Welding (GMAW - MIG) welding method. The optical and electron scanning microscopies (SEM) was applied to analyze the microstructure of the welded alloys. The mechanical properties of the alloys were determined by tensile testing. The fracture behavior of the joined alloys was analyzed by fractography using the SEM. The mechanism responsible for the resulted tensile and fracture behaviors were discussed based on the optical and SEM microstructural characterization.

EXPERIMENTAL PROCEDURE

Materials

The two base alloys selected for this study were V-HPDC alloy A356 and wrought alloy 6061. The nominal chemical compositions of alloys A356 and 6061 are listed in [Table 1](#). The A356 alloy was vacuum high pressure die cast in the shape of a plate with the dimensions of 300 mm long, 100 mm wide and 4 mm thick. The cast plates were also subjected to a stress relief treatment (5) at 220°C for two hours and air cooled to investigate the effect of solution treatment on mechanical properties of the vacuum die cast A356. To facilitate the welding of the cast plates and the selected wrought alloy, commercially-available 4-mm thick 6061 was sectioned into rectangular plates with the same dimensions as the cast ones as shown in [Figure 1](#).

Gas Metal Arc Welding (GMAW)

A Lincoln® Electric power wave 300 welder with semiautomatic wire feeding system was employed for welding operation. The applied filler alloy, ER4303, of which chemical composition was given in [Table 2](#), was selected due to its composition similarity to A356. The shielding gas of Argon was applied during welding with a gas flow rate of 25 L/min. The welding speed was set at 8.6 mm/s.

Table 1. Chemical composition of the investigated alloys (wt. %)

Alloy	Si	Mg	Mn	Cu	Zn
A356	7	0.3	0.1	0.2	0.1
6061	0.6	1.0	0.15	0.32	0.25

Table 2. Chemical composition of the filler alloy (wt. %)

Filler Alloy	Si	Mg	Mn	Cu	Zn
ER 4043	5.0	0.05	0.05	0.3	0.1

Tensile Test

The welded plates were perpendicularly marked along the welding bead. The marked plates as shown in [Figure 1](#), were sectioned to prepare specimens for testing and analyses.

Subsized flat tensile specimens were machined out of -cast samples and welded plates according to ASTM standard B557. Using the Instron 30KN Tensile Test Machine, Model 8562 equipped with a data acquisition system, the specimens were tested at room temperature. The load cell and test speed were set up at 10KN and 2 mm/min. The output data, including the displacement measured by extensometer, and tensile load, were analyzed. The ultimate tensile strength (UTS), 2% offset yield strength (YS) and elongation (EI%) were determined for all tested specimens based on the average of five tests.

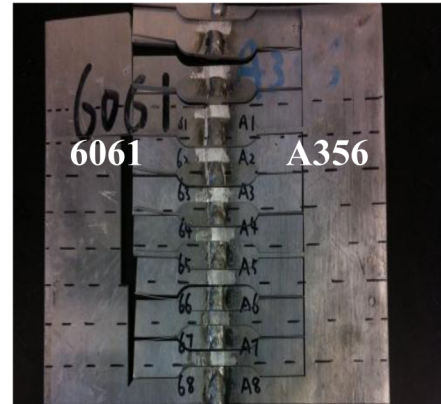


Figure 1. Welded plate of the vacuum high pressure die cast A356/T5 and wrought alloy 6061

Microstructure Analysis

The specimens were prepared following the procedure, including: sectioning, mounting, grinding and polishing. First of all, the specimens were grounded using 240, 320, 400 and 600 grit silicon carbide papers and polished using 0.5μm and 1μm Al₂O₃ suspension. The etchant used was sodium hydroxide solution (5ml NaOH and 95ml ethanol). After etching the specimens for 45s, the detailed microstructure changes were observed by using optical microscopy and scanning electron microscopy (SEM), equipped with an energy dispersive x-ray (EDX) system for elemental analysis.

RESULTS AND DISCUSSION

Tensile Properties

The typical engineering stress-strain curves of the T5 heat treated A356 and the welded T5 A356/6061 are shown in [Figure 2](#). [Table 3](#) summarized the average tensile properties and fracture location of the T5 heat treated A356 and the welded samples of A356/T5 with wrought alloy 6061 from 5 specimens.

It can be seen that T5-A356 had the average UTS and YS of 286.3MPa, 192.6MPa, respectively. They were higher than the welded 6061, of which the UTS and YS were 220.1MPa, 127.5MPa respectively. As such, the fracture of the joined T5-A356/6061 took place in wrought alloy 6061 due to its