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The Influence of Heat Treatments for Laser Welded Semi Solid Metal Cast A356 Alloy on the Fracture Mode of Tensile Specimens

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Abstract. The CSIR rheo-process was used to prepare the aluminium A356 SSM slurries and thereafter plates (4x80x100 mm^3) were cast using a 50 Ton Edgewick HPDC machine. Plates in the as cast, T4 and T6 heat treatment conditions which had passed radiography were then butt laser welded. It was found that the pre-weld as cast, T4 and post-weld T4 heat treated specimens fractured in the base metal. However, the pre-weld T6 heat treated specimens were found to have fractured in the heat affected zone (HAZ).

Introduction

Aluminium alloys are widely used in the automobile and aerospace industries, owing to their lightweight, excellent formability and forgeability [1]. The most commonly used cast alloys are, A356 and A319 because they are important for many automotive components, such as suspension, driveline, and engine parts, where increased durability and reliability are always desirable [2, 5]. The presence of relatively high density of the Al-Si eutectic phase increases the fluidity of the A356 alloy [3]. This makes the A356 alloy an excellent casting alloy. CSIR Rheo-process involves the preparation of semi solid metal (SSM) slurry direct from molten metal by stirring and cooling [4]. The laminar filling characteristic of SSM HPDC makes it an effective technology for producing components with low porosity [5]. Hence, SSM HPDC components have good weldability. Inherently, welding of aluminium alloys poses some defects such as a lack of penetration, porosity and blowholes, liquidation and solidification cracking, loss of alloying elements and reduced mechanical properties [1, 6]. However, the combination of low heat input, low welding distortion and high speed offered by laser welding reduces defects which are normally evident during welding of aluminium alloys [1, 6]. There have been a number of reported studies on the laser welding of wrought aluminium alloys. However, not much work has investigated the laser welding of cast aluminium alloys. One of the characteristic tensile behaviour of the casting A356 and A357 alloys is that they do not neck [7]. Therefore, the general failure of Al-7Si-Mg alloys occur in three stages [8, 9]: starting with nucleation, growth and coalescence of microcracks. The tensile properties depend strongly on the porosity levels, the size of the microstructure and heat treatment. There is not much research documented on the effect of the different heat treatments on the fracture mode of laser welded semi solid cast Al-Si-Mg alloys. This paper presents the influence of the different heat treatment conditions on the failure of Nd: YAG laser welded semi solid cast A356 alloy.

Experimental procedure

The chemical composition of the melt was analysed using the ARL Quantris Emission Spectrometer and the composition corrected where necessary. The CSIR-rheo process was used to prepare the aluminium A356 SSM slurries. Thereafter plates (4X80X100 mm^3) were cast using a 50 Ton Edgewick HPDC machine whilst the chemical composition of the castings was monitored throughout the process. Plates in the as cast, T4 and T6 heat treatment (HT) conditions which had passed radiography were then butt laser welded using a 4kW Rofin Sinar DY 044 Nd: YAG laser. The T4 heat treated samples were solution treated at 540°C for 6 hrs, quenched in water at room temperature and naturally aged for 6 days. While the T6 heat treated samples were solution treated at 540°C for 6 hrs, quenched in water at room temperature and artificially aged at 160°C for 6 hrs. The laser welding was conducted with the following parameters: power of 4.4kW, beam focused on to the workpiece by a lens of 200 mm focal length, twin spot separation of 0.4 mm and drag angle of 15°. A shielding gas of composition He 70 Ar 30 was used. The weld quality was investigated with radiography. The metallographic samples were prepared and analysed under the optical microscope after etching with 0.5 % HF solution. Tensile specimens were machined from the as cast and heat treated plates. The Instron tensile testing machine was used to measure the tensile properties for welded as-cast, welded T4 and T6, and post-weld T4 and T6 samples. The samples for fractography were sectioned from the fractured tensile specimens and polished. The fracture surfaces were analysed using the scanning electron microscope (SEM).

Results and Discussions

The results presented and discussed in this section are from the samples welded under the following HT conditions: as cast, pre-weld T4 and T6. However, for the scope of this paper, the effect of the chemical composition of the base metal and the variation of process parameters on the weld quality was not investigated.

Chemical composition. Illustrated in table 1 is the chemical composition for the virgin material, base metal and weld metal. From table 1, it must be emphasised that there was no significant difference between the chemical composition of both the weld and base metal. However, there was a slight loss of the volatile alloying elements (e.g. Mg and Sr) in the weld metal due to high temperatures at this area.

Table 1. Chemical composition in wt% of the base metal, weld metal and virgin A356 alloy.

Sample	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Sr	Al
A356 Literature Spec[10]	6.5 - 7.5	0.2 max.	0.20 max.	0.10 max.	0.25 - 0.45	0.10 max.	0.20 max.	- -	0.30 max	Bal.
Virgin material	7.33	0.13	0.01	0.01	0.35	0.01	0.14	0.01	0.03	91.98
Base Metal	7.22	0.12	0.01	0.01	0.28	0.01	0.09	0.01	0.02	92.23
Weld metal	7.19	0.11	0.01	0.01	0.24	0.001	0.07	0.01	0.01	92.35

Microstructure. Fig. 2 illustrates the microstructure of the as cast base metal and weld metal. The base metal consists of α-Al crystals surrounded by fine eutectic phase. This is due to the modification effect of strontium which increases the number of nucleation sites for the eutectic Si. The eutectic structure is the dark region due to the finely distributed Si particles. The weld metal consists of the fine dendrite structure due to high cooling rate [4]. Fig. 3 illustrates the microstructure of the semi solid cast A356 alloy which was pre heat treated to T4 and then welded. The microstructure of weld metal for both the as cast and T4 heat treatment condition were somehow similar. Fig. 3 (a) and 4 (a) resemble similar microstructures for the base metal. Illustrated in Fig.4 is the typical microstructure of the hypoeutectic Al-Si alloy, A356, pre heat treated to T6 and then welded. The clear fine eutectic structure in the as cast condition are indistinguishable under both T4 and T6 HT conditions as a result of spheroidising of the Si phase. The coarsening of the eutectic Si particles confirms the prediction that the temperature at this area is higher than the T6 HT temperature. The spheriodisation of Si particles was also evident in the weld metal under the pre-weld T6 HT condition, Fig.4.

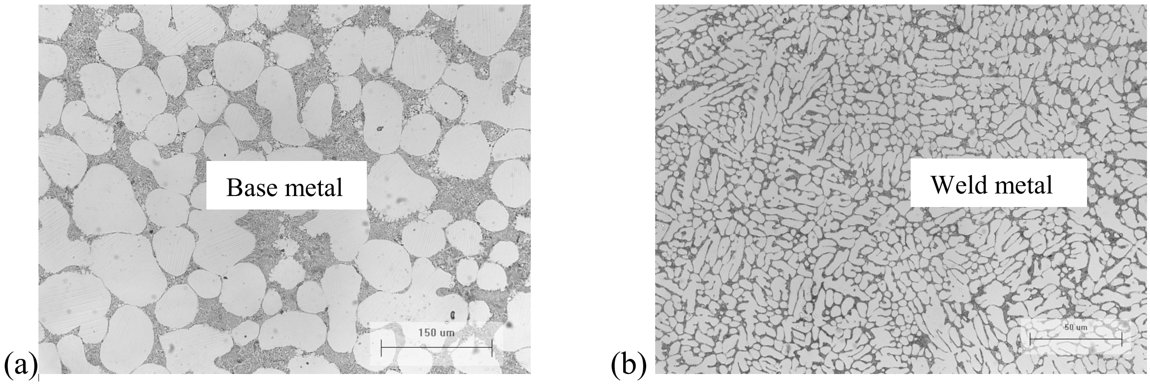


Fig. 2 Microstructure of the as cast SSM A356 alloy (a) base metal and (b) weld metal.

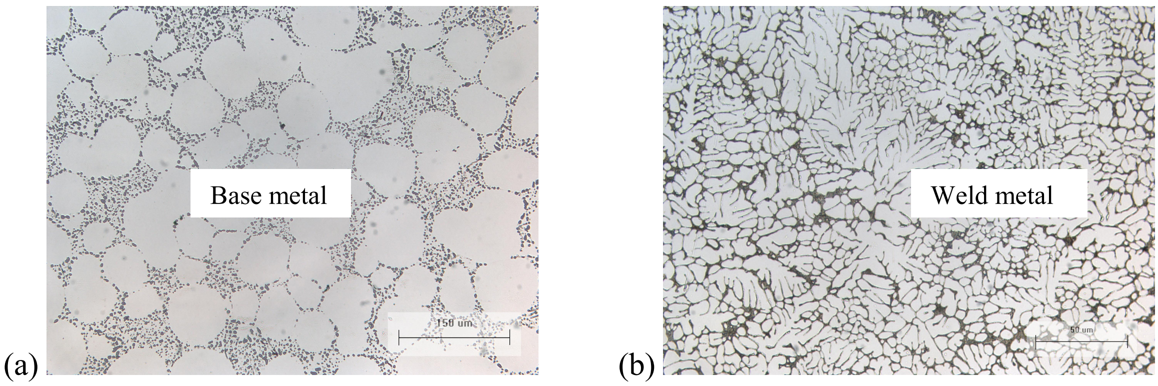


Fig. 3 Microstructure of the pre-weld T4 heat treated SSM A356 alloy (a) base metal and (b) weld metal.

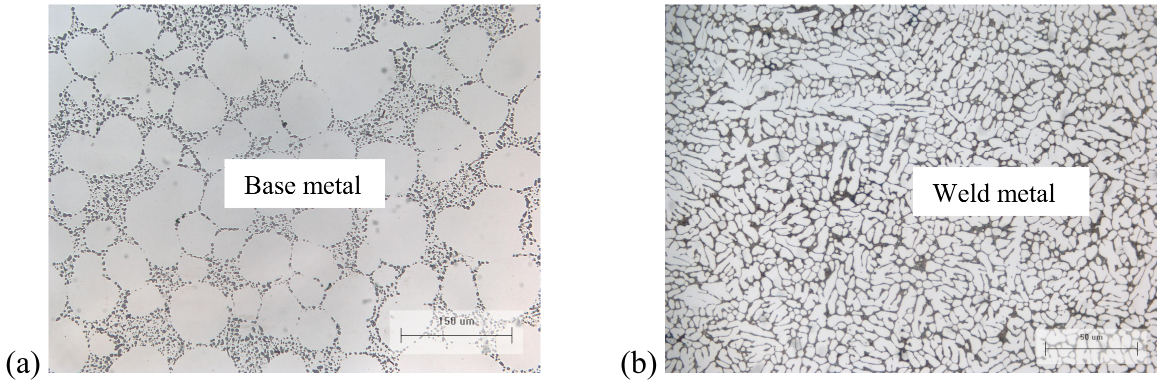


Fig. 4 Microstructure of the pre-weld T6 heat treated SSM A356 alloy (a) base metal and (b) weld metal.

Microhardness measurements. The more detailed analysis on the mechanical properties of laser welded SSM A356 alloy are presented in the separate paper by Ivanchev et. al. The hardness of the weld for both the as cast and pre-weld HT samples, shown in Fig. 5, increases due to fine dendrite structure in the weld metal and due to heat treatment [4].

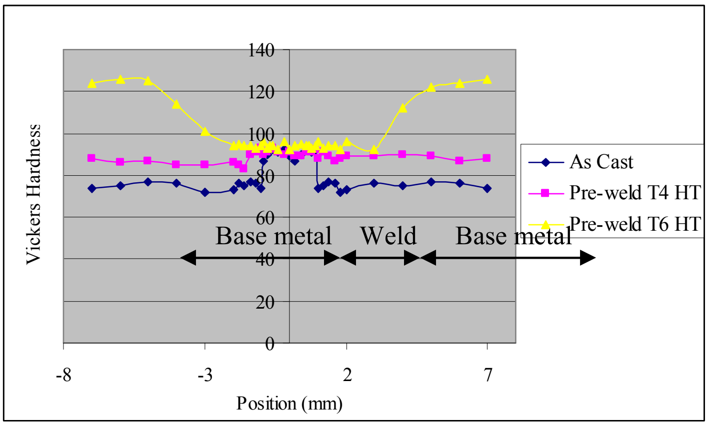


Fig. 5 Microhardness for as cast and heat treated SSM A356 samples across the weld.

Analysis of fracture surfaces. Shown in Fig. 6 is the fracture surface of the as cast tensile sample as observed under the optical microscope. The as cast samples fractured in the base metal. The mode of fracture for the α-Al and the eutectic Al-Si structure was ductile dimple frature. The ductile dimple fracture which was observed after the fracture of the base metal in the as cast tensile specimens is shown in Fig. 6. Shown in Fig. 7 is the fracture surface of the pre-weld T4 HT tensile sample as observed under the optical microscope. The pre-weld T4 HT specimen underwent overageing during welding at the base metal. The overageing effect at the base metal decreases the strength of the base metal. Therefore, the specimens fractured in the base metal because the weld metal was stronger. Shown in Fig. 7 (b) is the fracture surface under SEM investigation from the pre-weld T4 HT samples. Fig 8 illustrates the region of fracture and the mode of fracture for the pre-weld T6 HT samples. After the inspection of the grain structure in the fracture surface, it was also observed that the mode of fracture was ductile dimple fracture. The failure of the pre-weld T6 HT samples at the HAZ is due to additional artificial ageing which is caused by heat conduction from the weld zone. This effect makes the HAZ much weaker than the base metal. The pre-weld T6 HT samples exhibited ductile dimple fracture in both the eutectic Al-Si structure and α-Al pahse. Shown in Fig. 8 (b) is the fracture surface from the pre-weld T6 HT tensile samples. The pre-weld T6 HT samples fractured in the HAZ proving that in this case both the weld metal and the base metal were equally strong. Under all three heat treatment conditions (as cast, pre-weld T4 and T6 HT), it was observed that the fracture mode was of ductile dimple fracture.

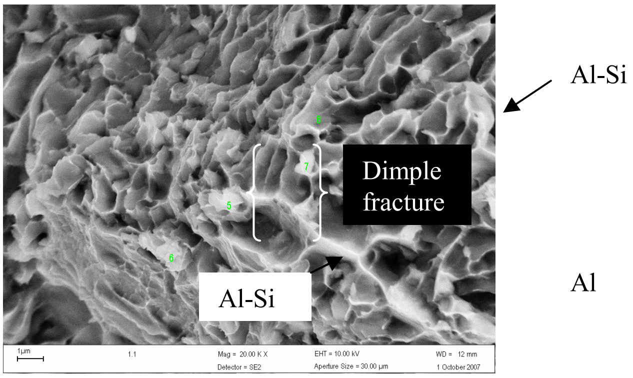


Fig. 6 Fractured surface of the as cast base metal as observed under SEM.

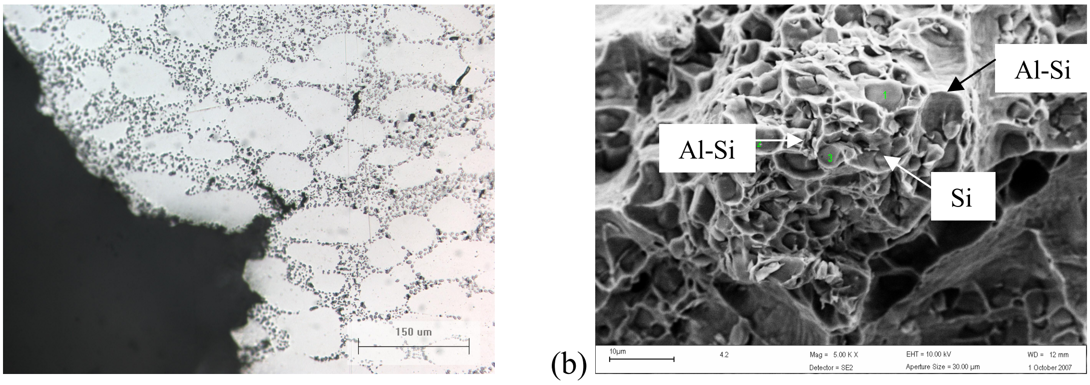
(a) (b)


Fig. 7 Microstructure of laser welded SSM A356 alloy after T4 heat treatment: (a) optical micrograph of the base metal after fracture and (b) SEM of fractured base metal.

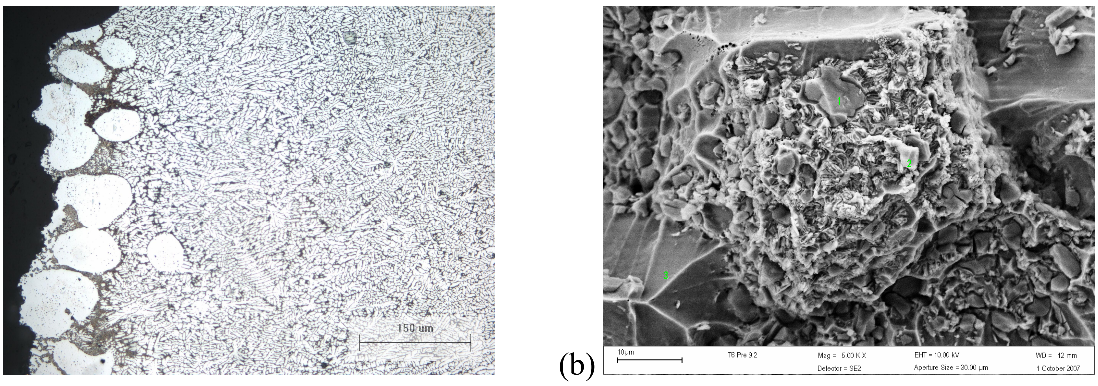
(a) (b)


Fig. 8 Microstructure of laser welded SSM A356 alloy after T6 heat treatment: (a) optical micrograph of HAZ after fracture and (b) SEM of fractured HAZ.

Conclusion

After the T4 and T6 heat treatment conditions, the eutectic Si particles spheroidised and coarsen. The coarsening effect of the Si particles confirms that the temperature at this region is much higher than the T4 and T6 HT temperatures. In addition, the double heat treatment applied to some samples accounts for the low elongation in these samples.

Similarly to the pre-weld T6 HT samples, the mode of fracture for both the as cast and pre-weld T4 HT samples was of ductile dimple fracture. For all the heat treatment conditions, the samples exhibited ductile dimple fracture in both the eutectic phase and the α-Al crystals. Both the as cast and pre-weld T4 HT samples fractured at the base metal which proved that the weld metal was stronger than the base metal. However, the pre-weld T6 HT samples fractured at the HAZ. This is due to the additional artificial ageing experienced by the HAZ, which is caused by heat conduction from the weld zone.

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