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Laser Welding of SSM Cast A356 Aluminium Alloy Processed with CSIR-Rheo Technology

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Abstract. Samples of aluminium alloy A356 were manufactured by Semi Solid Metals HPDC technology, developed recently in CSIR-Pretoria. They were butt welded in as cast conditions using an Nd:YAG laser. The base metal and weld microstructure were presented. The effect of different heat treatments on microstructure and mechanical properties of the welds were investigated. It was found that the fine dendrite structure of the weld metal contributed for equalizing the mechanical properties of the joint.

Introduction

CSIR-Rheo technology is a process which involves the preparation of semi solid metal (SSM) slurry direct from liquid alloys by stirring and cooling [1]. The automobile industries are increasing the use of aluminium alloys because of greater demand of light weight and high strength materials and hence for reduced fuel consumption [2]. Welding of aluminium alloys poses many problems like porosities and cracks in the weld bead [3]. Laser welding is widely used in industrial production owing to the advantages such as low heat input, high welding speed, formability and high production rate etc [4]. Due to unique processing advantages offered by laser, the technique is used to weld SSM aluminium A356. The weldability of this alloy is excellent because of its unique globular structure. The microstructure and mechanical properties of the welds are reported.

Materials & Methods

The SSM A356 aluminium plates (4x80x100 mm^3) were cast in steel moulds with a 50 Ton High Pressure Die Casting machine. The CSIR rheo-process and equipment was applied for the treatment of liquid metal to semi-solid temperature [1]. The welding was performed using a 4 kW Rofin Sinar DY 044 Nd:YAG laser. The beam was focused on to the work piece by a lens of 200 mm focal length. For each weld the specimen was clamped on a fixed table and the beam was moved over the sheet. A mixture of argon and helium gas was used for shielding of the weld. After the welding process, the welded specimen were sectioned, ground and polished. The weld microstructure was observed by optical microscope after etching with Keller's solution. A micro hardness tester was used to measure the hardness.

Heat Treatment. The samples were heat treated to T4 condition (solution treated at 540 °C for 6 hrs then quenched in water and naturally aged for 5 days) and T6 condition (solution treated at 540 °C for 6 hrs then water quenched and artificially aged at 160 °C for 6 hrs).

Results and Discussions

Laser Welding. Welding of SSM A356 aluminium alloy was performed using an Nd:YAG laser. A range of welding parameter was used for the bead on plate welds. Fig. 1 shows the relation between welding speed and depth/ width of the weld. Generally the depth and width decreases as the welding speed is increased.

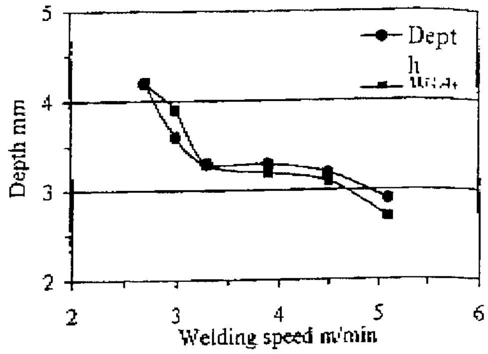
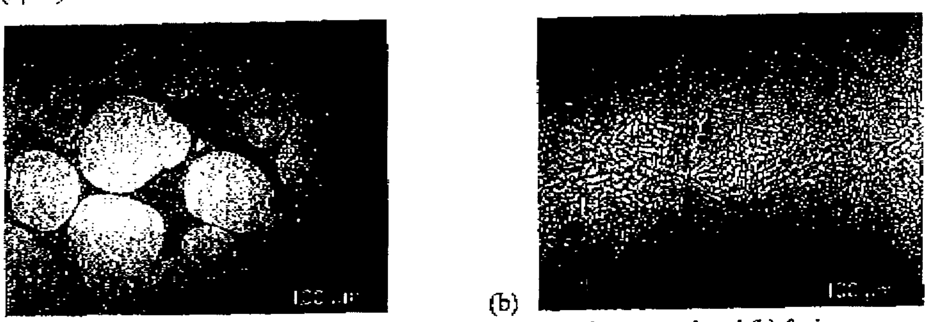


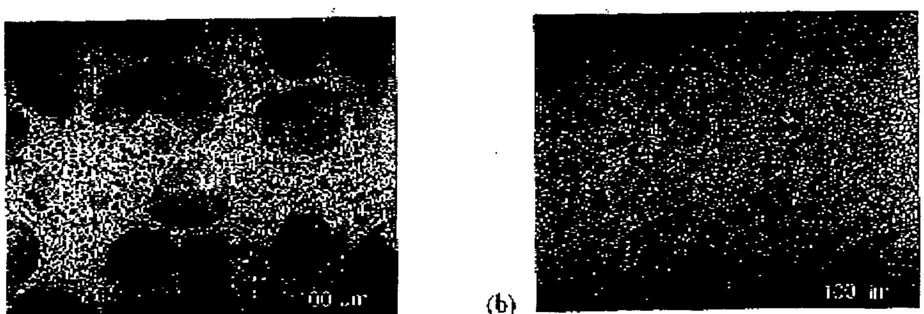
Fig. 1. Relationship between welding speed & depth/ width, SSM aluminium A356, laser power, 4kW, spot separation 0.49 mm.

Microstructure. The microstructure of the as cast SSM base metal and weld fusion zone is shown in Fig. 2. The base metal consists of globular α-Al and a eutectic mixture of Al and Si. The shape of eutectic is elongated and irregular as in a typical eutectic structure. The weld fusion zone consists of finer dendrite structure, due to high cooling rate during solidification. Fig 3 shows the microstructure of the alloy which was pre heat treated (HT) to T6 condition and subsequently welded. The base metal consists of α-Al globule and the Al-Si eutectic with spherodized Si particle as a result of T6 heat treatment [5]. The Si particle size in the base metal was around 4 μm. The fusion zone had a microstructure similar to as cast material, Fig. 2 (b). Fig. 4 shows the microstructure of the alloy which was T6 heat treated after welding. In this case the base metal is similar as in Fig. 3 (a). In the fusion zone, the fine dendrite eutectic structure also converted in to fine globular Si particles uniformly distributed in Al matrix. However, due to very fine eutectic in the fusion zone, the particle size (2μm) of the Si was smaller then in the base metal (4μm).



(a) (b)

Figure 2. Microstructure of as cast SSM A356 aluminium (a) base metal and (b) fusion zone.



(a) (b)

Fig. 3. Microstructure of T6 heat treated A356 aluminium (a) base metal and (b) fusion zone, welded after heat treatment.

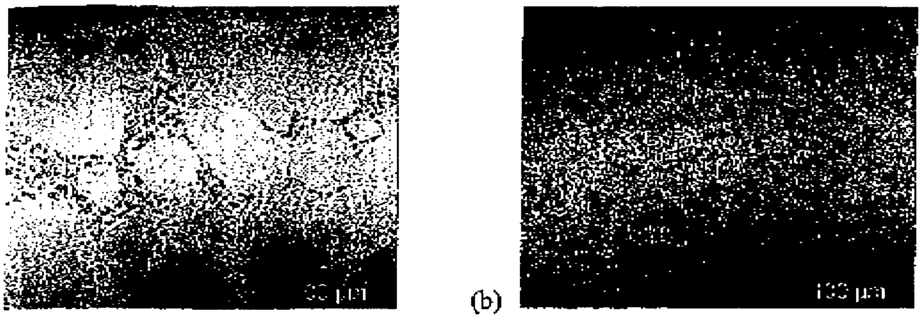


Fig. 4. Microstructure of T6 heat treated A356 aluminium (a) base metal and (b) fusion zone, heat treated after welding.

Hardness Measurements. The micro hardness was measured across the weld with 100g load. The results are shown in Fig. 5. In case of as cast conditions, the base metal shows an average hardness of 70 Hv, while the hardness of the weld metal was 90 Hv. The increase in hardness in the weld metal is attributed to the fine dendrite structure of the weld fusion zone. In the case of welds which were pre heat treated (HT) for T4 and T6, the average hardness of the base metal was 90Hv which was greater than as cast material. This shows an improvement in the hardness as a result of heat treatment. In the fusion zone the average hardness is 95 Hv and the microstructure was similar to the fusion zone of as cast weld, hence the hardness was similar to as cast fusion zone. In case of weld with post HT, T4 and T6 conditions, the welds were also undergone a heat treatment cycle. The average hardness of both base metal and fusion zone in T4 condition was 125 Hv and that for T6 heat treatment was 135 Hv. This means the hardness of the weld increases by two reasons, firstly due to fine dendritic structure in the fusion zone and secondly, due to heat treatment. It was found that the hardness of post-HT was higher than pre-HT and as cast conditions. The influence of the welding process of the T4 & T6 pre heat treated A356 base metal can be explained with over aging effect of the fusion heat, which changes the stage of incoherency of the precipitation to a more coherent stage. This could lead to a drop in the hardness and strength of the metal in the HAZ. The T4 micro hardness of welded pre HT plates is about 95Hv, which is less than 125Hv of the HT after welding, but higher than 75Hv of non HT, as cast condition.

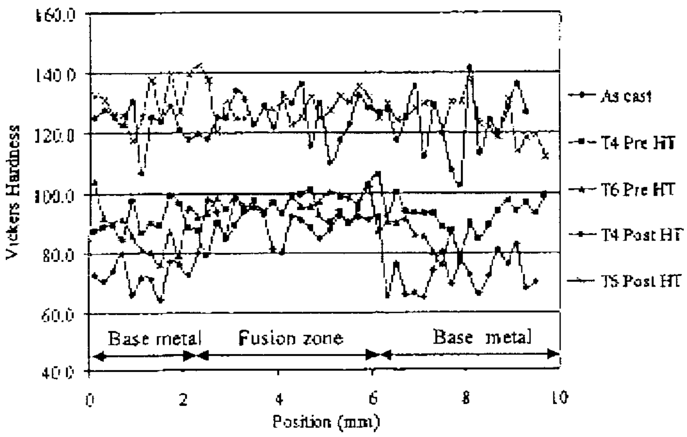


Figure 5. Micro-hardness of SSM A356 across the weld for as cast and heat treated samples.

Mechanical Properties. For tensile test, the samples were prepared with the weld at the centre of the specimen. Fig.6 shows the changes in mechanical properties of A356 in their as cast, welded heat treated conditions. The tensile properties (Yield Strength, YS and Ultimate Tensile Strength, UTS) of the unwelded as cast material was lower than the heat treated (HT) samples. Similar trend was seen for welded samples. For pre HT T4 samples the YS and UTS was almost similar to unwelded HT T4 samples, but was higher for HT T6 samples. Also tensile properties of T6 HT sample were higher than the T4 HT samples. For the case of welded sample, with no heat treatment the tensile properties are higher indicating the weld was stronger then the base metal. The fine dendrite microstructure obtained is normally responsible for the improvement of the mechanical properties. However, for the pre HT welds the tensile properties are lower than the unwelded samples indicating that the welding has destroyed the effect of pre heat treatment. In the case of post heat treatment weld the tensile properties of the T4 & T6 heat treated samples are higher than the unwelded samples indicating that the weld has been much stronger then the unwelded samples. The higher tensile strength obtained in the post HT welds is attributed to the change in microstructure as explained in previous section. In all the welds the fracture occurred at base metal indicating that weld fusion zone was stronger that the base metal. The elongations in the welded samples were found to be lower than the unwelded samples. Also T4 treated samples had higher elongation than T6 and as cast welded samples.

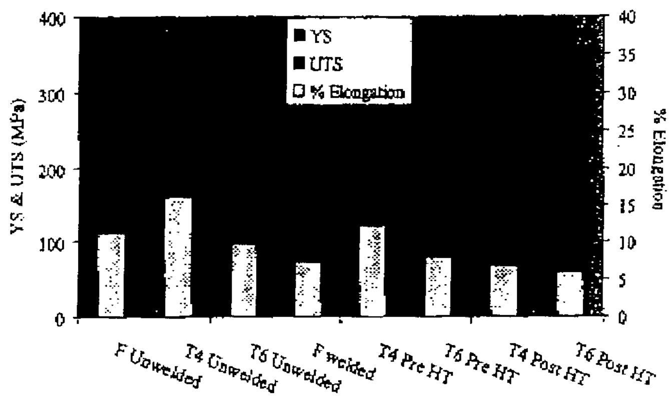


Fig.6 Yield Strength (YS), Ultimate Tensile Strength (UTS) and % Elongation of un-welded and welded, pre HT and post HT samples.

Conclusions

The weld microstructure of the laser butt welded aluminium alloy A356 is typical for a hypereutectic Al-Si alloy, but it is characterized with very fine α-Al dendrite of 10-15 μm length and Al-Si eutectic. The hardness of the pre heat treated samples was slightly higher than as cast welded samples. The hardness of the post heat treated samples was much higher than as cast and pre heat treated samples. The mechanical properties of the post heat treated welds were higher than pre heat treated and as cast welds. The elongation of the welded samples in as cast and heat treated condition was lower than the unwelded samples indicating a reduction in ductility after welding.

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