Mechanical Properties of 5083 Aluminium Welds After Manual and Automatic Pulsed Gas Metal Arc Welding Using E5356 Filler

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Abstract. Semi-automatic and automatic pulsed gas metal arc welding (GMAW) of aluminium alloy 5083 with ER5356 filler wire causes considerable softening in the weld. The tensile strength of dressed automatic welds approaches that of the base metal, but the stress concentration caused by the weld toe in undressed semi-automatic welds reduced the tensile strength significantly. Fully automatic welds displayed improved fatigue properties compared to semi-automatic welds.

Introduction

Magnesium-alloyed aluminium 5083-H111 displays excellent corrosion resistance and finds application in the ship building, structural and pressure vessel industries. It is one of the highest strength non-heat treatable aluminium alloys, and possesses excellent weldability and reduced sensitivity to hot cracking when welded with near-matching magnesium-alloyed filler wire [1].

The pulsed gas metal arc welding (GMAW) process is well suited to weld aluminium alloys due to its lower average heat input and excellent weld contour produced [1,2]. Although some research has been published comparing the mechanical properties of GMAW welds and friction stir welds in 5083 Al [3], there is currently little information available on the mechanical properties of Al5083-H111 after welding with semi-automatic and fully-automatic gas metal arc welding (SA-GMAW and FA-GMAW), and the effect of the weld bead shape on fatigue behaviour.

This project therefore aimed to compare the mechanical properties of Al5083-H111 after welding using pulsed SA-GMAW and FA-GMAW, and to evaluate the influence of weld defects and weld geometry on fatigue behaviour.

Experimental

Plates of 5083-H111 were joined using SA-GMAW and FA-GMAW. In SA-GMAW, the welding torch was manipulated manually by an operator, whereas in FA-GMAW the welding torch was manipulated automatically. The plates for the SA-GMAW process were prepared with a double-V preparation, degreased with acetone and preheated at about 100ºC. For the FA-GMAW process the plates were degreased and welded with a square butt preparation.

Vickers micro-hardness tests with a 10 g load were performed on polished unwelded and welded samples. Tensile and fatigue specimens, machined from the welded plates (fig. 1), were subsequently tested in ambient air at a temperature of 21°C and relative humidity levels between 35.7 and 70.6% RH.

Tensile and fatigue tests were performed according to ASTM standards B557 [4] and E466 [5], respectively, in the as-welded and dressed (welds were ground flush and polished) conditions. A stress ratio of 0.125 and frequency of 1 Hz were used for the fatigue tests. The number of cycles to failure was recorded for each specimen, and 3 to 6 experiments were performed at each stress level depending on the quality of the weld. Metallographic analysis was performed to observe any microstructural changes in the region of the weld and to reveal the presence of defects. The fracture surfaces were studied using a low magnification stereo microscope and a scanning electron microscope (SEM) to reveal the primary crack initiation sites and mode of fracture.

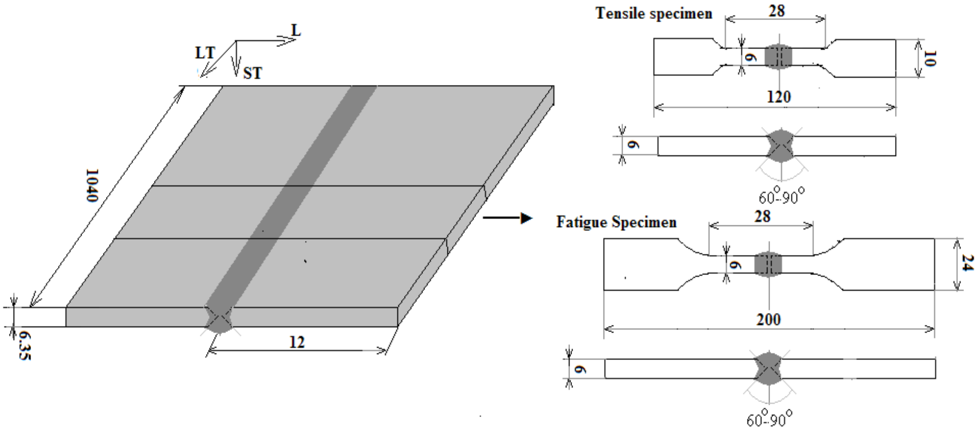

Figure 1. Specimen preparation from the welded plates

Results and discussion

Microstructural analysis revealed coarse grains with average grain diameters of approximately 113.1 µm in the SA-GMAW welds (fig. 2a) and 56.9 µm in the FA-GMAW welds (fig. 2b). The unwelded 5083-H11 plate material displayed a much finer grain size with an average grain diameter of 24.0 µm.

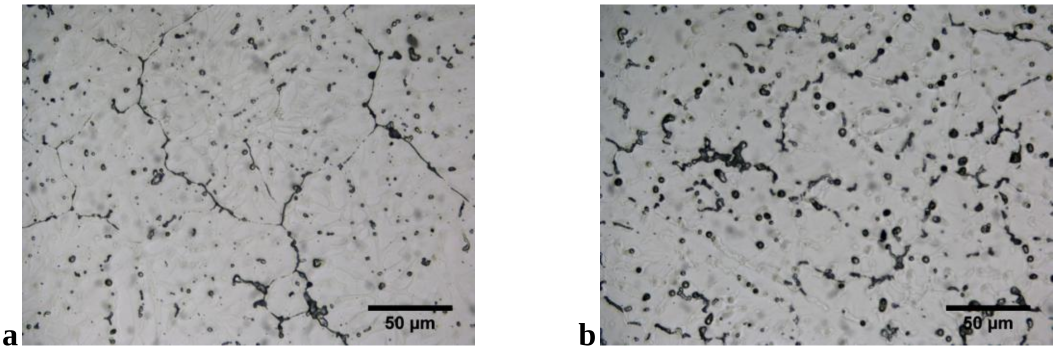

Figure 2. Microstructure of the welds (a) SA-GAMW and (b) FA-GAMW

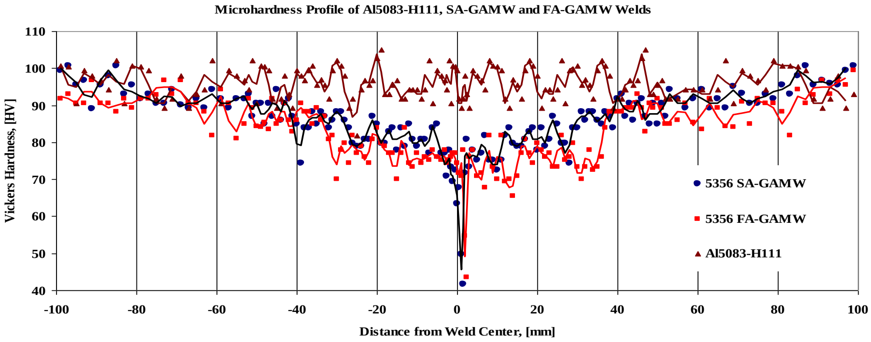

Figure 3. Micro-hardness profiles across SA-GAMW and FA-GAMW welds.

Hardness profiles across the base metal and welds are shown in fig. 3. The lowest hardness values were observed at the weld centre line in both the SA-GMAW and FA-GMAW welds. This hardness reduction can probably be attributed to grain growth and microstructural changes during the weld thermal cycle.

The measured ultimate tensile strength (UTS) and the 0.2% offset yield strength are illustrated in fig. 4.

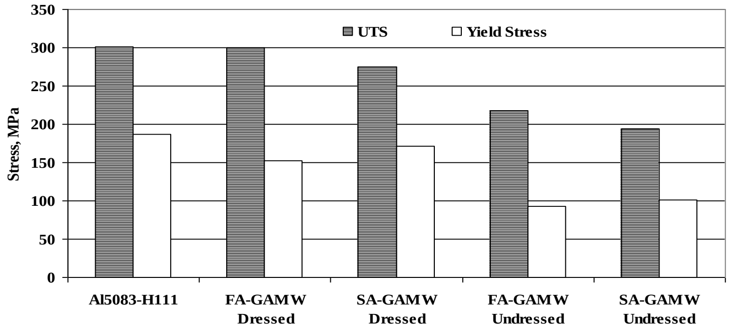

Figure 4. Tensile properties of unwelded Al5083-H111 and GAMW

The UTS of FA-GMAW dressed welds was very similar to that of the base metal. Welding reduced this strength to approximately 20% of that of the base metal in the undressed specimens. The UTS was reduced by about 10% in the SA-GMAW dressed welds (as compared to that of the base metal), with a further reduction in strength to about 77% of that of the base metal in undressed SA-GAMW welds. The decrease in UTS can be attributed to the stress concentration at the weld toes of undressed welds, specimen distortion, possible lack of fusion defects and incomplete penetration. The FA-GAMW welds displayed higher strength and improved elongation compared to the SA-GAMW joints.

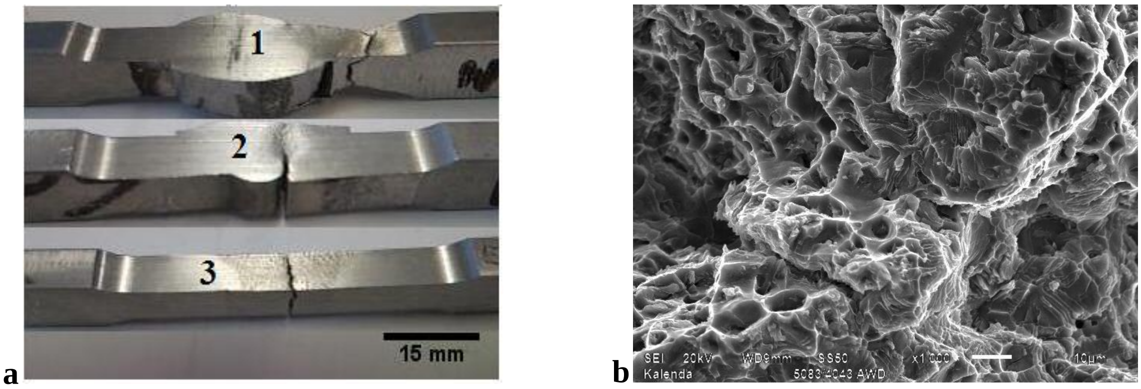

Figure 5. Fracture (a) (1) MWD, (2) AWD and dress weld (3) and (b) weld fracture

The dressed SA-GAMW and FA-GAMW welds failed in the weld metal (fig. 5a3), whereas rupture occurred in the heat-affected zone of the undressed SA-GAMW welds (fig. 5a1). The undressed FA-GAMW specimen failed within the weld metal (fig. 5a2) as a result of incomplete penetration caused by welding from one side only. Welds fractured in ductile manner, as shown in fig. 5d. Fatigue life measurements for the SA-GAMW and FA-GAMW welds were fitted using the power equation and are represented in fig. 6. It is evident that welded specimens possess lower fatigue strength than unwelded plate, and that dressing of welds to remove the stress concentrations at the weld toe improves the fatigue properties. The SA-GAMW welds display lower fatigue properties than the FA-GAMW welds (fig. 6).

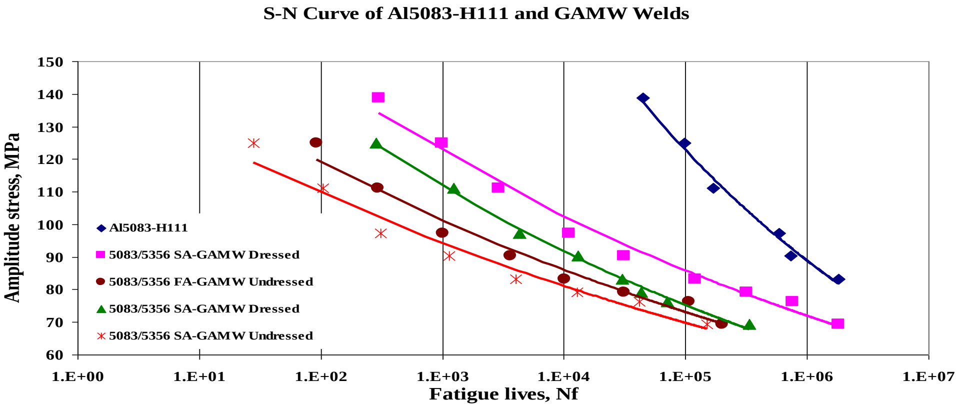

Figure 6. S-N curves of unwelded Al5083-H111, SA-GAMW and FA-GAMW welds.

The fatigue cracks initiated at gas pores, lack of fusion defects, incomplete weld penetration and at the weld toes of undressed beads (fig. 7a). Propagation occurred preferentially in the weld metal (fig. 7b).

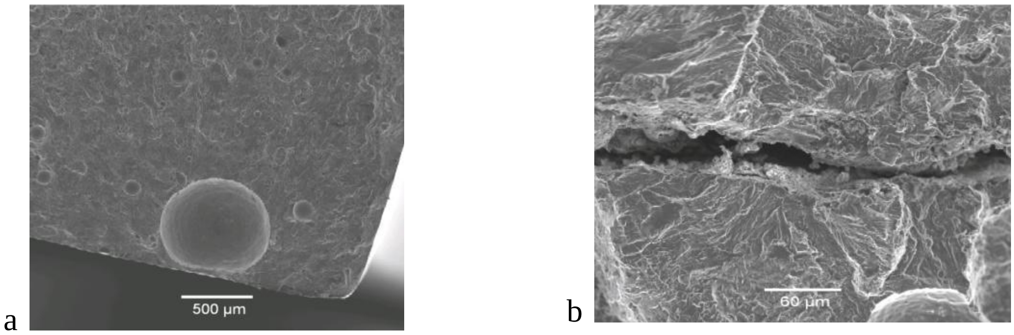

Figure 7. Cracks initiations and propagation in the 5083/5356 MIG welds

Conclusions

Both semi-automatic and fully-automatic welding reduces the strength and hardness of the Al5083-H111 welds produced with ER5356 filler wire. This loss in strength and hardness was more pronounced in the semi-automatic gas metal arc welds. Lower hardness was revealed in the center line of the semi-automatic and fully automatic welds.

The fatigue lives were severely reduced in the undressed semi-automatic welds due to the severe stress concentration presented by the weld toes. Dressing of the welds improved the fatigue properties significantly. As a result of improved control over weld profile, fully-automatic welds consistently outperformed semi-automatic welds. Fatigue cracks initiated at gas pores, lack of fusion defects, incomplete weld penetration and weld toes in all the welds.

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