PULSED CURRENT GAS TUNGSTEN ARC WELDING OF Al-Li ALLOY 1441

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Abstract

The scope of applications of Al-Li alloys can be substantially increased if they can be welded to the required quality and reliability. Pulsed Current Gas Tungsten Arc Welding (PC-GTAW) is known to have a number of advantages over Continuous Current GTA Welding (CC-GTAW), such as higher arc efficiency, greater control over heat sink variation and better control over the microstructure. In the present investigation, an Al-Li alloy made to Russian specification 1441 in the form of 2 mm thick sheets was welded by both CC-GTA and PC-GTA Welding processes.

First, it was shown that the weld surface preparation requirements (viz. removal of the oxide layer) and weld protection schemes (argon shrouding), which were established for conventional GTA welding of other commercial Al-Li alloys remained applicable in the present case also. Weld parameters were controlled so as to obtain full penetration sound welds. The heat input per unit length was maintained same for both the welding processes.

The grain size, the minimum segregation distance and the size of interdendritic second phase were found to be smaller in case of PC-GTAW. PC-GTAW welds showed greater hardness than CC-GTAW welds throughout the weld bead in the as welded (AW) and solutionised and aged (STA) conditions. UTS-elongation combinations were substantially improved in PC-GTA welds over CC-GTA welds. Overall, Pulsed Current GTA Welding appears to be a very promising process for weld fabrication of Al-Li alloy structures.

Introduction

The weight saving potential of Al-Li alloys, owing to their lower density and higher elastic modulus, makes them strong candidate materials for aircraft and spacecraft structural applications. Majority of the aerospace structures are joined by fasteners rather than by welding, although the welding option promises greater material economy. It is necessary, therefore, to understand the correlations between welding parameters and alloy composition on one hand, and weld soundness, microstructure and properties on the other. Control over the weld properties will also help expand applications of Al-Li alloys to areas such as marine hardware, light weight pressure vessels, light armour etc.

Weld soundness generally refers to the absence of defects like hot and cold cracks, porosity, inclusions, oxidation, incomplete penetration, undercuts, distortion etc. It is now well established that the moisture adhering to the complex surface oxide film present in Al-Li alloys is responsible for weld porosity [1,2]. Suitable methods for removing the oxide skin from the weld regions and also for protecting the weld during welding from atmosphere have been devised. The hot cracking tendency of Al-Li alloys was found to be maximum in the composition range 2-2.5% Li (which is optimum for the base metal), and was found to be comparable to that of other high strength Al-alloys like 2014 and 7074 [3]. Weld metal efficiencies ranged from 50% to 70% for 8090/2090 type alloys and Russian 1420 type alloys respectively in the as welded (AW) condition. These values increased to 80% and 99.5%, respectively, in the solution heat treated and aged (STA) condition [4-8]. Among the various filler metals used, 5356 was found to give the best weld properties and soundness, while the parent metal filler also gave satisfactory results [4-6].

Welding produces a completely new microstructure in the fusion zone, and partially in the heat affected zone. Joint properties of sound welds are largely influenced by the weld bead microstructure, in particular the grain size, shape, segregation, etc. Gas Tungsten Arc welding (GTAW) is a versatile and effective method for welding Al-Li alloys. Modifications such as current pulsation or arc oscillation are known to afford better control over weld microstructure [8, 9]. The aim of the present work was to examine and compare microstructure and properties of welds produced by continuous current GTAW and pulsed current GTAW. Alloy composition and weld heat input were kept constant to facilitate proper comparison.

Experimental Procedure

Aluminium-lithium alloy 1441 of nominal composition Al-1.9% Li-1.7% Cu-0.9% Mg-0.1% Zr, made in the form of 2 mm thick rolled sheets and heat treated to the T81 temper (ST+ 2% cold stretched + aged at 170 °C for 24h)served as the base metal for the welding experiments. Coupons of size 250 mm x 75 mm were cut such that the coupon length was parallel to the rolling direction. Bead-on-plate welds were made without filler across the rolling direction by AC GTA welding process with and without current pulsation. Weld parameter are listed in Table I.

Table I. Welding Conditions

Parameters	Continuous Current	Pulsed Current
Welding current	85 amps	I_p = 150 amps I_b = 15 amps
Welding Speed	7 mm/sec	3.4 mm/sec
Pulse duration	-	20%
Pulse frequency	-	6 Hertz
Electrode	W-2% thorium	
Arc length	2 mm	
Torch Position	Vertical	
Arc Voltage	20-22 volts	
Shielding	Argon 99.9%, Flow rate 35 CFH.	

The weld coupons were examined visually for depth of penetration, surface quality and presence of gross defects. Samples were sectioned, metallographically polished and etched using Keller's reagent for examination of the weld bead solidification structure. Elemental distribution was studied on as-polished surfaces using EPMA. Microhardness traverses were made across the weld using 100g load. Tensile tests were carried out on test pieces cut perpendicular to the weld line, in the as welded (AW) as well as in the solution treated and aged (STA) conditions.

Results

Soundness

Complete weld penetration was achieved, and no gross defects such as tarnishing, cracking or porosity were observed. Macrostructure of the weld bead is shown in Figure 1.

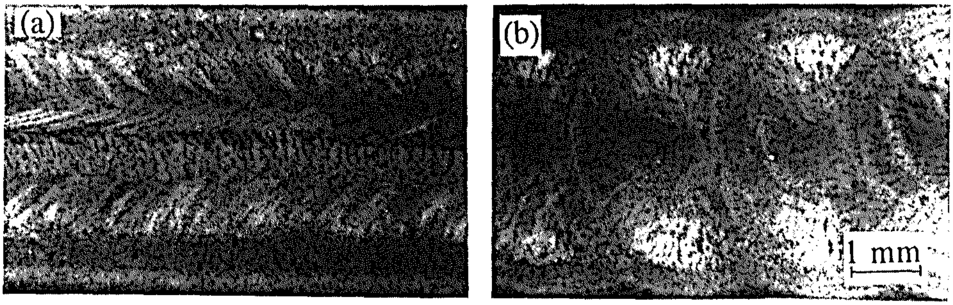

Figure 1. Weld bead macrostructure in (a) CC-GTAW and (b) PC-GTAW of Al-Li alloy.

Microstucture

The base metal had the typical lamellar recrystallised microstructure which is characteristic of Al-Li alloys. The degree of recrystallisation was substantial. The weld fusion zone showed all the three familiar features of as cast microstructure viz: chill zone, columnar zone and equiaxed zone, as shown in Figure 2.

The chill zone is observed to be more extensive in the continuous current welds compared to the pulsed current welds. The chill zone is followed by the columnar dendritic zone in both types of welds. A sharp columnar to equiaxed transition is observed in case of pulsed current welds, while the dendrite structure remained predominantly columnar up to the weld centre line in the continuous current welds, as seen in the microstructure on the longitudinal plane of the welds (Fig 3).

Figure 4 shows interdendritic segregation which occurs during solidification of the weldments. It is observed that the minimum segregation distance and the segregate particle size are smaller in case of pulsed current welds compared to the continuous current welds. The segregate particles have been analyzed by EPMA X-ray mapping, and are found to contain Cu, Mg and Si, (Li analysis could not be carried out due to low atomic number) as shown in Figure 5 for the case of continuous current welds.

Solution treatment of the welds at 530 °C for 30 min caused incomplete dissolution of the interdendritic and grain boundary segregation, as seen in Figure 6. The degree of dissolution was somewhat higher in case of pulsed current welds in comparison with the continuous current welds.

Properties

Microhardness traverses across the bead width are plotted in Figure 7. Hardness is minimum at the weld centre, and increases steadily towards the fusion line and into the base metal, where it reaches the base metal hardness valve. The weld metal responds significantly to heat treatment, shown by the increase in hardness upon solution treatment and ageing. The pulsed current welds show higher hardness than the continuous current welds.

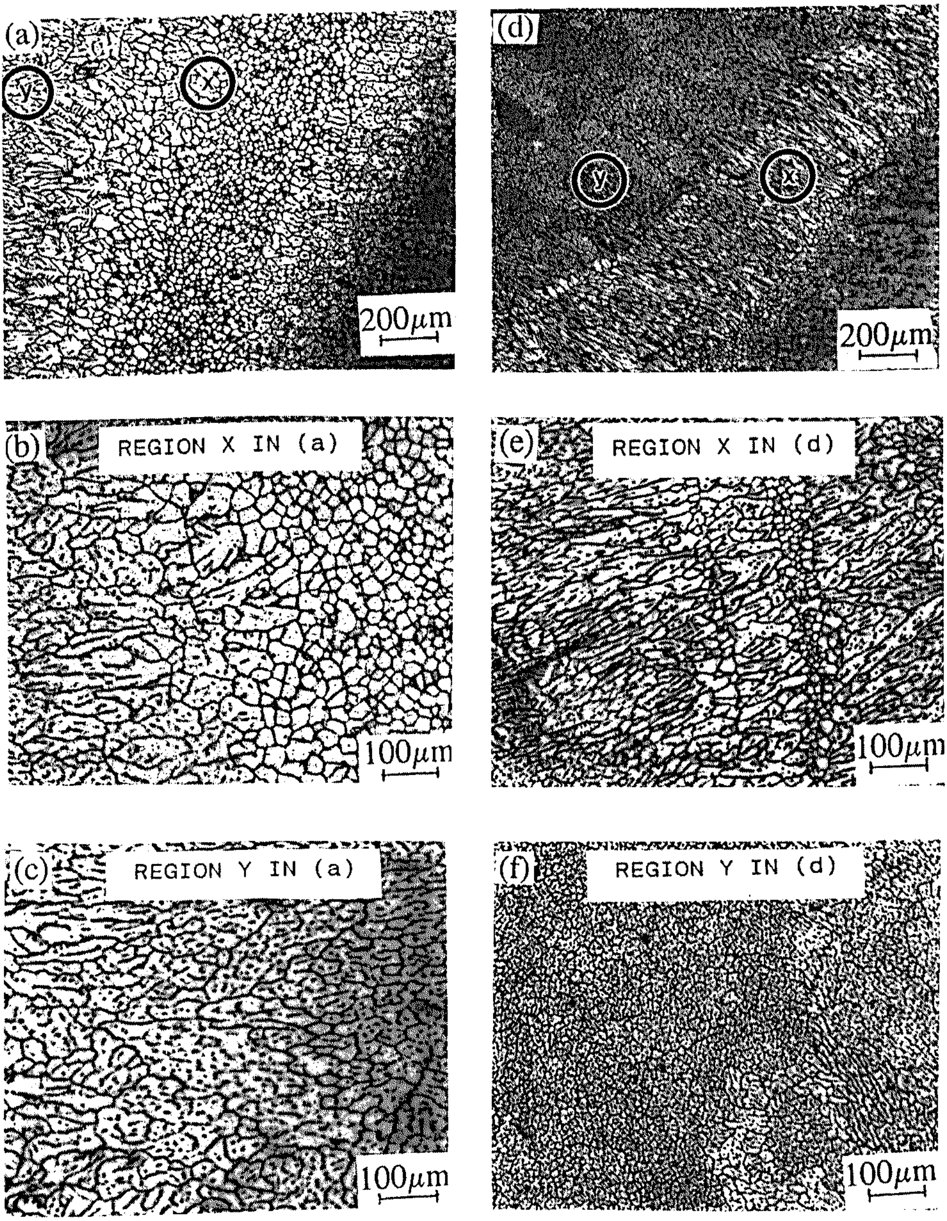

Figure 2. Optical microstructure along the weld bead cross section of Al-Li alloy 1441 in as welded condition (a-c) CC-GTAW and (d-f) PC-GTAW.

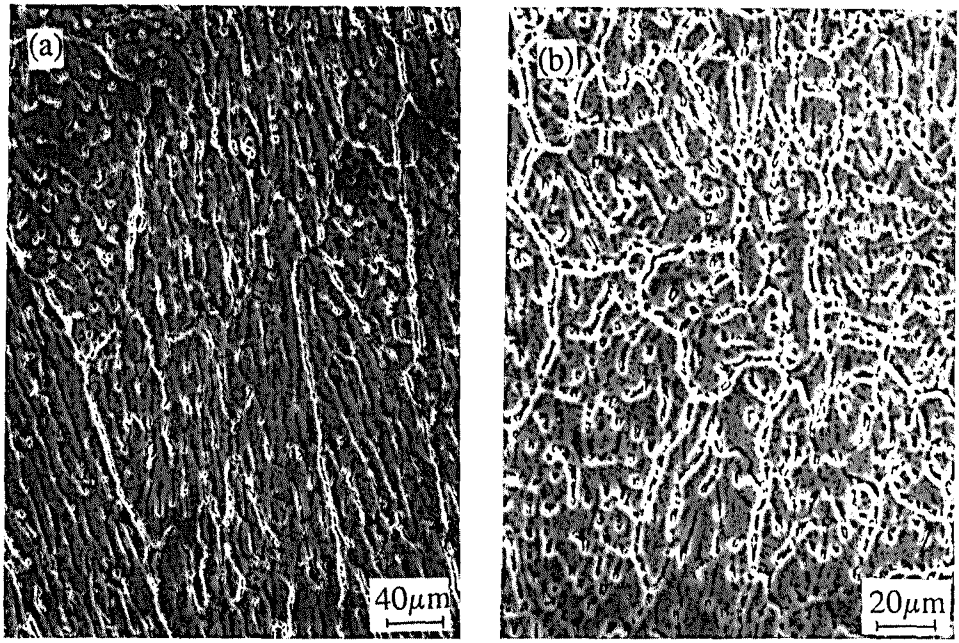

Figure 3. SEM images of the longitudinal section of the welds, as welded condition (a) CC-GTAW (b) PC-GTAW.

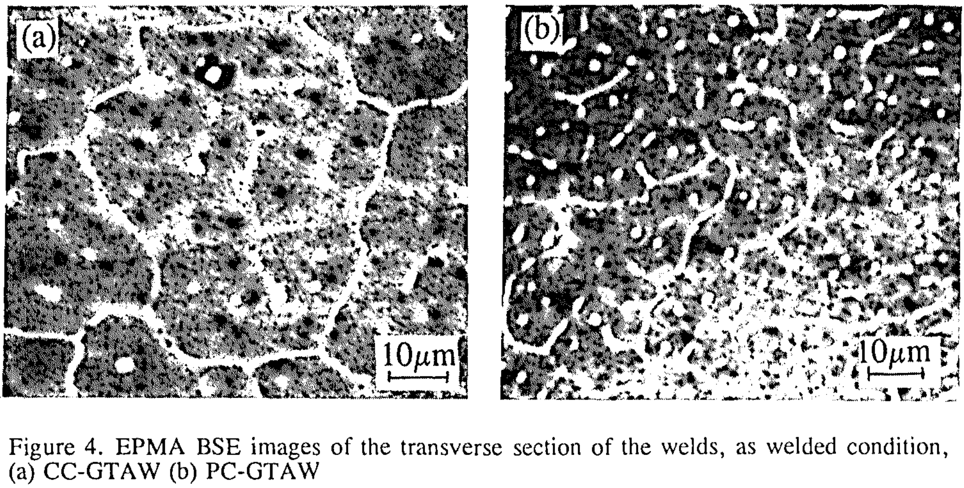

Figure 4. EPMA BSE images of the transverse section of the welds, as welded condition, (a) CC-GTAW (b) PC-GTAW

The tensile strength and ductility of the as welded samples was low, (see Table II). The strength increases significantly after heat treatment, while ductility increased to acceptable levels only, in case of the pulsed current welds. The weld metal efficiency based on the yield strength was 85% in pulsed current welds in the heat treated condition.

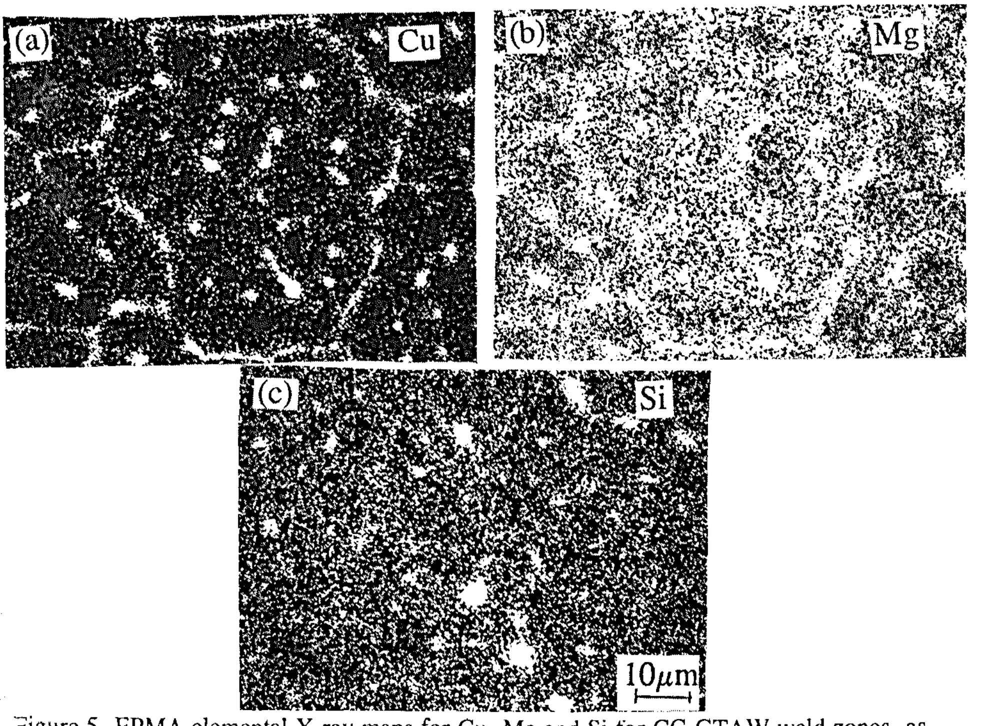

Figure 5. EPMA elemental X-ray maps for Cu, Mg and Si for CC-GTAW weld zones, as welded condition.

Table II. Tensile Properties of weldments

Process	Condition	UTS (MPa)	YS (MPa)	El (%)	Joint Efficiency k (%)
CC-GTAW	AW	233	--	--	--
	STA	380	340	1.4	85.2
PC-GTAW	AW	259	240	2.0	60.1
	STA	433	354	7.0	88.7
Base Metal	T81	450	398	9.3	--

AW= As welded, STA= solutionised and aged
k= (YS of weld joint / YS of base metal) x 100%

Discussion

In general, the formation of equiaxed grain structure in conventional GTA welds is known to be difficult because of the remelting of heterogeneous nuclei or growth centres ahead of the solid-liquid interface. This is due to the high temperature gradients in the liquid, which is a characteristic of weld pool solidification [8, 9]. Results presented in Figures 2(a to c) and 3(a) confirm this mechanism.

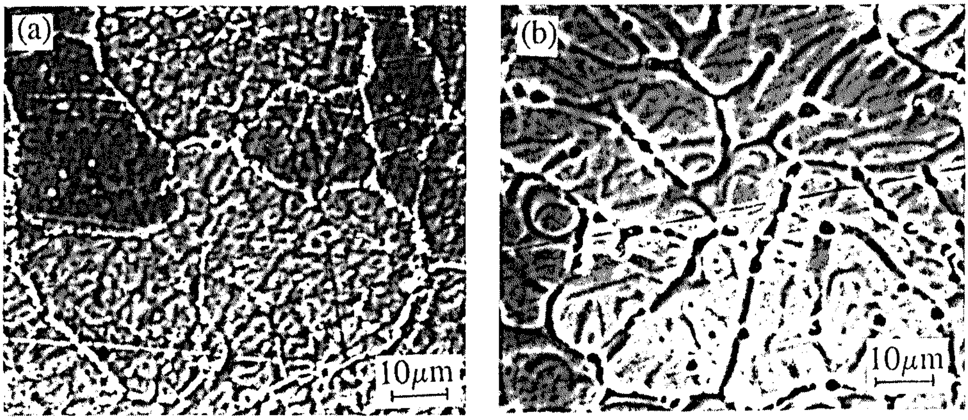

Figure 6. EPMA, BSE images of the transverse section of the welds, after solution treatment (a) CC-GTAW (b) PC-GTAW

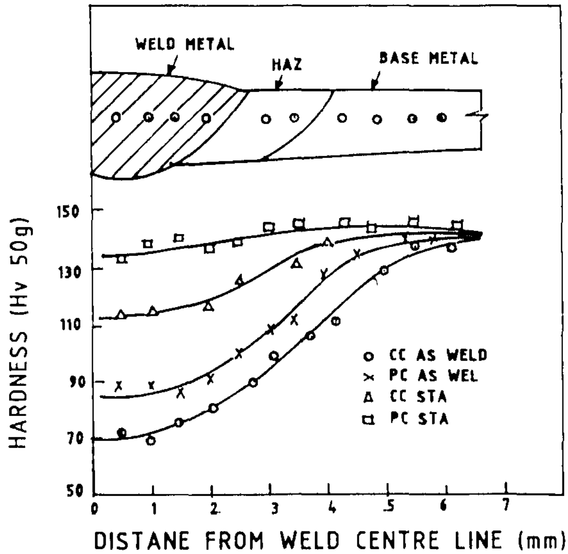

Figure 7. Microhardness across the bead width in as- welded and solutionised + aged conditions.

In pulsed current GTA welding, bulk of the bead solidifies during the background current period, during which the temperature gradients are relatively low, and the cooling rates are high. Also, the cyclic nature of the current wave causes periodic variations in the arc pressure leading to fluid flow in the melt [6, 9]. This can cause (a) transport of the chill zone crystals in the bulk liquid, (b) equalisation of liquid temperature because of forced convection and (c) increased cooling rate due, again, to forced convection in the liquid. Increased dendrite remelting/break off also remains a strong possibility.

It appears plausible, therefore, that the smaller chill zone size observed in pulsed current welds is due to fluid flow effects, and the survival of the swept-off chill crystals and broken/remelted dendrites is promoted by the lower temperature gradients in the melt. The smaller segregate size and smaller inter segregate distance in pulsed current welds are the consequence of higher cooling rates experienced by the solidifying welds.

The mechanical properties in the as welded condition are low because of the coarse microstructure and segregation in the as solidified bead. Solution heat treatment of the weld results in partial dissolution of the second phase leading to improvement in properties. The superiority of the properties of the PC welds over the CC welds can be explained by the relative fineness of the solidification structure and therefore better dissolution of the second phase leading to the precipitation of greater volumes of Al_3Li in the STA condition.

Conclusions

1. Defect free welds could be produced in Al-Li alloy 1441 sheets using continuous and pulsed current GTA welding without filler metal.

2. Solidification structure was finer and more equiaxed in case of PC GTA welding.

3. Hardness and tensile properties were higher in case of pulsed current welding.

4. Weld metal efficiency of 85% (based on yield strength) could be achieved in case of heat treated pulsed current welds.

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References

1. J.R. Pickens, J. Mat. Sci. 20, (1985), 4247.

2. M.H. Skillingberg, Aluminium Technology 86, ed. T. Sheppard, Institute of Metals, (1986),507.

3. C.E. Cross et al., Aluminium-Lithium alloy II, ed. T.H. Sanders and E.A. Starke, AIME, (1984), 675.

4. M.F. Gitto, "Gas Shielded Arc Welding of the Aluminium-Lithium Alloy 8090" (Report 794401/5556.2, England :Welding Institute, 1987).

5. G.M. Reddy and A.A. Gokhale, Trans. Indian Inst. Met. 46, (1993), 21.

6. M.R. Edwards and V.E. Stoneham, J. de. Phys. Coll., (1987), c3-293

7. A. Ya Ishchenko et al., Automatic Welding. 30 (1977), 38.

8. A.A. Gokhale et al., Grain Refinement in Castings & Welds, Eds. G. Abbaschian and S.A. David, (Warrandale, Pa, USA: TMS, 1983), 223.

9. B.P. Pearce and H.W. Kerr, Met. Trans. 12B (1981), 479.