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RESEARCH ARTICLE

THE DEVELOPMENT OF THE WELDING PROCEDURES AND HARDENING OF BUTT-WELDING STRUCTURES OF ALUMINIUM-6082 ALLOY

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ABSTRACT

The development of the welding of aluminum has seen greater demands upon the design of faster and larger aerospace and automotive industries. AA 6082 (EN AW 6082) grade aluminum alloy is mostly used for lightweight construction. These alloys contain small amounts of silicon and magnesium, typically less than 1% each, and may be further alloyed with equally small amounts of manganese, copper, zinc and chromium. Hardening constituent in this alloy is magnesium silicate Mg_2Si phase. The alloys are sensitive to metal cracking such as in the root pass of the weld due to, particularly, the high alloying element content in parent metal. In this study, the mechanical properties of the weld specimens were investigated based on the microstructure obtained from AA 6082 alloy heat treated with T0, T6 and T73 heat treatment scheme and the optimization of TIG welding procedures were also attempted. The information obtained in this study may help automotive producers to take full advantage of the developments in automotive grade aluminum alloys.

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INTRODUCTION

Aluminum is a unique and relatively young material, whose production value is steadily increasing more then other metallic materials (Kolarik *et al*., 2011). It is the most plentiful metal in nature. Unfortunately, aluminum does not occur in nature in the metallic form but in the form of silicates and other complex compounds (GaneMathers, 2002). There are already more than 120 different Al alloys described in the norms, so dramatic development of brand new Al alloys is not to be expected (Sperlink, 2003). AA6082 alloys FSW joints were produced by employing different welding parameters by P. Cavalier (Cavaliere *et al*., 2009). A. Kumar's (2009) work pertains to the improvement of mechanical properties such as hardness of AA5436 aluminum alloy welds through pulsed Tungsten Inert Gas (TIG) welding process. The attitude of the welded joints at the optimum condition of process parameters is attributed to the increase in the amount of Mg_2Al_3 precipitates that are formed in the aluminum matrix examining microstructure and micro hardness of different joints. A. Cabello Mun (2008) investigated the comparative microstructural and mechanical characteristics of Tungsten InertGas (TIG) and Friction Stir Welding (FSW) of Al-4.5 Mg-0.26 Sc heat- treatable aluminum alloy. A. Scialpi analyze the effect of different shoulder geometries on the mechanical and microstructural properties of a friction stir welded joints of 6082 T6 aluminum was analyzed (Scialpi and Cavaliere, 2007). The mechanical properties of welded joints of 6082-T6Al alloy with Gas Metal Arc Welding (GMAW), under the experienced welding conditions, undergo a remarkable reduction of the initial value i.e. about 60% of the parent metal (Missori and Sili, 2000). In the HAZ both tensile strength and hardness reduce to a minimum at a distance from the weld fusion line of around 6mm, presumably due to over-aging consequent upon the transformation of the strengthening metastable precipitate (Cavalier *et al*., 2008). The preferred welding process of aluminum alloy is frequently (TIG) welding due to its comparatively easier applicability and better economy (Senthil Kumar *et al*., 2007). TIG welding is a traditional technology for aluminum alloy welding, however, some problems would be formed, such as hotcracking in fusion zone due to segregation of alloying elements during solidification, as-cost coarse microstructure (Sato *et al*., 2008). In this study, an effort has been put to find out the aging effect on the structure and the TIG welding for better strength of Aluminum 6082. The joint thickness of 5mm has been selected with conventional AC mode on TIG welding. The study has investigated the influence of aging on hardness and

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metallurgical characterization of TIG welded butt Joints of aluminum alloy 6082-T6 and T73

Experimental work

The specimens used in the investigation were obtained from butt joints of EN AW 6082. The composition of the alloy is given in Table 1.T0, T6 and T73heat treatments were applied on them after the TIG welding operated with 120Amp at a welding speed of 400mm / min. The tensile specimen was retrieved from fused area in the shape of dog-bone. Welded joints allowed cooling slowly to room temperature in still air. The tensile strength of these alloys with but joints were determined using AG-IS-100KN SHIMADZU universal tensile test unit. A standard metallographic study was carried out on specimens welded and heat treated. The hardness measurements were made using Brinell C type testing machine. XRD study was carried out using Shimadzu XRD-6000 model machine for the 2-theta range of 10-90° at a scanning rate of 2° per minute.

RESULTS AND DISCUSSION

Metallography and analysis

Metallographic samples have been prepared to examine the microstructure of the basic material, and preliminary optical metallographic examination has been carried out on T0, T6 and T73. Micrographs of the base material are shown in Fig. (1-3). It is observed from these optical micrographs that as heat input increases, the dendrite size and inter dendritik spacing in the weld metal also increase. The dendrite size variation in 6082 aluminum alloy can be attributed to the fact that at low heat input, cooling rate is relatively higher due to steep thermal gradient established in the weld metal, which, in turn, allow lesser time for the dendrites to grow. However, with high heat input, the cooling rate is slow providing an ample time for the dendrites to grow farther into the fusion zone (Senthil Kumar *et al*., 2007)

Table 1. Chemical Composition of Base Material and Filler Wire (ÖzKorumaz Aluminumindustry and TIC, 2013; Magmaweld Welding Industry, 2013)

Elements	Composition % (EN AW 6082) Base material	Composition % (4047) Filler Wire
Silicon (Si)	0.70-1.30	12.00
Iron (Fe)	max.:0.50	0.60
Copper (Cu)	Max.:0.10	0.20
Manganese (Mn)	0.40-1.0	0.15
Magnesium (Mg)	0.60-1.20	-
Chromium (Cr)	Max.:0.25	-
Zinc (Zn)	Max.:0.20	-
Titanium (Ti)	Max.:0.10	-
Aluminium (Al)	Remainder	88.0

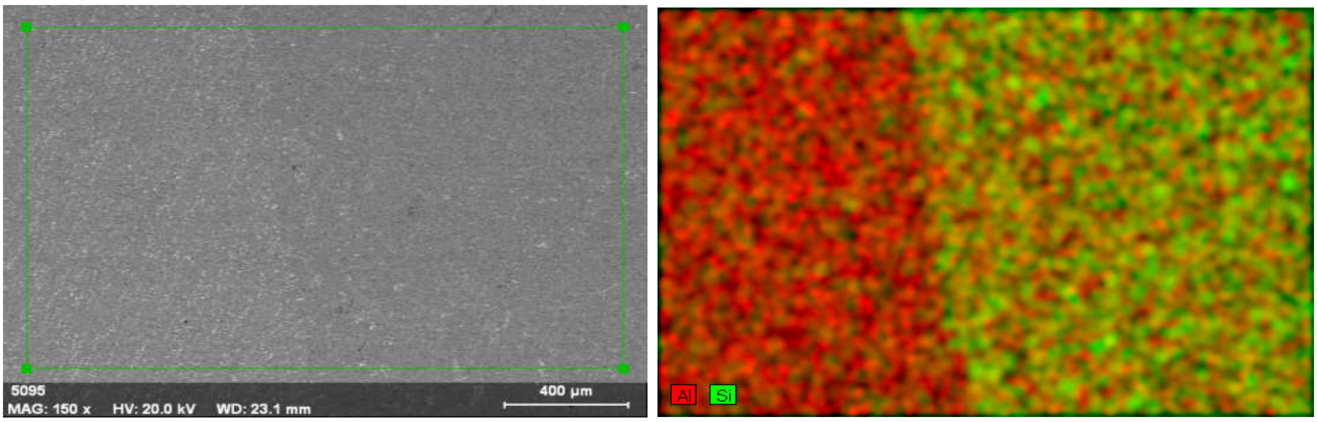

Fig.1. SEM microstructure of weld region of T0 treated specimen and its elemental mapping

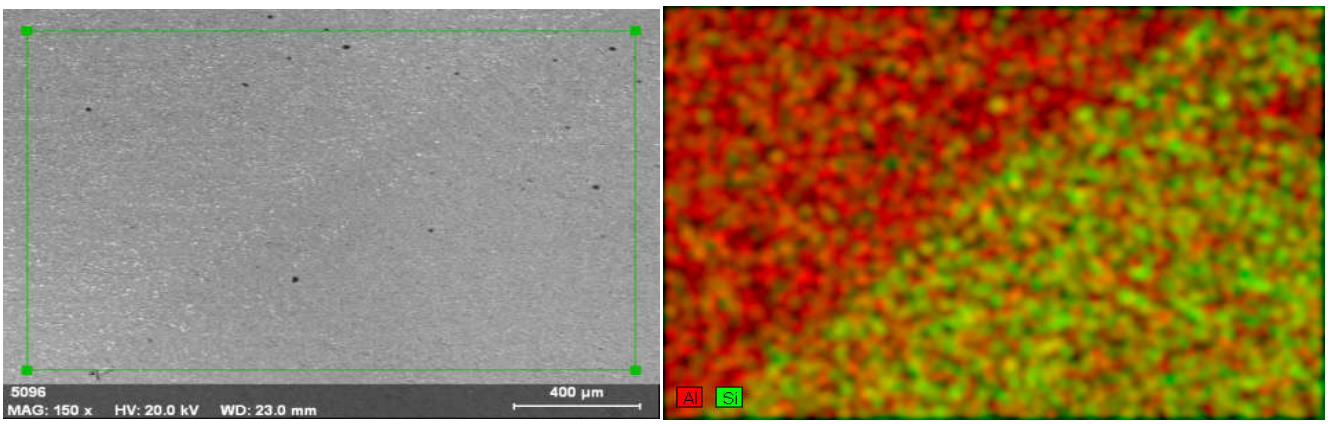

Fig.2. SEM Microstructure of weld region of T6 treated specimen and its elemental mapping

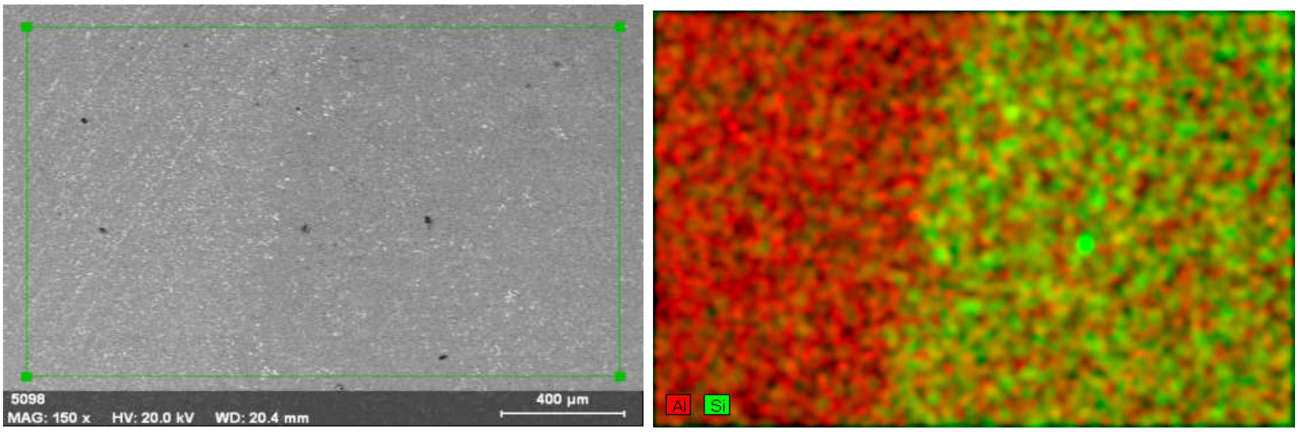

Fig.3. SEM microstructure of weld region of T73 treated specimen and its elemental mapping

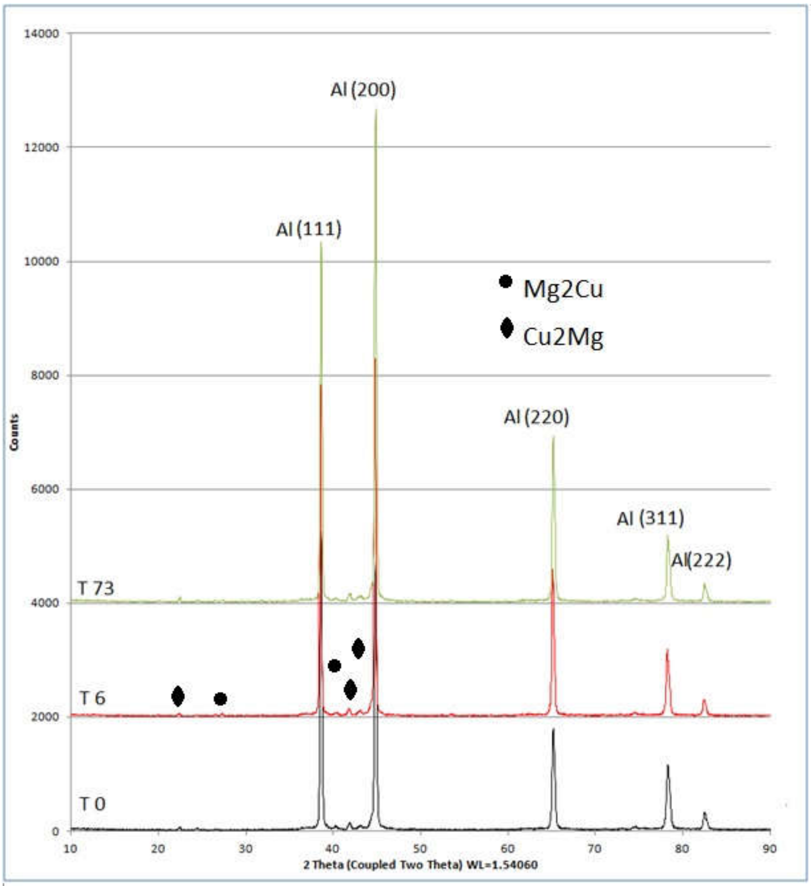

Fig.4. XRD Analyses from after T0, T6 and T73 heat treatments

Table 2. Mechanical properties of base metal, weld and filler wire

Grade		Tensile Strength (MPa)	Hardness Vickers (HV)	Elongation (%)
6082(12)		130	35	27
6082T6		340	100	11
6082T73		380	110	8
	T0	165	86	9.28
Butt Welded	T6	142	80	10.21
	T73	93	96	4.76
Filler Wire (GTAW, 2013)		>130	-	>5

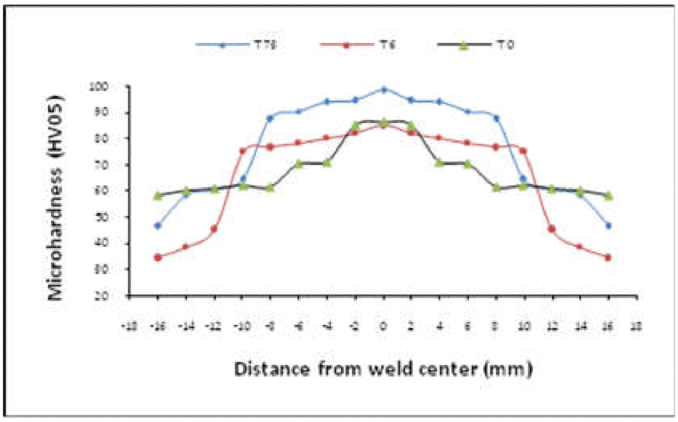

Fig.5. Microhardness of the welded regions with different heat treatments

The weld zones of three specimens were shown to be rich in Al and HAZ is relatively rich in Si as appears in Figures 1-3. It is observed that base metal contains small particles of which its composition is of concern. It is homogeneously distributed within the matrix. These particles were also seen in SEM images. XRD analysis results showed that (XRD), Figure 4, Mg_2Cu and Cu_2Mg intermetallic compounds are present. They also contain finely dispersed particles, probably of the Mg-Si-Al type. This appears to be in accordance with Katouh who investigated AA5456-H116 type aluminum alloy (Calcraft *et al*., 1999). In the base metal, there are dark coarse inclusions of several µm diameter and grey inclusion which are generally small. According to energy dispersive X-Rey (EDX) and electron probe micro analysis (EPMA), the black and grey inclusions show a concentration of magnesium and silicon, and iron and manganese, respectively. They are presumed to be Mg_2Si phase and $(Fe\text{-}Mn)Al_6$, or $FeAl_3$ + $MnAl_6$ (Kumar and Shapi, 2011).

Hardness and mechanical testing

The tensile test results are given in Table 2. The main problems of Grade 6082 aluminum alloys occurring during welding of Al alloys are solidification cracks, or commonly known as hot cracks. The weld metal (WM) intercrystalline solidification cracks and liquation cracking can occur in the heat affected zone (HAZ) (Kolarik *et al*., 2011). Therefore, welding research of Al alloys usually concentrated on hot cracking as criteria for base material and filler metal comparison. Lehigh test, Houldcroft test, Varestraint test, T-joint test can be listed as general weldability tests for hot cracking evaluation. Weldability tests for hot cracking are described in detail by Hrivnak (2009). Hardness of 6082aluminumalloywas measured afterheat treatment at different temperatures. Corresponding behaviors for the indenter traversing outwards from the center of weld zone were observed as shown in Figure 5. The micro hardness for specimen made at T6 varied from 35 to 80 VHN and T73 varied from 48 to 96 VHN, showing an increase a trend from center of nugget to weld metal. The reason for this trend may be due to the heat treatment and excessive aging. A micro hardness value near the top of the weld bead surface is higher than the center of the fusion/weld zone. Hardness values gradually reduced, which was due to the fact that cooling rate was relatively higher at the top of the weld bead surface than at the center of the weld metal.

Possessed by the fusion boundary zone (FBZ) in all the joints, high hardness values can be attributed to the presence of partially unmelted grains at the fusion boundary. These grains are partially adopted as nuclei by the new precipitating phase in the weld metal during the solidification stage. After reaching this peak value, micro hardness showed a decreasing trend in the HAZ. In all the joints, HAZ area adjacent to the fusion boundary was coarse grained HAZ (CGHAZ) possessing low hardness. However, the HAZ area adjacent to the base metal was fine grained HAZ (FGHAZ) possessing high hardness values. The reason for this trend of micro hardness in the HAZ of all the joints was that the area adjacent to the weld/fusion zone experienced relatively slow cooling rate and hence had coarse grained microstructure. However, the area adjoining the base metal underwent high cooling rate due to steeper thermal gradients and consequently, has fine grained microstructure. This is an evident from the trend depicted by the micro hardness profile within the HAZ of each of these joints (Kumar and Shapi, 2011).

Conclusion

1. In the hardening and aging applied to these alloys, the degree of increase in strength depends on the state of the reinforcing phase and the amount and distribution of the particles of these alloys. In this case, yield point increases while ductility, toughness, brittle fracture and corrosion resistances decrease.
2. After the aging phase, depending on the transformation of the alloy, the dislocations by passing around the unstable particles can generate many dislocation nodes and groups. Thus strength increases while ductility decreases.
3. TIG welding expands the cage of Si; Al situated on the additional welding wire and reduces the strength of the weld zone. This situation facilitates the movement of atoms or molecules.
4. The welded strength of heat-treated alloy may be slightly lower than non-welded alloy. The HAZ zone consists of solution annealing zone, annealing zone and over aged zone. This zone often lacks of ductility.

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