

Study on The Effect of Shallow Cryogenic Treatment on Hardness and Microstructure of Gtawwelded Aa6061 Specimens

R.Devanathan¹, Sanjivi Arul², S.Ilangovan³, A.Shanmugasundaram⁴,
Graduate Student¹, Associate Professor^{2, 3}, Assistant Professor⁴,
Department of Mechanical Engineering, Amrita School of Engineering
Amrita Vishwa Vidyapeetham, Coimbatore –641112, Tamilnadu – India

Abstract

The Aluminium alloy AA 6061 loses its hardness significantly after Gas Tungsten Arc Welding (GTAW). The effect of post welded shallow cryogenic treatment (SCT) on hardness and micro structure of AA6061-T6 weldment is studied in this work. The GTAW welding was carried out with different heat inputs by varying the welding speed. The hardness and microstructure were evaluated for as-welded and post weld shallow cryogenic treated specimens. It is found that the hardness of the post welded SCT AA6061-T6 specimens increased significantly due to the reactivation precipitation sequence in the welded region.

Keywords: AA6061, GTAW, Post-weld Treatment, Shallow Cryogenic Treatment, Hardness, Microstructure

Introduction

Aluminium alloys are extensively employed in structural, defence and aerospace applications because of their light weight and excellent mechanical properties which are normally achieved by thermal treatments [1]. The 6xxx alloys have medium strength, good weldability, formability and corrosion resistance and low cost. Due to high corrosion resistance, 6xxx alloys are superior when compared to 2xxx and 7xxx alloys [2].

Dong Peng [3] and M. Miyazaki [4] reports that the hardness in welded region of 6xxx Aluminium alloys is lower than that of base metal and heat affected zone (HAZ) due to high thermal gradient produced during welding process, resulting in overaging and liquation cracking. The reduction of metallurgical and mechanical properties, thus obtained, can be improved by the post weld aging procedure [5,6]. Both the tensile strength and hardness reduce to a minimum near the weld fusion line in the HAZ. This is caused because of overaging and transformation of strengthening metastable

precipitate [1]. An increase in hardness is observed through pulsed GTAW welding of AA 5456 alloy due to increase in the amount of Mg_2Al_3 precipitates, which are formed in the aluminium matrix [3].

The hardness of AA6061 weldment after fusion welding reduces from the base metal value in T6 condition [7]. The effect of heat treatment on the microstructure and the corrosion behaviour of AA 6061 alloy using GTAW welding have been investigated [8] and the heat treatment process the morphology of irregular shaped coarse particles changes to a globular shape. From the literature data, after slow solidification process in 6xxx Al alloy shows the formation of stable intermetallic equilibrium precipitates of β - Mg_2Si from the β' meta stable state in the α -Al matrix [9].

Cryogenic treatment can be employed as the additional process to the conventional heat treatment process [10]. The cryogenic treatment is an effective method to reduce residual stress and appreciable improvement in the hardness and tensile properties were found in aerospace aluminium alloys [11].

In this work, shallow cryogenic treatment is performed on the GTAW welded AA6061 specimens at $-77^\circ C$ and then the specimens are allowed to attain the ambient temperature. The effect of post weld shallow cryogenic treatment for 2hrs on the micro hardness and microstructure of GTAW welded AA6061-T6 is studied.

Experimental Procedure

Commercial AA6061-T6 extruded Al-Mg-Si alloy of size 25 mm width \times 200 mm length \times 20 mm thickness is used as the base metal. Then the specimen was cut to a length of 100 mm. Chemical composition of base metal is confirmed using the spectroscopic analysis as reported in the Table 1.

Table 1: Chemical composition of AA 6061-T6 (base material)

Elements	Composition (Wt. %)
Aluminium (Al)	97.16
Silicon (Si)	0.705
Iron (Fe)	0.471
Copper (Cu)	0.157
Manganese (Mn)	0.015
Magnesium (Mg)	0.945
Chromium (Cr)	0.068
Nickel (Ni)	0.009
Zinc (Zn)	0.026
Titanium (Ti)	0.007
Tin (Sn)	0.001
Lead (Pb)	0.002
Calcium (Ca)	0.010

Welding process

Various trial welds are done on the experimental samples to obtain adequate fusion of the base and weld metal by providing sufficient arc energies.

The welding speeds were kept at 2,3,4,5 and 6 mm/sec and the following welding parameters are kept constant and reported in the Table 2.

Table 2: Constant Welding Parameters

S. No.	Welding Parameter	Unit	Value
1	Welding current	A	150
2	Welding voltage	V	20
3	Distance between electrode and the work piece	mm	3
4	Electrode tip angle	Deg.	60°

The experimental samples with and without shallow cryogenic treatment process after welding are numbered as reported in the Table 3.

Table 3: Sample Numbers

Sample Number	Welded specimen without SCT	Welded specimen with SCT for 2hrs	Welding Speed (mm/sec)
A1	√	-	2
A2	√	-	3
A3	√	-	4
A4	√	-	5
A5	√	-	6
B1	√	√	2
B2	√	√	3
B3	√	√	4
B4	√	√	5
B5	√	√	6

The heat input during GTAW welding is calculated using the relationship [12] and reported in Table 4.

$$q/v = \frac{EI\eta}{v} \dots\dots\dots (1)$$

where, q/v is the heat input (J/mm)

E is the welding voltage (V)

I is the welding current (amps)

V is the electrode travel speed (mm/sec)

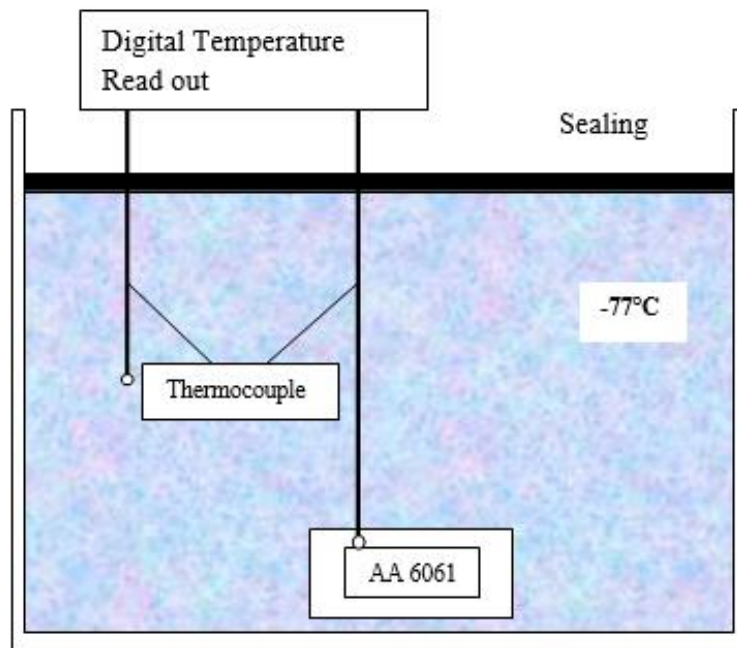
η is the efficiency of GTAW welding of aluminium = 0.74 [13]

Table 4: Heat Input To The Work Piece

S. No.	WeldingSpeed (mm/sec)	Heat Input (J/mm)
1	2	1110
2	3	740
3	4	555
4	5	444
5	6	370

Shallow Cryogenic treatment

Shallow cryogenic treatment at -77°C was done for samples B1 to B5 in a cryogenic treatment chamber after uphill quenching. The cooling rate of $0.25^{\circ}\text{C}/\text{min}$ was maintained to avoid thermal shocks and the temperatures were measured. Fig. 2 shows the schematic representation of shallow cryogenic treatment.

**Figure 2:** Schematic Representation of Shallow Cryogenic Treatment**Hardness test**

Micro hardness was measured using Mitutoyo Vickers micro hardness testing machine with 100gf load for 20 seconds.

Microstructure

The cross sections of welded region were prepared by standard metallographic procedures such as grinding, polishing and etching with Keller's reagent. The

standard polishing procedures are used for general microstructure observations as per ASTM E407 standard. A Zeiss Axiovert 25 CA inverted metallurgical microscope was used to capture the microstructure of the specimen.

Results and Discussion

Micro hardness

The average hardness of the AA 6061 – T6 is 107 HV. The average hardness values of welded region for different specimens are shown in the Fig. 5 for experimental conditions reported in Table 3.

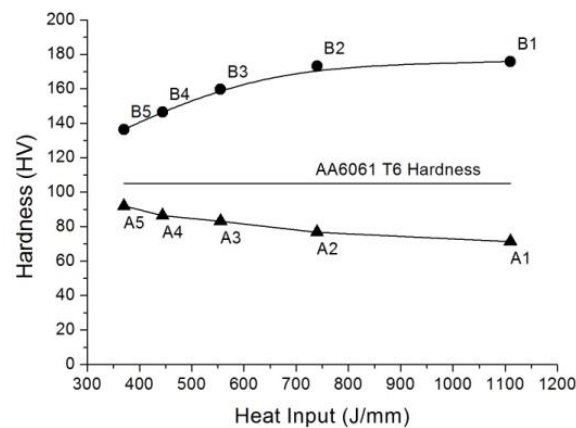


Figure 5: Micro Hardness Values for Various Samples

From the Fig. 5, it can be noted that the fusion zone hardness of the samples A1 to A5 decreases from 90 HV to 71 HV as the heat input increases, confirming with the trend reported by R. Nandan, T. DebRoy[14].

The minimum hardness value of 71 HV is obtained for the sample A1, which is 33% lower than the base metal hardness (105 HV). For the samples A2, A3, A4 and A5 the hardness is reduced by 26 %, 21 %, 19 % and 13 % respectively compared to the base metal hardness.

GTAW welding causes melting and re-solidification at the weld zone. Further, the high temperature gradient produced during GTAW welding results in the overaging, dissolution of precipitates [10] and coarsening of grains resulting in decrease in hardness [15].

From the Fig 5, it can be noted that the fusion zone hardness of the samples B1 to B5 increases from 130 HV to 170 HV, due to shallow cryogenic treatment after welding.

The maximum hardness value of 170 HV is obtained for the sample B1, which is 66 % higher than the base metal hardness (105 HV). For the samples B2, B3, B4 and B5 the hardness is increased by 64 %, 51 %, 39 % and 29 % respectively compared to the base metal hardness.

The increase in the hardness of the samples B1, B2, B3, B4 and B5 is due to excess heat input. Also the rate of cooling is slow, which increases the volume fraction of strengthening precipitates in the welded region [16, 17]. The increase in the hardness of the fusion zone of shallow cryogenic treated samples B1 to B5 as compared to the samples A1 to A5 is due to the formation of high volume fraction of stable intermetallic equilibrium precipitates of β - Mg_2Si from the β'' meta stable state in the solid solution (β'' to β - Mg_2Si) [8]. From the above it can be inferred that the post weld shallow cryogenic treatment shows better results over the as welded samples for GTAW welded AA6061.

Microstructure

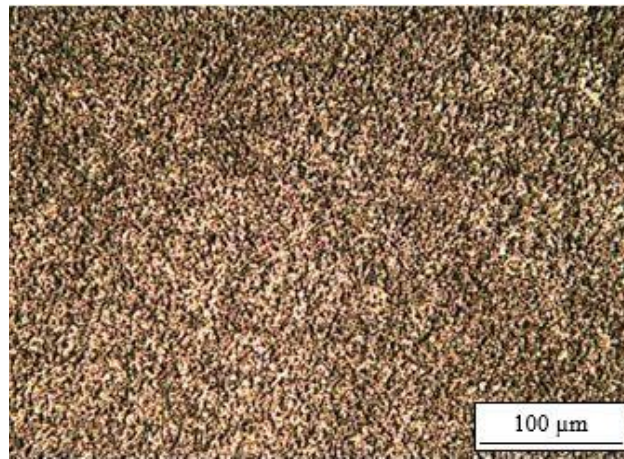


Figure 7: Microstructure of base metal

Fig.7 shows microstructure of base metal. It can be noted that the irregular distribution of coarse particles throughout the base material. This is formed during the casting and T6 artificial aging process [18].

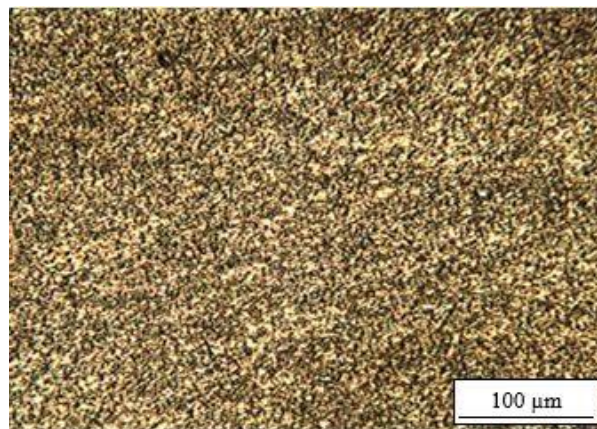


Figure 8: Microstructure of the Sample A1

The microstructure of weldment is displayed in Fig. 8. It can be observed that the grains in the welded region of sample A1 appears to be slightly coarse than the base metal due to the high heat input during the welding process [15]. Widely spaced, fewer and less dense precipitate can be seen. At low heat input the precipitate dissolves partially and the meta-stable phase transforms to a stable phase [17] resulting in marginal reduction in the precipitates than the base material.

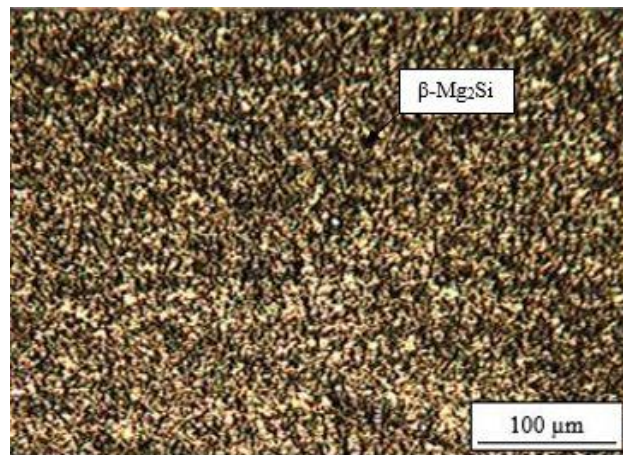


Figure 9: Microstructure of the sample B1

Figure 9 shows the microstructure of the specimen B1. It can be clearly noted that the post weld cryogenically treated sample B1 contains a fine and uniformly distributed grains, in the welded region compared to the base metal and as welded sample A1. But the change in the grain size of base metal (refer Fig.7) and welded specimen (refer Fig.8) are not obvious, showing that the post weld cryogenic treatment did not lead to substantial grain growth in this investigation. The main strengthening precipitate in AA6061 aluminium alloy is β - Mg_2Si formation and its distribution uniformly throughout alloy matrix. The stable β - Mg_2Si precipitate in sample B1 is denser with more volume fraction. This is similar to the results reported in the literature [4]. When the heat input is high, the cooling rate is slower and provides more time for precipitates to grow further. From these observation it is clear that volume fraction of the precipitation is based on the heat input during the GTAW welding process of AA6061.

Conclusion

In this work, post weld shallow cryogenic treatment is performed on the GTAW welded AA6061 T6 specimens and the following conclusions are made:

- The hardness of the fusion zone of welded samples decreases.
- The fusion zone hardness of the samples decreases from the base metal hardness as the heat input increases
- The grains become coarser after welding.

- The fusion zone hardness increases above the AA 6061 T6 after the welded specimens are subjected to shallow cryogenic treatment due to the reactivation of precipitation sequence.
- The high volume fraction of stable intermetallic equilibrium precipitates of β - Mg_2Si is formed which contributes to the increase in hardness after post weld shallow cryogenic treatment

References

- [1] Missori,S., and Sili, A., 2000, “Mechanical Behaviour of 6082-T6 aluminium alloy welds”, *Journal of Metallurgical Science and Technology*, 18(1), pp. 12-17.
- [2] Troeger, L.P., and Starke Jr,E.A., 2000, ” Microstructural and mechanical characterization of a superplasticxxx aluminium alloy”, *Materials Science and Engineering*, 277(1-2), pp.102–113.
- [3] Dong Peng, Jun Shen, Qin Tang, Cui-ping Wu, and Yan-bing Zhou., 2013, ”Effects of aging treatment and heat input on the microstructures and Mechanical properties of GTAW-welded 6061-T6 alloy joints”, *International Journal of Minerals, Metallurgy and Materials*, 30(3), pp. 259-265.
- [4] Miyazaki,M., Nishio,K., Katoh,M.,Mukae, S., and Kerr, H.W., 1990, ”Quantitative Investigation of Heat-Affected Zone Cracking in Aluminium Alloy A6061”, *Welding Journal*, 69(9),pp.362s-372s.
- [5] Liu , H.J.,Hou,J.C., Guo,H., 2013, ”Effect of welding speed on microstructure and mechanical properties of self-reacting friction stir welded 6061-T6 aluminium alloy”, *Materials and Design*,50, pp. 872–878.
- [6] Ehab, A., El-Danaf., Magdy, M., El-Rayes., 2013, ”Microstructure and mechanical properties of friction stir welded 6082 AA in as welded and post weld heat treated conditions”, *Materials and Design*, 46, pp. 561–572.
- [7] Lakshminarayanan,A. K.,Balasubramanian, V., and Elangovan, K.,2009,“Effect of welding processes on tensile properties of AA6061 aluminium alloy joints”, *International Journal of Advanced Manufacturing Technology*,40(3-4),pp.286–296.
- [8] Nikseresht,Z., Karimzadeh,F., Golozar,M.A., and Heidarbeigy,M., 2013, ”Effect of heat treatment on microstructure and corrosion behaviour of Al6061 alloy weldment”, *Materials and Design*, 31(5), pp.2643–2648.
- [9] Grazyna., Mrowka-Nowotnik., and Jan Sieniawski., 2005, “Influence of heat treatment on the microstructure and mechanical properties of 6005 and 6082 aluminium alloys”, *Journal of Materials Processing Technology*, 162–163(), pp. 367–372.
- [10] Debdulal Das., Apurba Kishore Dutta., and Kalyan Kumar Ray., 2010, ”Sub-zero treatments of AISI D2 steel: Part I. Microstructure and hardness”, *Materials Science and Engineering*, 527(9), pp. 2182–2193.

- [11] Po Chen., Tina Malone., Robert Bond., and Pablo Torres., 2001, "Effects of Cryogenic Treatment on the Residual Stress and Mechanical Properties of an Aerospace Aluminium Alloy", Proceedings of the 4th Conference on Aerospace Materials, Processes, and Environmental Technology, 2001.
- [12] M Ericsson, R Sandström, 2003, "Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG", International Journal of Fatigue, 25(12), pp. 1379-1387.
- [13] Arul, S., and Sellamuthu,R., 2011, "Application of a simplified simulation method to the determination of arc efficiency of gas tungsten arc welding (GTAW) and experimental validation". Int. J. Computational Material Science and Surface Engineering, 4(3), pp. 265-280.
- [14] Nandan,R., DebRoy,T.,and Badeshi,H.K.D.H.,2008, "Recent advances in friction-stir welding – Process, weldment structure and properties", Progress in Materials Science, 53(6), pp. 980–1023.
- [15] Subodh Kumar., and Shahi, A.S., 2011,"Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints", Materials and Design,32(6), pp. 3617–3623.
- [16] Temmar,M.,Hadji,M., andSahraoui,T., "Effect of post-weld aging treatment on mechanical properties of Tungsten Inert Gas welded low thickness 7075 aluminium alloy joints", Materials and Design, 32(6), pp. 3532–3536.
- [17] Ma,T., and DenOuden,G., 1999, "Softening behaviour of Al–Zn–Mg alloys due to welding", Materials Science and Engineering, 266(1-2), pp.198–204.
- [18] Agarwal, H., Gokhale, A. M., Graham, S., Horstemeyer, M. F., "Void growth in 6061-aluminum alloy under triaxial stress state", Materials Science and Engineering, 341(1-2), pp. 35-42.

