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Microstructure and Mechanical Properties of Welded Joints of AA6061-T6 Alloy by Cold Metal Transfer Method

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Abstract**: *CMT bonding process were done on the 2 plates of 5 mm thick AA6061-T6 alloy by means of ER 4043 wire-electrode of Φ1.2 mm as the filler metal. This study concentrates the impact of a PWHT on the micro-structural and mechanical characteristics of an AA6061-T6 alloy specimen bonded by means of GMAW and by CMT. The welded samples here separated as as-welded and PWHT samples. The ASTM standard E8M-04 was used for cutting all samples in order to get the tensile strength and to measure the bonded joint elongation. The hardness across the bonded joints was measured by using Vickers micro-hardness testing setup. Scanned electron microscopy (SEM) is employed to analyse failure pattern of tensile test performed specimens.***

Keywords**: *Microstructure, CMT welding, PWHT.***

I. INTRODUCTION

The Al alloys has been employed in wide range of manufacturing industries. Shipbuilding, aerospace and automotive industries are few industries are trying to make their product higher efficient one by reducing weight of its body. This can be achieved by adding few aluminum parts with the steel structures. When joining aluminum parts with steel structure by fusion welding will lead a major problem due to development of brittle inter-metallic compounds which further can disintegrate the mechanical characteristics of the bonded joints.

Burger GB et al [1] 6061 Al-alloys are extensively used in the automotive manufacturing industry for fabricating numerous types of automobile parts. Lee SH [2] it is extremely estimated that replacement of Al alloys instead of steel will cause drastic development in recycling and cost of the product life cycle. For exact nominated heat treatment the characteristics of different Al-alloys shall changed. To raise the strength and hardness of certain aluminum alloys solution treatment can be done. This is usually done at temperature up to 200 ºC [3].

M. Kreimeyer et al [4] have shown that when aluminum is welded with steel, welding joint could be performing mechanically well. M.J.M. Hermans [5] proposes fusion welding is one of the welding methods to solve dissimilar metal joining problems due to its greater efficiency. Kavery Elangovan [6] et al has examined the effect of the FSW joints for AA6061 aluminum alloy plates. During joining process a very common incidence in GMAW is spatters, which are droplets of molten material that generated at or near the welding arc which create trouble to the welder. Eirefaey et al [7] have pointed out that the CMT welding process can offer adaptability, energy efficiency and friendliness environment. Since no spatter, low thermal heating input and ability to bridge the gap, the CMT process is considered as best method for bonding thin Al-alloys as indicated by [8] Pickin et al. H.T. Zhang et al [9] have used CMT as altered MIG welding process and the process for droplet transfer has been examined. R. Akhter et al [10] have used Aluminium alloy A356 and the study on the impact of pre and post T6 HT on the mechanical characteristics for the above material. In this research, Z. Nikseresht [11] has described the corrosion behaviour and micro-structural behaviour of Al6061 alloy welded by GTAW and followed by different HT has been investigated. From the literature review, it is clearly understood that more research to be concentrated on the effect of a PWHT in Aluminium alloy series by GMAW-CMT process. Thus, the current study were executed to know about the impact of PWHT at AA and STA conditions on the micro-structural and mechanical characteristics for AA6061-T6 alloys bonded by GMAW-CMT welding process.

II. RESEARCH METHODOLOGY

A 5 mm thickness AA6061-T6 has used in this work and wire-electrode ER 4043 of Φ1.2 mm were actively used as fillers. Table 1 elucidates the Al alloy's nominal chemical compositions.

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The mechanical properties for wire-electrode are elucidated in Table 2. The AA6061-T6 alloy has sliced into several pieces of breadths 100 mm according to the ASTME8M 04standards. Milling machine have used to prepare grooving with an angle of 300 for each part according to ISO 9692 as delineated in Fig. 1 and 2. The GMAW-CMT welding process has employed to bond the work samples. The shielding gas used is Ar of fixed discharge 18 lit/min to protect weld area from the oxygen and water vapour which is presents in atmosphere. The linear 6D robotic displacement machine is used to perform the welding. Fronius CMT advanced 4000R welding system has a remote control unit to control the speed of the wire-feed. The complete bonding parameters were shown in Table 3, and in this study the parameters used in CMT welding are optimized in different runs of pre-experiments. Before welding, alcohol was used to wipe the base material to abolish impurities like as grease, dust, and oil which will normally exist next the grooving and cutting processes to ensure better welding process [12]. The microstructure of AA6061-T6 is shown in Fig. 3.

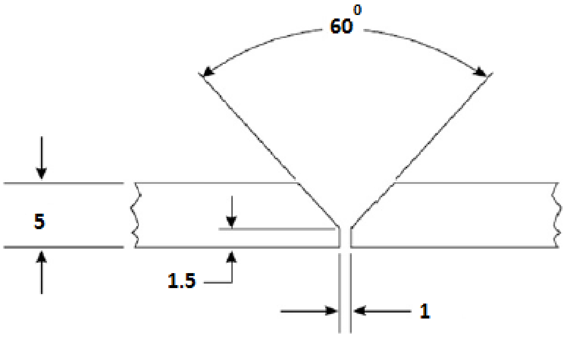


Fig. 1. Single V groove joint (mm) as per ISO 9692 Weld Joint Preparation

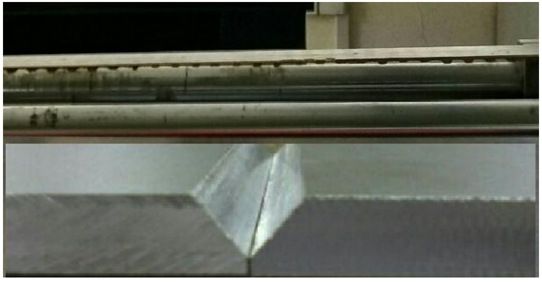


Fig. 2. Finished grooving for welding

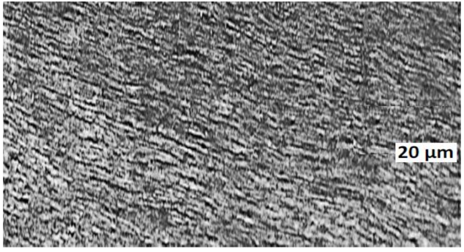


Fig. 3.Microstructure of base metal (Al 6061-T6 alloy)

Table 1
Chemical compositions of work samples and wire-electrode

Material	Si	Cu	Fe	Mn	Ti	Cr	Zn	Mg	Al
AA6061-T6	0.7	0.32	0.5	0.07	0.02	0.19	0.12	1.0	Bal.
ER4043	4.5–5.5	–	<0.6	<0.15	<0.15	–	<0.1	<0.2	Bal.

Table 2
Mechanical properties of work samples and wire-electrode

Materials	Elastic Modulus (GPa)	Yield Strength (MPa)	Elongation Rate (%)	Ultimate Tensile Strength (MPa)
AA6061-T6	72	286	14	333
ER4043	71.2	70	22	145

At ambient temperature let say about 250C, the single V-grooved joint were bonded. To restore the mechanical characteristics in the Heat Affected Zone of the weldments, AA treatment at1200C for 24 hours soaking period was applied on Al 6061-T6 alloy samples which was used in this study and the STA were done by solutionizing at 4800C for 60 min soaking period followed by quenching by water and done ageing for 24 hours at 120 ºC. Specimens were cut in accordance to E8M-04 ASTM standard to perform tensile testing. A CNC wire EDM machine setup was employed for cutting the welded workpieces into the selected dimensions, as delineated in Fig. 4. Tensile specimens were taken to Universal Testing Machine and testing was done at 100 kN load and a cross head speed of 1.51 mm/min, at room temperature. SEM analysis used to examine the fracture occurred on the surface of the specimens. Hardness at three various zones of the samples were found using Vickers micro-hardness machine with a load capacity of 0.2 kg and 15 sec as the dwell time.

Table 3
Process parameters during CMT welding.

Parameters	Value
Welding speed (mm/s)	7
CMT current intensity (A)	95
Wire feed rate (m/min)	5.5
CMT voltage (V)	14.5

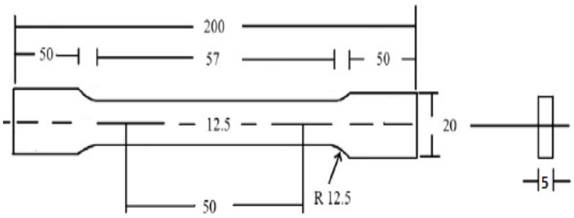


Fig. 4.Tensile test dimension (mm)

III. RESULTS AND DISCUSSION

A. Mechanical properties

Fig. 5. Elucidates average of four stresses value to determine the tensile strength. The numerical results for as-welded tensile strength and PWHT's samples are 90.33 and 92.31 MPa respectively [13]. Hence, a 2.2 % increment in tensile strength was attained when applying PWHT on bonded joints.

An improvisation in tensile strength for PWHT of AA6061-T6 joined by GMAW method was also observed [14], where specimens were solutionised, water quenched and artificial aged.

Fig.6. delineates the % elongation of as-welded samples and PWHT samples. For as-welded samples the percentage elongation were recorded as 7.49% and for PWHT's were 9.73% respectively. Due to PWHT applied on the welded samples there were increase in percentage of elongation by 29.91%. This increase in percentage of elongation achieved due to Solution Heat Treatment (SHT). An increase in the ductile property and reduction in the higher flow stress shall be obtained for any aluminum alloy by SHT [15]. Due to the solution heat treatment done on the welded samples at elevated temperature, increase in ductility was achieved and this increase in ductility further increased the percentage elongation of the bonded samples.

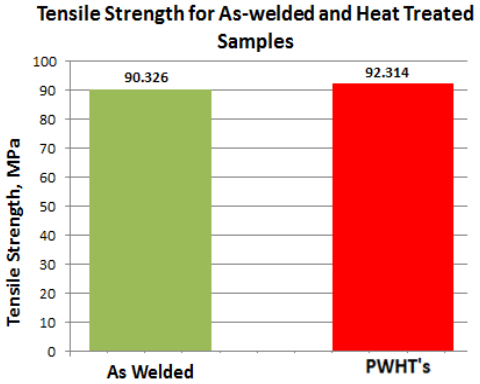


Fig. 5. Comparison of TS of as-welded samples and PWHT samples

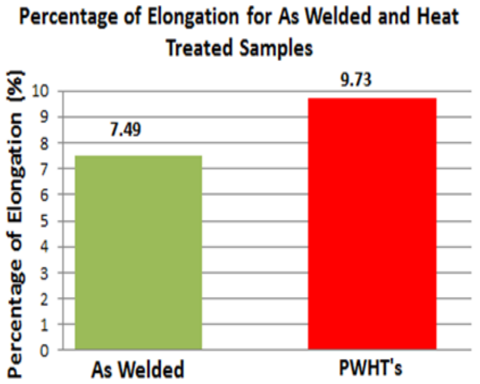


Fig. 6. Comparison of % Elongation of as-welded and PWHT's work specimens

Table 4
HV of as-welded and PWHT's work specimens

Sample	Upper (HV)	Centre (HV)	Lower (HV)	Average (HV)
As-welded	78.8	71.3	83.2	77.77
PWHT's	95.3	95.3	91.4	94.0

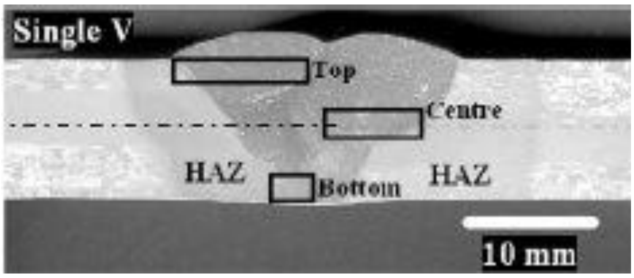


Fig. 7. Etched welds view indicating the regions for micro-hardness test

A Vickers Micro-hardness checking machine setup was employed for testing hardness of the samples at 3 various parts: at the upper, centre and lower parts of the weldment areas, with loading of 0.2 kg as delineated in Fig. 7. The Table 4 elucidates as-welded and PWHT's work samples average hardness values. As reported by M. Hajihashemi et al [16], the hardness of bonded area dissipates lesser value than the base metal. The Fig. 8 delineates the hardness values for different locations of as-welded and PWHT's work specimens. Fig. 9 delineates the values of average hardness for as-welded and the PWHT's work specimens. From Table 4 and Fig. 8, the highest hardness value 83.2 HV has achieved at the bottom position for as-welded samples. AA6061 was bonded by varying polarity CMT method at different gap widths and their micro-hardness values are between 51 and 76 hardness value. Though, highest hardness value 95.3 HV had achieved at top and centre position for PWHT's samples. The highest average hardness value 94.0 HV had achieved for PWHT's samples. By applying PWHT for welded AA6061 T6, the range of the hardness has considerably improved by 20.87% than those of the as-welded work specimen and same type of responses were reported by R. Ahmad et al [17]. By the implement of PWHT's on the CMT welded joints of AA 6061 T6 has given the significant improvements in properties like hardness, tensile strength and elongation when related with the as-welded joints.

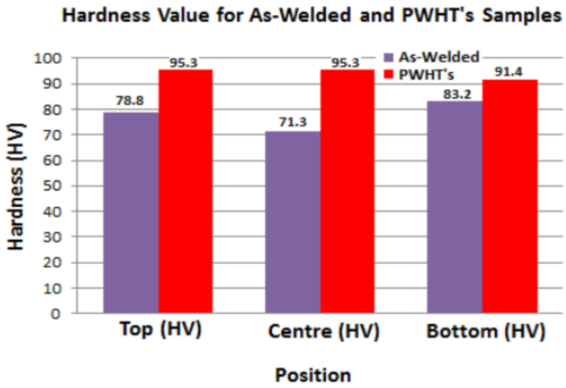


Fig. 8. HV at different positions of as-welded and PWHT's specimens

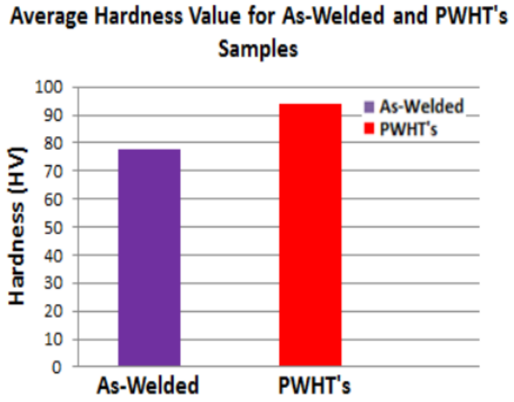


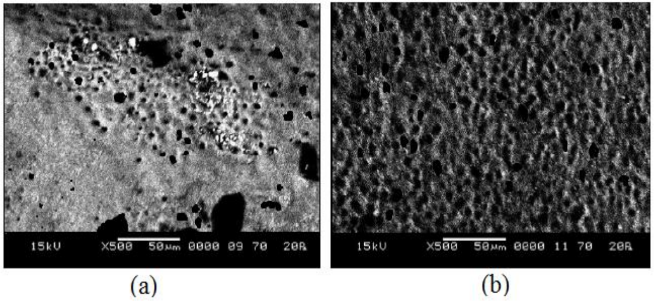
Fig. 9. Average HV of as-welded and PWHT's specimens

Bahman Mirzakhani et al [13] have applied combination of age hardening process and cold rolling process to the AA6061.

Cold working processes on the welded joints higher the density of the dislocation in the material structure which also raises the yield strength as well as the tensile strength of AA6061 alloy. Effect of PWHT on the tensile and micro-structure properties of FSW armour AA7075-T651 was investigated [18], where the PWHT's categorized as solution HT, water quenching and AA. Impact of TIG welding parameter current in the micro-structure and mechanical characters of AA6061-T6 by TIG–CMT bonding process was employed in this work [19], where the heat input during joining process increased by increasing TIG current. The TIG joining was done on 2 AA6061-T6 alloy plates by means of the filler type ER5356 [20], PWHT performed on the welded joints which improved Ultimate tensile and yield strength whereas the elongation decreased. From the many research work, it is also evident that the strength of AA6061 T6 achieved further when PWHT's implemented on the welded joints.

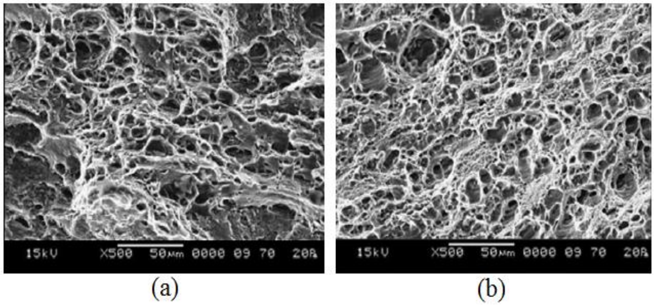
B. Fracture surfaces

Fig. 10 elucidates the SEM fractograph of upper surface of bonded area, size and grains spacing developed during welding. The grains size almost constant and reasonably small in size and the grains was positioned very near to each other. The ductility nature of the welded joint can be realized from the spacing between the grains. As the grains spacing is very close to each other in PWHT specimens and thus it resulted in a ductile fracture along with a good plastic deformation. As it is clear from the mechanical test which presented in the Fig. 5, the strength of this alloy after the PWHT were enhanced but the HAZ was weakest part and the specimens normally fails in this region. Fig. 11 shows the middle portion of the tensile fractured surfaces of as-welded and PWHT specimens. This result is also concluded by Zhang [21] and reported that for smaller dimple size will lead relatively better ductility for the material AA6061 alloy. Fig. 12 shows the bottom portion of the tensile fractured surface. As shown in Fig. 12 cleavage like failure patterns at the bottom region were revealed.



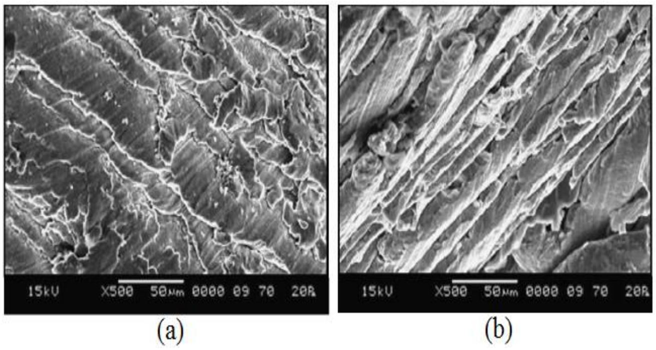
(a) (b)

Fig. 10. SEM image of upper surface of tensile tested workpieces; (a) as-welded; (b) PWHT



(a) (b)

Fig. 11. SEM image of centre of tensile tested workpieces; (a) as-welded; (b) PWHT



(a) (b)

Fig. 12. SEM image of the weld bottom of tensile tested workpieces; (a) as-welded; (b) PWHT

IV. CONCLUSION

The impact of PWHT on micro-structural and mechanical behaviours for the CMT joints of AA6061-T6 has been examined. Based on the results, the listed conclusions were drawn:

- Micro-structural investigations of CMT weld joints under as – welded and PWHT were carried out on AA6061-T6.
- By applying PWHT on a welded specimen, 2.2 % increase in tensile strength, 20.87 % increase in hardness value and a 29.91 % higher elongation was attained.
- The good welding characteristics of CMT method along with PWHT on the weld joints produced grains of fine and uniform distribution on specimen. Due to these facts, increased hardness value, tensile strength and the elongation was achieved.
- From the SEM images, a lesser grain size, lesser grain gap, fairly small voids and smaller cleavage facets was identified.
- All the tensile specimen was failed in the HAZ, which indicates that heat affected zone still have lesser ability for plastic deformation than the remaining base material.

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