

# Experimental Investigation of Aluminium 6061 Alloy By Gas Tungsten Arc Welding Process

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**Abstract**—Aluminium and its alloys have been used in recent times due to their light weight, moderate strength and good corrosion resistance. The aluminium alloys requires special tool and skill to weld due to high thermal conductivity. In this paper, mechanical properties of the 6061 aluminium alloy single V butt joints welded using ER4043 filler metal with a gas tungsten arc welding (GTAW) were studied. An aluminium alloy plate of 6mm thickness has been selected as specimen. The aluminium welded joint specimens were prepared using the (GTAW) process by different welding parameter values. The input parameters welding current, filler rod diameter, bevel angle, gas flow rate were varied according to full experimental design. Experimental work included tensile test and hardness test on both welded and unwelded specimens. The values of mechanical properties are affecting the mechanical properties of 6061 aluminium alloy specimen joints. GTAW exhibited lower tensile strength, hardness than the parent metal.

**Keywords**- Component; Bevel Angle, ER4043, Tensile Strength, Hardness.

## I. INTRODUCTION

Aluminium alloy 6061 (Al-Mg-Si alloy) is widely used in the fabrication of food processing equipment, chemical containers, passenger cars, road tankers and railway transport systems due to its high strength, excellent weldability and resistance to corrosion. As these Al alloys (6xxx series) are precipitation-hardened, they suffer from a strength reduction in heat affected zone (HAZ) and like most face-centered cubic metals, they do not exhibit clear endurance limit [1]. GTAW is an arc welding process, where arc is produced between non-consumable tungsten electrode and base metal. Pulsed GTA welding process is frequently used for welding of aluminium alloys as heat input during welding can be precisely controlled. This process is strongly characterized by bead geometry, which plays an important role in determining mechanical properties of the weld [2]. Pulse process variables are controlling factor for heat input, which in turn leads to grain refinement in fusion zone, width reduction of HAZ, segregation of alloying elements, reducing hot cracking sensitivity and residual stresses [3,4]. Improved mechanical properties of weld are achieved by using current pulsing due to the grain refinement occurring in the fusion zone. The main aim of pulsing is to achieve maximum penetration without excessive heat built-up. The use of high current pulses is to penetrate deep and cater for longer arc period at lower current. Deep penetration in pulsed current welding is produced by arc pressure at peak for longer durations [4]. In addition to this argon-helium gas mixture offers certain ad-

vantages by increasing heat input of the arc during welding. Argon is known for stable arc with better arc ignition whereas helium provides higher thermal conductivity. There exists a linear relationship between heat input of a weld and maximum temperature at a given distance from the weld centre line. It shows that pulsed arc welds are cooler and exhibit less thermal distortion than conventional GTA welds of the same penetration [5]. Heat input is typically calculated as follows:

$$H = [60 E I] / 1000 S$$

where  $H$  = Heat Input (kJ/mm),  $E$  = Arc Voltage (Volts),  
 $I$  = Current (Amps) and  $S$  = Travel Speed (mm/min).

The evolution of microstructure in weld fusion zone is influenced by current pulsing and cyclic variations of energy input into the weld pool causing thermal fluctuations. Consequently this leads to periodic interruption in solidification process. As pulse current decays, solid liquid interface advances towards the arc and becomes susceptible for disturbances in the arc formation. As current increases again in the subsequent pulse, the growth of dendrites can also occur. Current pulsing also results in periodic variations of the arc forces resulting in additional fluid flow, which lowers the temperature in front of the solidifying interface. Furthermore, the temperature fluctuations inherent in pulsed welding leads to a continual change in the weld pool size and shape favoring growth of new grains. It is to be understood that effective heat input for unit volume of weld pool should be considerably less in pulse current welds and thus expecting the average weld pool temperatures to be low [6].

## II. EXPERIMENTAL PROCEDURE

The material under investigation is 6.00 mm thick Al alloy 6061. A non-consumable tungsten electrode of 2.4 mm  $\Phi$  shielded by argon gas is used to strike the arc with base metal. Filler rods (31.5 mm  $\Phi$ ) of Aluminium alloy 5183 are recommended for welding of this alloy for getting maximum strength and elongation. The chemical composition of base metal and filler rod are tabulated in **Table 1**. Sample plates of size 300  $\times$  150  $\times$  5 mm were prepared by milling and EDM wire-cut machines. Welding of the samples was carried out on Automatic Pulse GTAW Tri-ton 220 V AC/DC. In order to remove oil, moisture and oxide layer from base metal, they were thoroughly wire brushed, cleaned with acetone and preheated at 150°C in the oven. The quality of weld is based

on the process parameters, such as pulse current in the range of 150 - 210 A, base current in the range of 75 - 135 A, pulse frequency in the range of 50 - 150 Hz, pulse-on-time in the range of 30% - 90% and percentage of He in Ar + He mixtures in a range of 10% - 50%.

Tensile specimens of required dimension as per ASTM E8M were separated out from welded coupon plates and tests were carried out on 400 kN computer controlled Universal Testing Machine. The specimens were loaded at the rate of 1.5 kN/minute as per ASTM specifications, so that the tensile specimen undergoes deformation. All specimens finally fail after necking and the influence of load on displacement profile was recorded. Higher the tensile properties have better quality characteristics.

At the same time for microhardness measurement, samples of transverse cross-section of joint were taken from the weld coupons. The specimens for microstructural characterization were mechanically polished using 220, 320, 400, 600 and 1000 grit waterproof SiC emery papers and alumina grade-II paste. Microhardness tests were carried out on a Leco Digital Microhardness Tester with 50 gf load and 15 second dwell time incorporated with diamond indenter. Final polishing was carried out using 3 and 1 μm diamond paste. To reveal the macro-structures of the welded sample, deep etching technique using 10% HF acid solution in water was used. However, for further revealing of microstructures, Keller's reagent was used as etchants. Metallurgical microscope coupled with Image Analysis system was used for the microstructural characterization and to measure the porosity level in the weldment.

TABLE 1. Chemical Composition of Base Metal and Filler Rod.

| Aluminium Alloys | Weight Percentage |     |      |      |      |      |
|------------------|-------------------|-----|------|------|------|------|
|                  | Mg                | Si  | Cu   | Zn   | Mn   | Al   |
| 6061             | 1.1               | 0.7 | 0.25 | 0.25 | -    | Rest |
| 5183             | 4.55              | -   | -    | 0.1  | 0.65 | Rest |

2.1 Welding Parameters During Experimentation

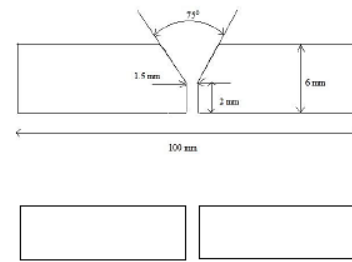
The process parameters values are selected depend upon material thickness. The following welding parameters for the experimentation. They are,

- Welding current
- Filler rod diameter
- Gas flow rate
- Bevel angle

The range of the welding parameters of sample-1, sample-2, sample-3 are shown in Table 2

2.2 Sample preparation

Aluminium alloy 6061 plates with the dimensions of 200x30x6 mm are prepared with the welding current 170A, 190A, 210A. Bevel angle 30°, 40°, 50°. Filler rod diameter 1.6mm, 2mm, 2.4mm. and the shielding gas flow rate 5 L/min, 8 L/min, 10 L/min. the specimen are welded by tungsten inert gas welding process. Figure 1 shows the single V-butt joint configurations.



All dimensions are in mm

Fig.1 sample specimen with bevel angle

Table 2 Welding Process Parameter For Experimentation

| PROCESS PARAMETERS   | SAMPLE-1 | SAMPLE-2 | SAMPLE-3 |
|----------------------|----------|----------|----------|
| Current(A)           | 170      | 190      | 210      |
| Filler Rod Dia(mm)   | 1.6      | 2        | 2.4      |
| Gas Flow Rate(L/min) | 5        | 8        | 10       |
| Bevel Angle(degrees) | 30       | 40       | 50       |

2.3 Welding Procedure

First of all the specimen are cleaned of dirt, grease and other foreign materials by using cleansing agents, dirt removers or other re-agents. After cleaning of work pieces, welding set-up is prepared and tested. Further, the parameters are adjusted according to required level and made ready for welding. Then two pieces are taken which are set up in such a way so as to maintain a 2 mm root gap. Then 18 numbers of welded samples are made by carrying out welding with different levels of current, gas flow rate and preheating of samples.

III. MECHANICAL TESTING

3.1 Tensile Test

To identify the weakest portion of the welded joint transverse tensile test was carried out the reduced section of the specimen contained base metal affected zone (HAZ) and weld metal. Samples for tensile tests were machined as per AWS B4.0.98 reduced transverse rectangular tension test specimen.

Tensile testing was carried out using a 100 kN, electro-mechanical controlled Universal Testing Machine (Make: FIE-Bluestar, India; Model: UNITEK-94100). The 0.2% offset yield strength was derived from the load-displacement diagram. Tensile specimens were prepared from the weld metal region (longitudinal direction) alone as per the ASTM E8M-04 standard to evaluate all weld metal tensile properties. The welded joints were sliced using a power hacksaw and then machined to therequired dimensions as shown in Figure 2.

Testing of Materials (ASTM E8M-04) guidelines were followed for preparing the test specimens. The tensile specimens were prepared to evaluate yield strength, tensile strength, elongation and reduction in cross sectional area.

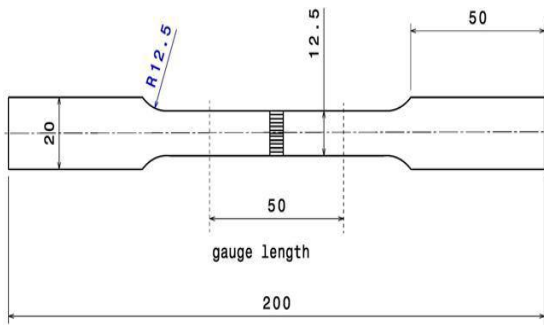


Figure 2. Tensile Test Specimen  
All dimensions are in mm

3.2 Hardness Test

Hardness was measured under 40x objective and an applied load of 300gms using Vickers microhardness tester. Three readings were taken and the average value has been reported in Tables 4 and 5. Measurement were taken along a line at half of the depth of fusion zone across the entire weld region at an interval of four times the indenter's size to avoid the effects of localized strain hardening in the vicinity of the indentation attributed to the dissolution of precipitates' into solution and subsequently.

IV. RESULTS AND DISCUSSION

4.1 Tensile test

The tensile properties i.e, the ultimate tensile strength and the position of the fracture of AA6061 conventional TIG welding process weld ment are tabulated in above table. The average values of ultimate tensile strength for AA6061 weld ments were found to be 105.820MPa, 128.968mpa, and 88.987mpa respectively. Even though fracture occurred in the weld region its ultimate tensile strength is higher than the recommended value. This shows that the weld quality is good and the joint efficiency is high. As compared to specimen 1 and specimen 3, specimen 2 have better tensile strength.

TABLE 3. TRANSVERSE TENSILE TEST RESULT

| Specimen | YS in (MPa) | Ult.stress in (MPa) | Elongation in (%) | Breaking load in (Kgf) |
|----------|-------------|---------------------|-------------------|------------------------|
| 1        | 84.656      | 105.820             | 1.25              | 25.231                 |
| 2        | 99.206      | 128.968             | 2                 | 26.374                 |
| 3        | 66.741      | 88.987              | 2.5               | 26.770                 |



Fig. 3 Fractured tensile specimen

4.2 Hardness Test

Hardness profile indicates a decrease in the weld hardness in the weld region, and this has been a Hardness measurement of the various weld regions were performed using a Vickers diamond indenter. favor nucleation and growth of all precipitates .The transition region indicates a reduction in

hardness because of coarsening precipitates. The average hardness at different areas of the welded work piece are as given below.

Table.4 Hardness Values for Welded Specimen-1

| Distance (mm) from the weld | 0     | 5    | 10   | 15   | 20   |
|-----------------------------|-------|------|------|------|------|
| Hardness value (HRF)        | 38.02 | 23.4 | 45.4 | 52.5 | 68.8 |

Table.5 Hardness Values for Welded Specimen-2

| Distance (mm) from the weld | 0     | 5    | 10   | 15   | 20   |
|-----------------------------|-------|------|------|------|------|
| Hardness value (HRF)        | 40.21 | 41.5 | 52.4 | 69.7 | 76.3 |

Table.4 Hardness Values for Welded Specimen-3

| Distance (mm) from the weld | 0     | 5    | 10    | 15    | 20   |
|-----------------------------|-------|------|-------|-------|------|
| Hardness value (HRF)        | 43.12 | 44.3 | 62.41 | 76.58 | 84.9 |

V. CONCLUSIONS

On the basis of present experiment work following conclusion were drawn

- In macro examination, the sample was macro etched and examined visually reveals complete fusion between weld and base metal. No weld defects are observed.
- Tensile strength of welded joints of 6061 aluminium alloy, under experienced welding conditions, It is found that the tensile strength is optimum at welding current 190A. Filler rod diameter 2mm, bevel angle 40 degree, shielding gas flow rate 8 L/min (sample2).The increasing of welding current will reduce the tensile strength of 6061 aluminium alloy welded metal.
- Hardness is higher in the weld metal region compared to the HAZ and BM regions. High hardness is recorded in the weld zoon. And the maximum hardness of 84.9 HV in the weld zoon . the parent metal 69.1 HV is recorded. It is found that the highest hardness value at the welding current 210 A, filler rod diameter 2.4mm, bevel angle 50 degree, shielding gas flow rate 10 L/min (sample 3).

VI. NOMENCLATURE

- GTAW Gas Tungsten Arc Welding
- GMAW Gas Metal Arc Welding
- WM Weld Material
- HAZ Heat Affected Zoon
- BM Base Material
- TIG Tungsten Inert Gas
- MIG Metal Inert Gas
- HV Vickers Hardness
- HB Brinell Hardness
- ER Electrode, Rod

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