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Design and Experimental Analysis of Aluminium Alloy Weld Joint by Using P-GMAW Process

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ABSTRACT

The alumimium alloy weld joints sizing the weld plates 300mm X 150mm having 10 mm thickness are studied to investigate the influence of welding parameters on the mechanical properties of gas metal arc welding process. The quality of a weld joint is strongly influenced by process parameters during the welding process. This paper influences development of mathematical models for the selection of process parameters and the prediction of bead geometry (bead width, bead height and penetration). Full factorial design is employed for optimization of process parameters. The various welding parameters like welding speed (N), shielding gas, wire feed rate (f), current (I), voltage (V), power supply, filler wire material and gas flow rate (Q) are affecting the mechanical properties of weld joint. In order to achieve high quality welds, mathematical models that can predict the bead geometry and shape to accomplish the desired mechanical properties of the weld should be developed.

Keywords: **Aluminium Alloys, Gas Metal Arc Welding, Mechanical Properties, Welding Parameters**

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I. Introduction

a Recent trend in the automotive world has been transition from conventional materials to light materials like aluminium. The welding behaviour of aluminium alloys significantly differ from conventional materials like steel.

Physical properties that influence the aluminium alloy weld joints are:

- high thermal conductivity;
- high solidification shrinkage;
- oxide formation at the surface;
- high thermal expansion coefficients;
- high solubility of hydrogen in molten state;
- solidification temperature range;

The traditional method of joining mechanical components in structural applications through fasteners, rivet joints etc. These methods can be replaced by welding process in considerable reducing time for manufacturing, decreased weight and improved mechanical properties. The process is more efficient, economical and dependable.

Welding is a process of joining two similar and non similar metals through coalescence resulting in suitable combination of temperature, pressure and metallurgical conditions using filler material.

Different methods of welding processes are as follows :

- Arc Welding
- Gas Welding
- Resistance welding
- Solid state welding
- Fusion welding
- MIG welding
- TIG welding
- Friction Stir welding

Nowadays, gas metal arc welding (GMAW) is widely used in various constructions such as steel structures, bridges, automobiles, construction machineries, ships, offshore structures, pressure vessels and pipelines because of high welding efficiency. This welding process requires specific welding knowledge and welding technology to get sound weld joints. The quality of weld joints made by GMAW is affected by the welding parameters set by a welding operator. The use of a wrong welding parameter or improper handling of the welding equipment results in non acceptable weld joints that contain welding defects.

GMAW was initially developed as a high deposition rate, high welding rate facilitated by continuous wire feed and high welding currents. The sensitivity to porosity and fusion defects, limited its use where weld quality was not of that importance. In order to improve quality and to overcome the limitations of conventional GMAW process which led in the development of pulsed arc technologies.

The pulsed GMAW process works by forming one droplet of molten metal at the end of the electrode per pulse. Then, required amount of current is added to push that one droplet across the arc and into the puddle. In conventional GMAW process, the current supply was continuous. In pulsed GMAW process, the current drops at times when extra power is not needed hence cooling off the process occurs. It is this “cooling off” period that allows Pulsed GMAW to weld better on thin materials, controls distortion and wire feed speed is low.

II.LITERATURE REVIEW

a Lakshminarayanan A.K. et al investigated the AA6061 Aluminium alloy joints mechanical properties welded by gas metal arc welding, gas tungsten arc welding and friction stir welding. Single V joint configuration, pure argon shielding gas and AA4043 filler wire were used for the gas metal arc welding and gas tungsten arc welding. Non consumable high carbon steel tool was used for the friction stir welding. Diamond compound was used for a final polishing. The friction stir weld (FSW) joints produced the high strength values than GMAW and GTAW. The strength value 34% higher than the GMAW and 15% higher than the GTAW. The base metal and heat affected zone produced the high hardness values than the weld metal. FSW produced the high hardness value and GMAW produced low hardness value. Equiaxed uniformly distributed fine grains increased the high tensile properties in the weld region for FSW joints [4].

Balasubramanian V. et al studied the high strength aluminium alloy joints produced by gas metal arc welding and gas tungsten arc welding under the effect of continuous current and pulsed current technique. Pure argon used as a shielding gas. The pulsed current gas metal arc weld joints produced high strength values and high joint efficiency than other welded joints. Due to that of fine grains the Base metal and heat affected zone regions produced high hardness values than weld metal. Pulsed current gas tungsten arc weld joints produced high highness values and continuous current gas metal arc weld joints produced low hardness values. A very fine grain in the welded region was produced by the pulsated current gas metal arc welding [4]..

G. M. Domínguez Almaraz et al conducted a fatigue test on welded and non-welded specimens of AA 6061 T6. Experimental tests show an important reduction on fatigue endurance of welded specimens in regard the non-welded specimens. Crack initiation is localized frequently at the partial melting zone (PMZ),where crystallographic modifications take place induced by the heat welding. Principal results and originality of this work are: fatigue endurance under rotating bending fatigue for welded and non-welded specimens, crack length behavior with the number of cycles for the welding zones, crack growth rate for welded and non welded specimens and the nonlinear regression models correlating applying load and fatigue life for both specimens[5].

V. Balasubramanian et al investigated the influences of welding and post weld aging treatment on fatigue crack growth behaviour of AA7075 aluminium alloy (Al–Zn–Mg–Cu alloy). Rolled plates of 6 mm thickness have been used as the base material for preparing single pass butt welded joints. The filler metal used for joining the plates is AA5356 (Al–5Mg (wt.%)) grade aluminium alloy. Argon (99.99% pure) has been used as the shielding gas. Fatigue crack growth behaviour of the welded joints has been evaluated by conducting the test using servo hydraulic controlled fatigue testing machine. Current pulsing leads to relatively finer and equi-axed grain structure in GTA welds. Grain refinement is accompanied by an increase in fatigue crack growth resistance and fatigue life [6].

Sivashanmugam M et al They worked on Aluminum alloy 7075 by the process of GTAW using argon as metal inert gas and Tungsten was used as electrode. The Butt joint was made of 300 x 150mm using 99.99% argon as a shielding gas .The parameters considered for investigation are tensile strength, hardness and impact test. The tensile strength get decreased with respect to parent metal. Hardness is get increased at weld metal. From impact load it was found that absorption of energy is less from charpy & Izod test [7].

V. Balasubramanian et al studied high strength aluminium alloys (Al–Zn–Mg–Cu alloys) have gathered wide acceptance in the fabrication of light weight structures requiring high strength-to weight ratio, such as transportable bridge girders, military vehicles, road tankers and railway transport systems. The preferred welding processes of high strength aluminium alloys are frequently gas tungsten arc welding (GTAW) process and gas metal arc welding (GMAW) process due to their comparatively easier applicability and better economy. In this investigation, an attempt has been made to refine the fusion zone grains by applying pulsed current welding technique. Rolled plates of 6 mm thickness have been used as the base material for preparing single pass welded joints. Single V butt joint configuration has been prepared for joining the plates. The filler metal used for joining the plates is AA 5356 (Al–5Mg (wt%)) grade aluminium alloy. Four different.Fatigue properties of the welded joints have been evaluated by conducting fatigue test using rotary bending fatigue testing machine. Current pulsing leads to relatively finer and more equi-axed grain structure in gas tungsten arc (GTA) and gas metal arc (GMA) welds. In contrast, conventional continuous current welding resulted in predominantly columnar grain structures. Grain refinement is accompanied by an increase in fatigue life and endurance limit[8].

Tetsuo et al. investigated the effect of forming speed and the temperature on the deep drawability of Al-Mg alloy sheet by performing cylindrical deep drawing tests at the various forming speeds and at the various die temperature rates. They found that the formability increased with increasing die temperature and it lowered with increased forming speed at all temperatures. The aluminium alloy 7075 is one of the most important engineering alloys .It has been widely used as structural material in the transport applications, including marine, automotive and aviation applications due to their attractive properties, such as low density, high strength, ductility, toughness and resistance to fatigue [9].

I .O.Oladele et al worked on Wrought (6063) aluminum alloy for investigation using MIG welding .The current and voltage is used as parameters current and voltage on microstructure, tensile strength, toughness and impact strength. Since in arc welding is directly related voltage and current, the two conditions are applied i.e. at constant voltage the current was I_1=75A & I_2=100A and at constant current the welding voltage was varied as V_1=25V & V_2=30V.Tensile strength is more when current is at 100A.Toughness property is found to be good at V_1=25V and other are nearer to it. Hardness is more at I_1=75A & at V_2=30V.The micro structure of I_1= 75A shows that the constant Mg_2Si precipitation surrounding aluminum matrix leaded to fine particles are more responsible for high ultimate tensile strength & Hardness. From this it can be concluded that as current get increased heat input get increases & leads to better fusion of grains which give best possible mechanical properties (Ultimate tensile strength & hardness) and Change in current or voltage doesn't effect more on impact strength [7].

III. EXPERIMENTAL SETUP

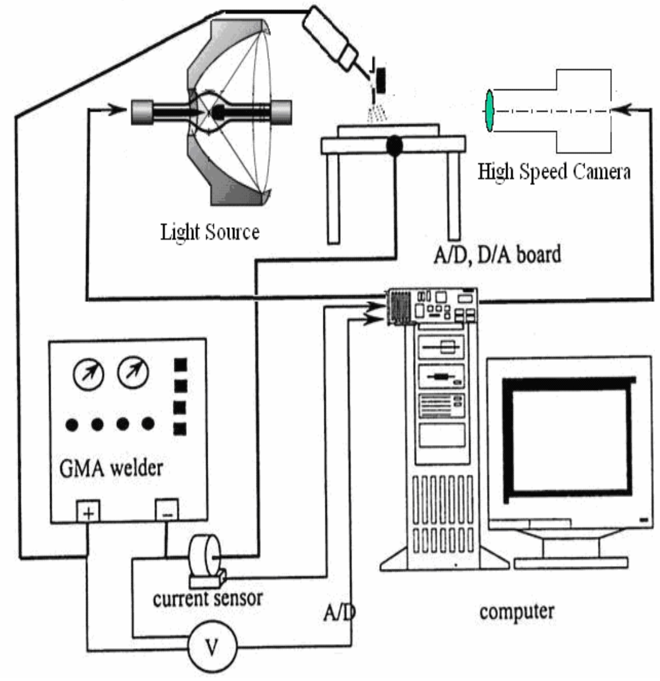

FIGURE 1. P- GAS METAL ARC WELDING PROCESS

The rolled plates of AA 7075 aluminium alloy have been cut into the required sizes (300mm X 150 mm) by power hacksaw cutting and grinding. The Single 'V' butt joint configuration, as shown in Fig. 1 has been prepared to fabricate gas metal arc (GMA) welded joints. The initial joint configuration is obtained by securing the plates in position using tack welding. The direction of welding is parallel to the rolling direction. All necessary care is taken to avoid joint distortion and the joints are made after clamping the plates with suitable clamps. Multi pass welding procedure has been applied to fabricate the joints. High purity (99.99%) argon gas has been used as shielding gas. The chemical composition and mechanical properties of base metal and weld metals are presented in Tables 1 and 2.

The welding conditions and process parameters presented in Table 3 have been used to fabricate the joints. The welded joints are sliced using power hacksaw and then machined to the required dimensions as shown in Fig. 2 for preparing fatigue specimens. American Society for Testing of Materials (ASTM) guidelines are followed for preparing the test specimens. Two different fatigue specimens have been prepared to evaluate the fatigue properties. Hourglass type (smooth) specimens have been prepared as shown in Fig. 2a to evaluate fatigue limit and notched specimens have been prepared as shown in Fig. 3b to evaluate the fatigue notch factor and notch sensitivity factor. The rotary bending fatigue testing experiments have been conducted at different stress levels and all the experiments have been conducted under completely reversed bending load conditions, where mean stress is zero and stress ratio is 1.Tensile specimens have been prepared as shown in Fig. 3c to evaluate yield strength, tensile strength and elongation. Tensile test has been carried out under the load of 100kN, electro-mechanical controlled Universal Testing Machine. The specimen is loaded at the rate of 1.5kN per min as per ASTM specifications, hence tensile specimen undergoes deformation. The specimen finally fails after necking and the load versus displacement has been recorded. The 0.2% offset yield strength is derived from the diagram. Vicker's micro hardness testing machine has been employed for measuring the hardness of the weld metal with the load of 0.05kg.

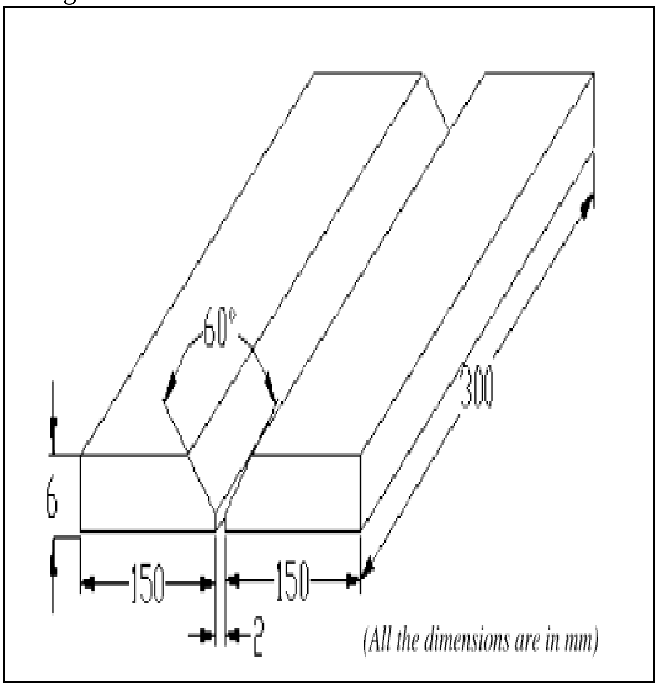

Fig.2 Dimensions of Single V butt joint

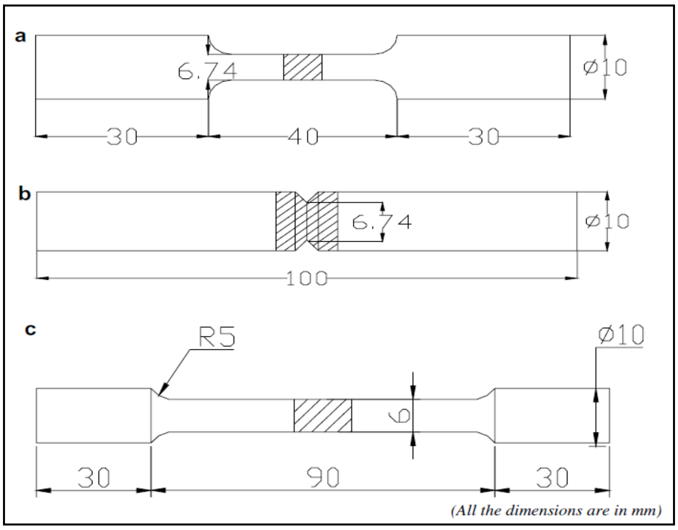

Fig. 3 a) Un-notched fatigue specimen b) Notched fatigue specimen c) Tensile specimen

Table I. Mechanical properties of base metal

Type of material	Yield strength (MPa)	Ultimate tensile strength (MPa)	Elongation (%)	Reduction in cross sectional area (%)	Hardness (VHN)
Base metal AA7075	417	520	14.2	9.1	140

IV.RESULT

a Effect of pulsed current on mechanical properties:

(a) Fatigue properties:

Three specimens have been tested at each stress level and average of three test results is used to plot S–N curves. The S–N curve in the high cycle fatigue region is sometimes described by the Basquin equation,

$$S^n N = A \quad (1)$$

where ‘S’ is the stress amplitude,
‘N’ is the number of cycles to failure and
‘n’ is slope of the curve and
‘A’ is intercept of the curve

The effect of notches on fatigue strength is determined by comparing the S–N curves of notched and un-notched specimens. the fatigue limit is expressed by the fatigue strength reduction factor or fatigue notch factor, K_f. The fatigue notch factor for all the joints has been evaluated and the notch sensitivity of a material in fatigue is expressed by a notch sensitivity factor ‘q’ and ‘q’ can be evaluated using the following expression:

$$q = (K_f -1) / (K_t -1) \quad (2)$$

K_t is the theoretical stress concentration factor
q is the notch sensitivity factor

(b)Tensile properties:

The transverse tensile properties such as yield strength, tensile strength and percentage of elongation of AA 7075 aluminium alloy joints have been evaluated. In each condition, three specimens have been tested and the average of three results is presented. It has been observed that there is a 30% increase in ductility due to pulsed current welding. PCGMAW process is found to be beneficial to enhance the strength of welded joints and the yield strength and tensile strength of PCGMAW joints are 195 MPa and 254 MPa, respectively. This shows that there is a 8% increase in strength values due to pulsed current welding. This shows that there is a 7% increase in strength values due to pulsed current welding.

(c) Hardness:

The hardness across the weld cross section has been measured using Vicker’s micro hardness testing machine. The hardness of base metal (un welded parent metal) in its initial T6 condition is approximately 140 VHN. But the hardness of the CCGMAW joints in the weld metal region is 70 VHN. This suggests that the hardness is reduced by 70 VHN in the weld center due to welding heat and the usage of lower hardness filler metal (Al–5%Mg). However, the pulsed current welding technique has enabled to regain the hardness level to some extent in the weld metal region. P-GMAW joints exhibited hardness of 80 VHN, which is 10 VHN greater than the C-GMAW joints. Similar trend has been observed in partially melted zone (PMZ), heat affected zone (HAZ) and base metal (BM) regions. The hardness is relatively higher in the PMZ and HAZ regions compared to WM region and this may be due to the formation of very fine recrystalized grains in that region.

Table II. Micro hardness values of weld joint (VHN)

Joint type	LOCATION			
	WM	PMZ	HAZ	BM
C-GMAW	70	80	95	136
P-GMAW	80	90	104	138

(d)Microstructure:

Microstructure of all the joints was examined at different locations but the optical micrographs taken at weld metal the current pulsing is very effective in fusion zone grain refinement. Hence, an attempt has been made to measure the average grain diameter of the weld metal region (fusion zone) of all the joints. The measured average grain diameter of C-GMAW joints is 75 lm but the average grain diameter of P-GMAW joints is 50 lm and this indicates that reduction in grain diameter is 25% due to pulsed current welding of gas metal arc welding (GMAW) process. 66% reduction in grain diameter has been observed compared to P-GMAW joints [6].

V.DISCUSSION

a) Effect of pulsed current welding on fusion zone grain refinement:

Heat transfer experienced by the weld joint during welding can alter the microstructure and thus the property of the weldment. Therefore the heat transfer and fluid flow in the weld pool can significantly influence factors such as weld pool geometry, temperature gradient local cooling rates and solidification structure The refinement of microstructure due to the pulsed current welding results in a uniform distribution of the fine precipitates more effectively governed by its zinc pick up enhancing the amount of precipitates in the matrix. Hardness in the fusion zone is the lowest due to the as-cast nature of the microstructure, which is characterized by coarse dendritic grains, inter dendritic segregate phases and lack of strengthening phases.

b) Effect of weld metal strength on fatigue behaviour of joints:

Higher yield strength and tensile strength of the P-GMAW joint is greatly used to enhance the endurance limit of the joints and hence the fatigue crack initiation is delayed. Larger elongation (higher ductility) of the P-GMAW joints also imparts greater resistance to fatigue crack propagation and hence fatigue failure is delayed. If strength of the weld metal is higher, the plastic zone extends into the parent material as the deformation and yielding occur in both weld metal as well as the base metal. The stress relaxation can take place in the crack tip region. Hence, more crack driving force is needed for crack extension and the fracture resistance of the higher strength weld metal is greater than the lower strength weld metal.

c) Effect of fusion zone grain size on fatigue behaviour:

Grain size has its greatest effect on fatigue life in the low stress, high cycle regime in which stage I cracking predominates. In the high stacking fault energy materials, the cell structures develop readily and these control the stage I crack propagation. Hence, the dislocation cell structure masks the influence of grain size and fatigue life at constant stress is insensitive to grain size. In a low stacking fault energy material, the absence of cell structure because of planar slip causes the grain boundaries to control the rate of cracking. In this case, fatigue life is inversely proportional to grain diameter. The average grain diameter in the fusion zone region of P-GMAW joints is in the order of 20–30 lm and the grain size is much coarser in the fusion zone region of C-GMAW joints. Fine grained microstructures relatively contain higher amount of grain boundary areas than coarse grained microstructure and in turn offer more resistance to fatigue crack propagation and this may be the reason for improved fatigue performance of C-GMAW joints compared to other joints.

VI.CONCLUSION

It has been found that many experiments have been carried out on high strength aluminium alloy weld joint to study the effect of welding parameters on mechanical properties by using GMAW process. But we found that mechanical properties such as ultimate tensile strength, ductility, microstructure at the weld region improved a lot. Depending upon the microstructure, the hardness at the weld joint may vary. The heat affected zone will be lesser in case of P-GMAW process as compared to continuous current welding process.

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