Influence of Process Parameters on Aluminium Alloy 6061-O Joints by Friction Stir Welding Process

A. Varun Kumar and M. Balasrinivasan

Abstract--- *The present work reports the influence of process parameters (tool speed, traverse speed and axial load) on the metallurgical and mechanical properties of joints fabricated by friction stir welding process. The samples were friction stir welded under tool rotational speed of 1120, 1250 & 1500 rpm and traversing speed of 0.5, 0.6 & 0.8 mm/sec with an axial load of 9000 Kg constant for all the trials. Single pass friction stir welding process was followed in this investigation. Metallographic analysis was carried out across various zones of weldments (Unaffected Base Metal, Heat Affected Zone, Thermo Mechanically Affected Zone and Nugget Zone). Mechanical tests (microhardness survey & tensile test) were evaluated and all the results were correlated with the parent base metal. For better understanding scanning electron microscope (SEM) analysis was carried out in the nugget zone to predict the flow of materials due to severe stirring process. It is observed from the results that joint fabricated with a tool speed of 1250 rpm, traverse speed of 0.8 mm/sec and axial load of 9000 Kg showed a defect free joint, with better refined grain structures and high tensile strength when compared to all other trials done.*

Keywords--- *Friction Stir Welding (FSW), Single Pass Welding Process, Metallographic Analysis, Microhardness Test, Tensile Test and Scanning Electron Microscope (SEM) Analysis*

I. INTRODUCTION

ALUMINIUM alloys are widely used in various applications around the automotive and aircraft industries because of their light weight properties, better corrosion resistant and high strength to weight ratio. Different welding processes were available for welding light weight alloys among this friction stir welding process is more compatible when compared to other fusion welding processes due to better weld quality [1]. Friction stir welding process is a solid state welding process in which the joint is produced between two alloys both similar and dissimilar [2]. The welding process is carried by means of friction between the parent material and tool, due to a severe stirring process the

material gets plasticised and movement takes place from the retreating side to advancing side, the various zones of FSW process can be classified as nugget zone [NZ], heat affected zone [HAZ], thermo mechanically affected zone [TMAZ] and unaffected base metal [UA] on both retreating and advancing sides [3]. Similarly the weldment strength can also varied by the tool pin design such as threaded, square, plain cylindrical, etc., [4]. There are lot of works been carried out with different combinations of process parameters in the friction stir welding process. So we considered to produce joints between two similar aluminium alloy by varying only the tool speed and traverse speed with the axial load as constant for all the joints. Main factor is to determine the impact of these two process parameters on the fabricated joint. Similarly few works has been conducted with double pass either multi pass of tool material over the parent metal [5-6], here we tried to produce the joints by a single pass friction stir welding process in order to reduce the time factor to produce a joint and also to check the reliability of the joints made by single pass friction stir welding process by conducting metallurgical analysis across various zones of the weldments and mechanical test (tensile test & microhardness test).

II. EXPERIMENTAL PROCEDURE

A. Materials Used

The materials used in this work are AA 6061-O (150 x 100 x 6 mm) and high carbon steel D3 (hardened to 58-60 HRC) as tool used for stirring process, dimensions of the tool are rod diameter 20 mm, shoulder diameter 15 mm, pin probe length 5.7 mm, pin diameter 5.7 mm (pin used is a straight flat cylindrical type). The shoulder of the tool is tilted to 2° for better movement of material from retreating side to the advancing side. The material properties of material and tool were listed in table 1 & 2. The process parameter used in this experiment is listed in table 3. The set up was made as per the requirement and the joints were produced by varying the tool speed, traverse speed and axial load of 9000 Kg constant for all the trials.

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Table 1: Chemical Compositions of AA 6061-O in (Wt %), [7]

Elements	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Composition	95.8 -98.6	0.04 -0.35	0.1 - 0.4	0.7	0.8 - 1.2	0.15	0.4 - 0.8	0.15	0.25

Table 2: Chemical Compositions of High Carbon Steel D3 in (Wt%), [8]

Elements	C	Si	Mn	Cr	V
Composition	2.15	0.40	0.40	12.25	0.25

Table 3: Process Parameter Response Table

Experiments (Samples)	Tool Speed (rpm)	Traverse Speed (mm/sec)
1	1120	0.5
2	1120	0.6
3	1120	0.8
4	1250	0.5
5	1250	0.6
6	1250	0.8
7	1500	0.5
8	1500	0.6
9	1500	0.8

III. RESULTS AND DISCUSSIONS

A. Metallographic Analysis

All the samples were friction stir welded under different tool and traverse speed. Samples were polished and etched using Keller's reagent which is most suitable for all the aluminium alloys. Optical microstructures were observed for sample number 6 across various zones based on the tensile results obtained (Unaffected base metal, heat affected zone, thermo mechanically affected zone and nugget zone) both retreating and advancing sides. Figure 1(a) shows base metal microstructure with equiaxed grains, with relatively uniform grain structures [9-10]. It is also inferred from the NZ figure. 1 (d) refined formation of grains due to stirring process across the weld bond, considerably correlating the TMAZ zone on both sides figure. 1 (e & f) that there is an increase in grain structure which leads to deterioration of tensile properties [11]. From figure. 1(g & h) the HAZ grains were less recrystallized to that of TMAZ zone, similarly material flow from the advancing side to retreating side can be seen from figure. 1(e). Compared to the base metal the unaffected base metal of welded sample showed less equiaxed grains due to heat generation during the process figure. 1(b & c). Correlating the metallurgical properties of weldments (various zones) with base metal it resulted in better refined grain structures due to material transfer and plasticisation in the friction stir welding process.

Figure 1: Optical Microstructures of Sample Number 6 - (a) Base Metal, (b) UA Base Metal - AS, (c) UA Base Metal - RS, (d) NZ, (e) TMAZ - AS, (f) TMAZ - RS, (g) HAZ - AS, (h) HAZ - RS

B. Scanning Electron Microscope (SEM) Analysis

Figure. 2 (a & b) shows the (SEM) micrograph for sample number 6 with a tool speed of 1250 rpm, traverse speed of 0.8 mm/sec and axial load of 9000 Kg. The scanning electron microscope test has been done in the nugget zone of the friction stir welded sample in order to predict the flow of materials from the retreating side to advancing side due to severe stirring process that takes place with the contact of pin probe in the weld bond length. From the figure it can be clearly seen that pattern of flow from the retreating to advancing side of the alloy with no voids and cracks. Figure. 2 (b) shows the presence of

silicon (Si) in the nugget zone. Also the grains boundaries and structure were well refined in the nugget zone due to the stirring process, better plasticization of aluminium alloy which shows the good fusion had happened in the nugget zone as reported by [12]. Figure. 2 (a & b) reveals that a strong stirring action had occurred in the nugget zone region as discussed by [13].

Figure 2: SEM Micrograph of Sample Number 6 – (a & b) Nugget Zone

C. Tensile Properties

The ultimate tensile strength (UTS) for the weldments was evaluated using a tensile testing machine figure. 3 shows the tensile properties profile of weldments all the samples were prepared as per (ASTM E08) standard for testing. Compared to the base metal, friction stir welded samples showed better tensile properties due to the stirring process and plasticization of material. The UTS value is increased with the increase in traverse speed which results in defect free joint and better UTS value to that of base metal, further increase in traverse speed resulted in decreased UTS value [14]. UTS values were listed in table 4.

Figure 3: Tensile Properties of Welded Samples

Table 4: Tensile Properties of Friction Stir Welded AA 6061-O

Experiments (Samples)	Experimental UTS (Newton)	Percentage Elongation (mm)
1	2112	2.02 ± 0.2
2	3562.5	3.42 ± 0.2
3	1637.5	2.95 ± 0.2
4	3162.5	3.05 ± 0.2
5	4512	3.66 ± 0.2
6	4887	4.51 ± 0.2
7	3637.5	3.97 ± 0.2
8	1962.5	2.36 ± 0.2
9	2725	2.25 ± 0.2

D. Microhardness test

Figure 4. shows the microhardness profile for the welded samples. Base metal has a 40 μ HV microhardness value [15]; compared to the base metal the welded samples resulted in better hardness property due to material movement. In the present experiment the failure occurred in TMAZ zone which is very adjacent to weld nugget which resulted in higher hardness value in the nugget zone [16]. Also from graph it is inferred that hardness values were similar in the TMAZ and HAZ zone both retreating as well advancing side due to plasticization of material. The UA base metal showed some deviations in the hardness value when compared to the base metal due heat transfer from the adjacent zones of the weldments.

Figure 4: Microhardness Profiles of Welded Samples

IV. CONCLUSION

In the present work influence of process parameters on fabricated joints of aluminium alloy 6061-O was evaluated and the following conclusions were made

- Successful joints were made on similar aluminium alloy 6061-O by friction stir welding process.
- Metallurgical survey were carried on parent base metal and across the various zones of weldments (UA base metal, TMAZ, HAZ, NZ) on both retreating & advancing sides.
- SEM results revealed a better flow of materials in the nugget zone with no voids which shows a defect free joint.
- Tensile strength of the weldments showed a better result to that of base metal.

- Microhardness values showed better enhancement when correlated with base metal.
- Nugget zone plays a vital role in friction stir welding process, because the bonding of material either a similar or dissimilar alloys can be made successful only with the refined grain boundaries at the nugget zone.
- Comparing with the mechanical and metallurgical properties it is revealed that tool speed of 1250 rpm, traverse speed of 0.8 mm/sec and axial load of 9000 Kg resulted in a defect free joint among all other parameters used in this work.

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