



A STUDY OF PROCESS PARAMETERS OF FRICTION STIR WELDED AA 6061 ALUMINUM ALLOY IN O AND T6 CONDITIONS

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ABSTRACT

Friction Stir Welding (FSW) is fairly a recent technique that uses a non consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location while the material is in solid state. The principal advantages are low distortion, absence of melt related defects and high joint strength. Tool design and material plays a vital role in addition to the important parameters like tool rotational speed, welding speed and axial force. The paper focuses on optimization of FSW parameters in different conditions of base material and the microstructures of the as-welded condition are compared with the post weld heat treated microstructures welded in annealed and T6 condition.

Keywords: Friction Stir welding, 6061 aluminum alloy, post welded condition, tool rotational speed, welding speed, axial force, tensile strength.

1. INTRODUCTION

Aluminum alloys are important for the fabrication of components and structures which require high strength, low weight or electric current carrying capabilities to meet their service requirements. Among all aluminum alloys, AA 6061 alloy plays major role in the aerospace industry in which magnesium and silicon are the principal alloying elements. It is widely used in the aerospace applications because it has good formability, weldability, machinability, corrosion resistance and good strength compared to other aluminum alloys. When using the conventional arc welding techniques, long butt or lap joints between AA 6061 and other aluminum alloys are particularly difficult to make without distortion because of high thermal conductivity and special welding procedures and high levels of welder skill are generally required.

The more specialist laser and electron beam techniques can overcome the weld distortion and skill problems, but tracking of very long butt joints is difficult. Moreover, all fusion techniques can cause loss of alloying elements through evaporation and often these have to be replaced by the addition of special filler material to achieve welds which satisfy service requirements. Furthermore, some aluminum alloys cannot be fusion welded. Fusion welding of aluminum alloys poses certain problems like porosity, distortion due to high thermal conductivity and solidification shrinkage. AA 6061 Aluminum alloy cannot be TIG welded without filler wire because it leads to solidification cracking due to its chemistry. In the present work an attempt is made to study the feasibility of joining AA6061 aluminum alloy by friction stir welding (FSW) technique. Friction Stir Welding (FSW) developed in the year 1991 at The Welding Institute (TWI) in UK is a solid state joining process, meaning there is no melting involved in joining the two work pieces and is used for joining aluminum alloys [1-6]. Friction Stir Welding can be used to produce butt, corner, lap T, spot, fillet, and hem joints, as well as to weld hollow objects, such as tanks and tubes/pipes, stock

with different thickness, tapered sections and parts with 3-Dimensional contours [7-11]. The technique can produce joints utilizing equipment based on traditional machine tool technologies, and it has been used to weld a variety of similar and dissimilar alloys. Replacement of fastened joints with Friction Stir welded joints can lead to significant weight and cost savings, attractive propositions for many Industries. In this process, a specially designed tool rotates and traverses along the joint line, creating frictional heating that softens a column of material underneath the tool. The softened material flows around the tool through extensive plastic deformation and is consolidated behind the tool to form a solid-state continuous joint.

As the FSW process does not release toxic acids or fumes, it is an environment protective process. No consumable filler material or edge preparation is normally necessary. The distortion is significantly less than that caused by arc fusion welding techniques. By welding Aluminum alloys by fusion welding process there is possibility of cracks, porosity, alloy segregation and hot cracking and the fusion welding process completely alters microstructure and varies the mechanical properties [3]. By FSW both similar and dissimilar materials can be successfully joined.

The mechanical properties of the alloys are affected not only by their chemical composition but also by their condition, e.g. annealed, cold worked, precipitation hardened. The work pieces are secured against the vertical, longitudinal and lateral forces, which will try to lift them and push them apart during the process. Figure-1 illustrates the salient features of the process which operates by generating frictional heat between a rotating tool and the work piece, to plasticize the abutting weld region. Commonly the tool is shaped with a large diameter with shoulder and a small varying diameter, specially profiled probe that makes contact first as it is plunged into the joint region.

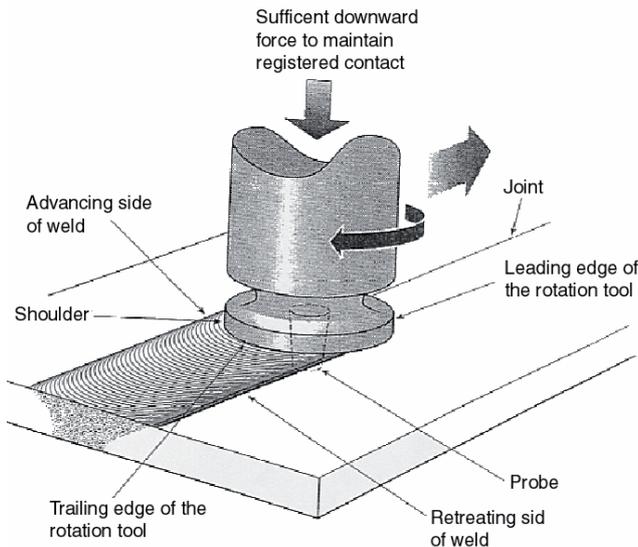


Figure-1. Friction stir welding with a rotating tool.

The depth of penetration is controlled by the length of the probe below the shoulder of the tool. The initial plunging friction contact heats the adjacent metal around the probe as well as a small region of material underneath the probe, but once in contact with the top surface of the job, the shoulder contributes significant additional heat to the weld region. In addition, the contacting shoulder, which can be profiled to provide improved coupling, prevents highly plasticized material from being expelled from the welding region. Once the rotating tool is in position the thermally softened and heat affected region take up a shape corresponding to that of the overall tool geometry. The system divides the weld zone into distinct regions as shown in the Figure-2. The heat-affected region is much wider at the top surface (in contact with the shoulder) and tapers down as the probe diameter reduces. This highly plasticized material provides for some hydrostatic effect as the rotating tool moves along the joint, which helps the plasticized material to flow around the tool. The plasticized weld material then coalesces behind the tool as the tool moves away.

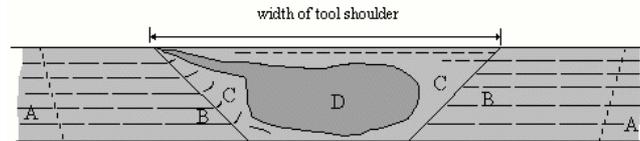


Figure-2. Friction stir welding principle and microstructure.

A Unaffected material,
B Heat-affected zone (HAZ),
C Thermo-mechanically affected zone (TMAZ),
D Weld nugget (Part of TMAZ)

The tool has two primary functions: (a) Localized heating, and (b) material flow. In the initial stage of tool plunge, the heating results primarily from the friction between pin and work piece. Additional heating results from deformation of material. The tool is plunged till the shoulder touches the work piece. The friction between the shoulder and work piece results in the biggest component of heating. From heating aspect, the relative size of pin and shoulder is important, and the other design features are not critical. The second function of the tool is to 'stir' and 'move' the material.

For FSW, two parameters are very important: tool rotation rate (ω , rpm) in clockwise or counter clockwise direction and tool traverse speed (v , mm/min) along the of joint [14]. The rotation of tool results in stirring and mixing of material around the rotating pin and the translation of tool moves the stirred material from the front to the back of the rotating pin and finishes welding process. Higher tool rotation rates generate higher temperature because of higher friction heating and result in more intense stirring and mixing of material. However, it should be noted that frictional coupling of tool surface with work piece is going to govern the heating. So, a monotonic increase in heating with increasing tool rotation rate is not expected as the coefficient of friction at interface will change with increasing tool rotation rate.

2. EXPERIMENTAL PROCEDURE

The composition and mechanical properties of AA6061 aluminum alloys is given in Tables 1a and 1b, respectively.

Table-1a. Chemical composition of aluminum alloy.

Al alloy	Si	Fe	Cu	Mn	Mg	Cr
6061	0.4-0.8	0.7 max	0.15-0.4	0.2-0.8	0.8-1.2	0.15-0.35

Table-1b. Mechanical properties of base metal.

Tensile strength (MPa)	Yield strength (MPa)	% Elongation	Hardness
283	235	26.4	105



AA 6061 Aluminum Alloy plates (150mm X 75mm X 6.6mm) in the annealed and solutionized and aged conditions were chosen for the present project work. Specially designed tool is used in the Friction stir welding. The material of the tool is H11 tool steel. A non-consumable high-speed steel tool is used for welding 6061 Al alloy having the shoulder diameter of 10 mm and the tool has probe (tool pin). The tool has frustum shaped probe with threads. Probe diameter is varied from 5 mm to 3 mm. The diameter of the shoulder is 10 mm. The FSW tool was subjected to heat treatment to improve its hardness. The hardness of tool after heat treatment is around 54 HRC. The FSW is carried out on a CNC milling machine.

The plates are positioned in the fixture, which is prepared for fabricating FSW joints by using mechanical clamps so that the plate will not be separated during welding. To test the mechanical performance of the welding, tensile strength is measured. The micro structural affects leads to substantial change in post-weld mechanical properties. In the following sections, typically mechanical properties, such as strength, ductility, and bending are briefly reviewed. Friction stir welding was carried out on the AA6061 aluminum alloy in different conditions i.e., in annealed condition (O) and solutionized and aged condition (T6).

The evaluation of mechanical properties at room temperature i.e., tensile strength, bend property in as weld and post weld heat treatment conditions is done. Micro structural analysis is done by optical microscopy. Two Aluminum plates of size 75X150mm were perfectly clamped in a milling machine bed on a backup plate. Specially designed welding tool is inserted into the tool holder. Tool is plunged into the joint in the downward direction with feed rate of 5 mm/min clockwise direction. The tool welded the joint along the X-axis with feed rate of 10 mm/min. Higher tool rotation rates generates higher temperature because of higher friction heating and result in more intense stirring and mixing of material. The insertion depth of tool pin into the work piece is important for producing sound weld joints [15-16]. When the insertion depth is too shallow, the shoulder of tool does not contact the original work piece surface. Thus the rotating shoulder cannot move the stirred material efficiently from the front to the back of the tool pin, resulting in generation of welds with inner channel or surface groove. When the insertion depth is too deep, the shoulder of tool plunges into the work piece creating excessive flash, resulting in sticking of joint to the backup plate. Process parameters were optimized for annealed and

T6 conditions welding. In annealed condition the welding was done at different process parameters.

3. RESULTS AND DISCUSSIONS

In the present work, different FSW butt welds were obtained by varying the process parameters within the range and the optimal values are drawn based on the trend of the values. The weld joints are tested for tensile strength and the specimens are cross sectioned from the joints perpendicular to the welding direction and are as per ASTM guidelines. The parameters tool rotational speed and welding speeds are varied by keeping the axial force constant. In annealed condition and T6 condition the welding was done at different process parameters 800 rpm, 15 mm/min and 800rpm, 10 mm/min. As received AA6061 samples are mounted, polished flat and are finally etched with Keller's reagent and observed under the optical microscope.



Figure-3. FSW process.

The microstructure studies aimed at characterization of either the shape and dimensions of the grains across the joint for different kinds of conditions (i.e., annealed and T6) of Al alloy, the distribution and size of precipitates, the dislocation density of the AA 6061 aluminum alloy material and the types of orientation referred to the pin surface. Based on micro structural characterization of grains and precipitates, three distinct zones have been identified such as stirred (nugget) zone, thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ) as shown in Figure-4 [12].

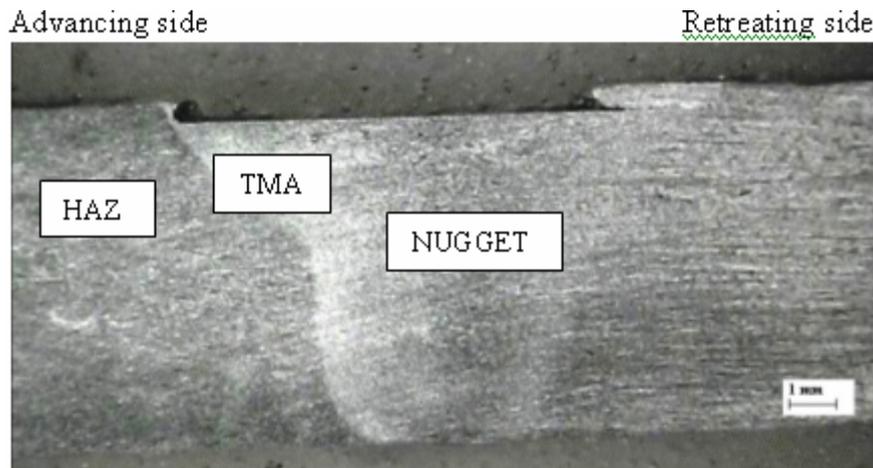


Figure-4. Macrograph showing various micro structural zones.

The optical microstructures of the base metal and weld center in annealed and solutionized and aged (T6) conditions are shown in Figures 5a and b.

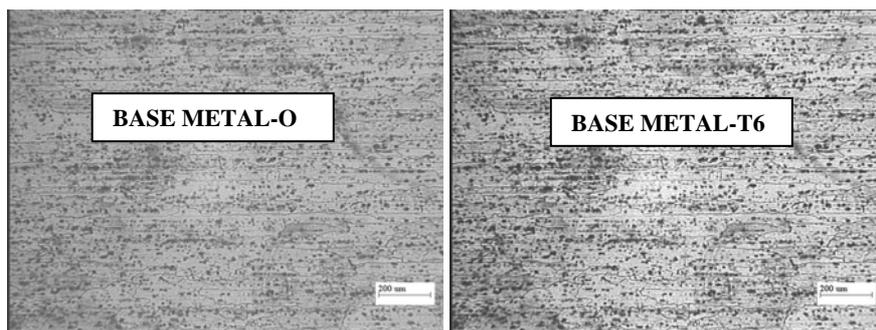


Figure-5a. Optical microstructures of base metal after heat treatment annealed and T6.

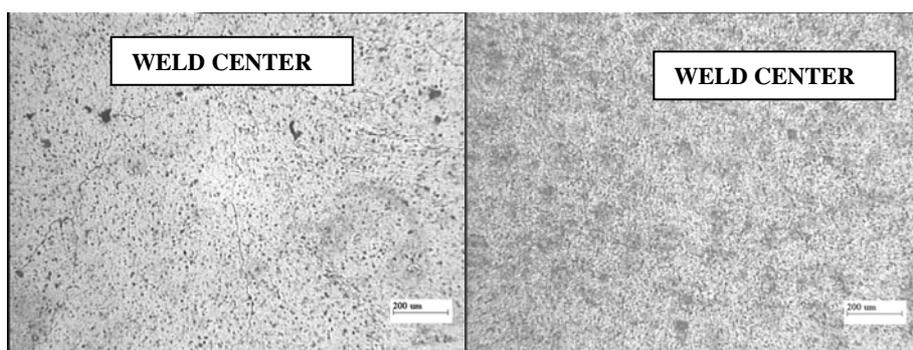


Figure-5b. Optical microstructures of weld-O and weld-T6.

Friction stir welding created thermo-mechanically affected zone (TMAZ) between the parent material and the weld center as shown in the Figure-6.

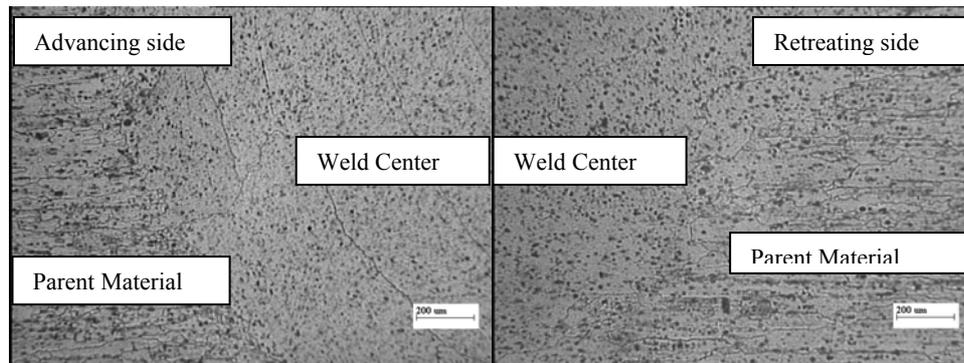


Figure-6. Optical microstructures of TMAZ in FSW.

3.1 Discussions

In this nugget zone long grains are observed contain sub grains, sub-boundaries and dislocations. It is completely dependent upon the shape of tool pin of FSW. The interface between the recrystallized nugget zone and the parent metal is relatively diffuse on the retreating side of the tool, but quite sharp on the advancing side of the tool. In the optical microstructure of the solutionized and aged condition welded in annealed state. Figure-4 has big grains in the nugget zone compared to the base metal grains. The parameters like welding speed, tool rotational speed, axial force, tool profile has affect on the weld [16]. From the results obtained it can be inferred that tool rotational speed and welding speed has got influence on the welded joint.

4. CONCLUSIONS

So it can be concluded that in annealed condition tool rotation speed 800 rpm and welding speed 10 mm/min and 15 mm/min are the optimal parameters. The tool rotation speed 1000 rpm and welding speed 10 mm/min are the optimal parameters in 'T6' condition. The effect of different parameters on the mechanical properties of the butt welded joint AA6061 is analyzed.

REFERENCES

- [1] Thomas WM, *et al.*, 1991. Friction Stir Butt Welding, International Patent Appl. PCT/GB92/02203 and GB Patent Appl. No. 9125978.8, December.
- [2] Rhodes CG, Mahoney MW, Bingel WH. 1997. Micro structural hanges determining joint strength in friction stir welding of aluminum alloys. Scripta Mater.
- [3] C.J. Dawes, W.M. Thomas. 1996. Friction stir process welds aluminum alloys, Weld. J. 75: 41-45.
- [4] M. Vural, A. Ogur, G. Cam, C. Ozarpa. 2007. On the friction stir welding of aluminium alloys EN AW 2024-0 and EN AW 5754-H22. Archives of Materials Science and Engineering. 28: 49-54.
- [5] G. Liu, L.E. Murr, C.S Niou, J.C. McClure, E.R. Vega. 1997. Micro structural aspects of the friction stir welding of 6061-T6 aluminum. Sriptra materials pp.32.
- [6] L.E. Murr, G. Liu, J.C. McClure. 1998. A TEM study of precipitation and related microstructures in friction-stir welded 6061 aluminum. J. Mater. Sci. 33: 1243-1251.
- [7] M.J. Brooker, A.J.M Van Deudekom, S.W. Kallee, P.D. Sketchley. 2000. Applying friction stir welding to airane 5 main motor thrust frame, Proceeding of the European Conference on Spacecraft Structures, Materials and Mechanical Testing, Noordwijk, The Netherlands. 29 November - 1 December. pp. 507-511.
- [8] M.G. Dawes, S.A. Karger, T.L. Dickerson, J. Przyoatek. 2000. Strength and fracture toughness of friction stir welds in aluminum alloys, In: Proceedings of the 2nd International Symposium on Friction Stir Welding, Paper No. S2-P1, Gothenburg, Sweden. TWI Ltd. and IVF. June.
- [9] S.W. Williams. 2001. Welding of airframes using friction stir. Air and Space Europe. 3: 64-66.
- [10] Krishnan KN. 2002. On the formation of onion rings in friction stir welds. Mater Sci Eng. 246-251.
- [11] W. M. Thomas, E. D. Nicholas, S.D. Smith. 2001. In: S.K. Das, J.G.Kaufman, T.J. Lienert (Eds.), Aluminum 2001-proceedings of the TMS Aluminum Automotive and Joining Sessions, TMS. p. 213.
- [12] Xie GM, Ma ZY, Geng L. 2007. Development of a fine grained microstructure and the properties of a nugget zone in friction stir welded pure copper. Scripta Mater: 73-76.
- [13] Park HS, Kimura T, Murakami T, Nagano Y, Natka K, Ushio M. 2004. Microstructures and mechanical



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properties of friction stir weld of 60% Cu- 40% Zn.
Mater Sci Engg. A: 160-169.

- [14] H.J. Liu, H. Fujii, M. Maeda, K. Nogi. 2003. Tensile properties and fracture locations of friction-stir welded joints of 6061-T6 aluminum Alloy. Mater. Sci. Lett. p.22.
- [15] Indira Rani. M, Marpu R. N, A.C.S. Kumar. 2010. Effect of shoulder shape on Mechanical Properties of friction stir welded Al alloy, NWM.
- [16] Fujii H, Cui L, Maeda M, Nogi K. 2006. Effect of tool shape on mechanical properties and microstructure of friction stir welded aluminum alloys. Mater Sci. Eng. A. pp. 25-31.
- [17] Balasubramanian V. 2008. Relationship between base metal properties and friction stir welding process parameters. Mater Sci. Eng. A. pp. 397-403.