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Investigation of Friction Stir Welding of AA2024-T6 Alloy –A Review

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Abstract: *The AA2024-T6 is widely used in the air craft structure and truck body. The alloy cannot be welded by gas welding techniques due to poor weldability. Welding of this Al alloy by arc and resistance welding require special techniques and hence costly. The most suitable method for welding AA 2024-T6 is friction stir welding process. The effect of friction stir welding process parameters on the mechanical properties of the AA 2024-T6 alloy joints produced by friction stir welding have been discussed in this study. Effects of tool tilt angle, rotation speed and tool traverse speed on mechanical properties have been analysed using L9 Taguchi orthogonal array design of experiments technique. There are three different tool rotation speeds (500, 1000, 1500 rpm) and three different tool traverse speeds (10, 15, 20 mm/min). For each combination of tool rotation speeds and tool traverse speeds, three different values of tool tilt angles have been used. The study indicates that tool tilt angle is the main process parameter that has the highest statistical influence on mechanical properties. However, other parameters such as tool rotation speed and tool travel speed has also significant effect on mechanical properties.*

Keywords: *Friction Stir Welding, Tool Design, Mechanical Properties, Taguchi Orthogonal Array, Analysis of Variance (ANOVA).*

I. INTRODUCTION

Friction stir welding (FSW) is a solid state welding process (i.e., the metal is not melted during the process) developed and patented by the welding institute (TWI), UK in 1991 [1], emerged as a new welding technique is to be used in high strength alloys that are difficult to join with conventional fusion welding techniques. The process was initially developed for aluminium alloys but since then FSW was suitable for joining large number of other metals [2]. Conventional fusion welding of aluminium alloys often produce a weld which suffers from defects, such as porosity, distortion developed as a consequence of entrapped gas not being able to escape from the weld pool during solidification process. In contrast, with FSW the interaction of non-consumable rotating tool traversing along the joint line creates a welding joint through plastic deformation and consequent heat dissipation resulting temperatures below the melting point of the materials being joined. Other interesting benefits of FSW compared to fusion welding processes are low distortion, excellent mechanical properties in the weld zone, execution without a shielding gas and suitability to weld all aluminium alloys [3].

FSW can be used to produce lap, butt, corner, T, spot, fillet and hem joints, as well as to weld hollow objects, such as tanks and tubes/pipes, stock with different thicknesses, tapered sections and parts with 3-dimensional contours [2&4]. 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 along with welding metal matrix composites and to repair existing joints. Replacement of fastened joints with FSW joints can lead to significant weight and cost savings, attractive propositions for many industries [5]. The basic principle of friction stir welding process is remarkable simple. A rotating tool with pin and shoulder is inserted in the material to be joined and traversed along the joint line. The heating is localized and generated by friction between the rotating tool and work piece, with additional adiabatic heating from metal deformation [6-7]. The pin and shoulder of the tool can be modified in number of ways to influence material flow and micro structural formation.

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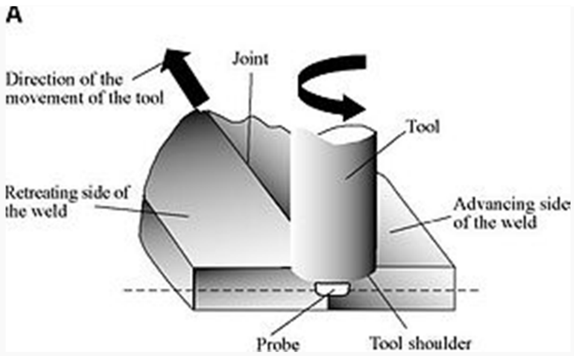
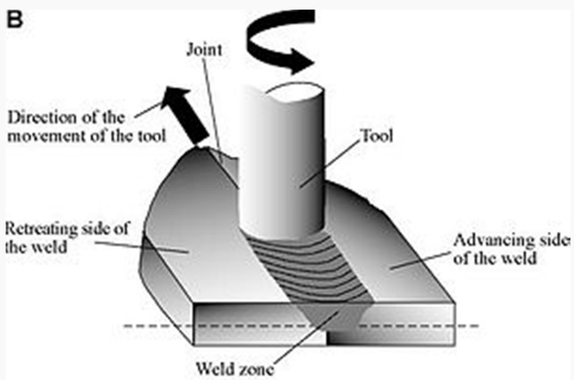
II. Friction Stir Welding

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough. It is primarily used on aluminium, and most often on extruded aluminium (non-heat treatable alloys), and on structures which need superior weld strength without a post weld heat treatment.

i. Principle of Operation



Schematic diagram of the FSW process: (A) Two discrete metal work pieces butted together, along with the tool (with a probe).



(B) The progress of the tool through the joint, also showing the weld zone and the region affected by the tool shoulder.

A constantly rotated non consumable cylindrical-shouldered tool with a profiled probe is transversely fed at a constant rate into a butt joint between two clamped pieces of butted material. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface.

Frictional heat is generated between the wear-resistant welding components and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the pin is moved forward, a special profile on its leading face forces plasticised material to the rear where clamping force assists in a forged consolidation of the weld.

This process of the tool traversing along the weld line in a plasticised tubular shaft of metal results in severe solid state deformation involving dynamic recrystallization of the base material.

ii. Microstructural Features of FSW

The solid-state nature of the FSW process, combined with its unusual tool and asymmetric nature, results in a highly characteristic microstructure. The microstructure can be broken up into the following zones:

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- The stir zone (also nugget, dynamically recrystallized zone) is a region of heavily deformed material that roughly corresponds to the location of the pin during welding. The grains within the stir zone are roughly equated and often an order of magnitude smaller than the grains in the parent material.[4] A unique feature of the stir zone is the common occurrence of several concentric rings which has been referred to as an "onion-ring" structure.[5] The precise origin of these rings has not been firmly established, although variations in particle number density, grain size and texture have all been suggested.
- The flow arm zone is on the upper surface of the weld and consists of material that is dragged by the shoulder from the retreating side of the weld, around the rear of the tool, and deposited on the advancing side.
- The thermo-mechanically affected zone (TMAZ) occurs on either side of the stir zone. In this region the strain and temperature are lower and the effect of welding on the microstructure is correspondingly smaller. Unlike the stir zone the microstructure is recognizably that of the parent material, albeit significantly deformed and rotated. Although the term TMAZ technically refers to the entire deformed region it is often used to describe any region not already covered by the terms stir zone and flow arm.
- The heat-affected zone (HAZ) is common to all welding processes. As indicated by the name, this region is subjected to a thermal cycle but is not deformed during welding. The temperatures are lower than those in the TMAZ but may still have a significant effect if the microstructure is thermally unstable. In fact, in age-hardened aluminium alloys this region commonly exhibits the poorest mechanical properties.

iii. Advantages of Friction Stir Welding

A number of potential advantages of FSW over conventional fusion-welding processes have been identified:

- Good mechanical properties in the as-welded condition
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables — A threaded pin made of conventional tool steel, e.g., hardened H13, can weld over 1 km (0.62 mi) of aluminium, and no filler or gas shield is required for aluminium.
- Easily automated on simple milling machines — lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

However, some disadvantages of the process have been identified:

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

II. Experimental Work

Friction Stir Welding was carried out on AA 2024-T3 plates having dimensions 100 mm (l) × 100 mm (w) × 6mm (h) in butt joint configuration. The chemical composition and mechanical properties of base metal are tabulated. For the present work high carbon high chromium steel d2 has been chosen as tool material. D2 is very wear resistant but not as tough as lower alloyed steels. The mechanical properties of D2 are very sensitive to heat treatment. It is widely used for the production of shear blades, planer blades and industrial cutting tools; sometimes used for knife blades. The diameter of the tool rod is 20mm and the diameter of the pin is 5mm.For welding purpose vertical milling machine was used. Trial runs were conducted prior to conducting actual experiments. During welding process tool pin profile was kept constant. FSW carried out for different tool rotation speed, tool traverse speed and tool tilt angle using Taguchi orthogonal array design of experiments technique. Other process parameters like downward force & heat sink etc. were kept constant. Weldments prepared by Friction Stir Welding processes were visually inspected for their soundness.

Table 1.Chemical composition of AA2024-T6 alloy

Element	Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
Amount Wt%	90.7	0.1	3.8	0.5	1.2	0.3	0.5	0.15	0.25

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Table 2.Chemical composition of D2 tool

Element	Content (%)
C	1.40 – 1.60
Mn	0.60
Si	0.60
Co	1.00
Cr	11.00 – 13.00
Mo	0.70 – 1.20
V	1.10
P	0.03
Ni	0.30
Cu	0.25
S	0.03

Table 3.Physical properties of D2 tool

Properties	Metric	Imperial
Density	7.7 x 1000 kg/m^3	0.278 lb/in^3
Melting point	1421°C	2590°F

Table 3.Mechanical properties of D2 tool

Mechanical Properties	Metric	Imperial
Hardness, Knoop (converted from Rockwell C hardness)	769	769
Hardness, Rockwell C	62	62
Hardness, Vickers	748	748
Izod impact unnotched	77.0 J	56.8 ft-lb
Poisson's ratio	0.27-0.30	0.27-0.30
Elastic modulus	190-210 GPa	27557-30457 ksi

Table 4.Thermal properties of D2 tool

Properties		Conditions	
		T (°C)	Treatment
Thermal expansion	$10.4 \times 10^{-6}/°C$	20-100	-

For the present study Taguchi orthogonal array design of experiment with three factors at three levels was used. Following three variables have been chosen as independent variables: Tool rotation speed, Traverse speed of tool and tool tilt angle. All the factors and their levels are tabulated in Table 4.

Table 4 .DOE-Experimental levels and factors

Factors	Tool rotation speed (rpm)	Tool traverse speed (mm/min)	Tool tilt angle (degrees)
Notations	B	C	D
Levels			
1	500	10	2
2	1000	15	3
3	1500	20	4

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Table 5. Variations of process parameters by Taguchi`s L9 orthogonal array

Experiments run order	Tool rotation speed (rpm)	Tool traverse speed (mm/min)	Tool tilt angle (degrees)
1	500	10	2
2	500	15	3
3	500	20	4
4	1000	10	3
5	1000	15	4
6	1000	20	2
7	1500	10	4
8	1500	15	2
9	1500	20	3

For obtaining tensile test specimen Friction Stir welded plates were sliced in traverse direction using a power hack shaw. Tensile test specimens will be prepared as per ASTME8MM-04 using CNC Milling machine. Two tensile test specimens will be prepared for each combination of process parameters. Then average values of these two tests will have been reported. The welded specimens will also be tested for its micro-structure, hardness and fatigue strength. For this radiography test, Vickers's hardness test and fatigue test will be conducted.

Conclusion

Friction stir welding will be carried out successfully on 2024-T6 aluminium alloy. Taguchi orthogonal DOE technique is used to analyse effect of major process parameters- tool rotation speed, tool traverse speed and tool tilt angle on mechanical properties of weldments. From the ANOVA, it will be concluded that the tool tilt angle is the main input parameter that will be the highest statistical influence on tensile strength and nugget harness. It will be also found that, there is very minor variation in the mechanical properties by changing the tool travel speed.

References

1. W. M. Thomas, E. D. Nicholas, J. C. Needham, M. G. Murch, P. Templesmith, C. J. Dawes, Improvements relating to friction welding, European patent specification 0615480B1 (1992).
2. R. Nandan, T. Debroy and H.K.D.H. Bhadshia, Recent advances in friction stir welding-process, weldment structure and properties, Progress in Material Science, 53, pp.980-1023 (2008).
3. R.M. Mishra, M. W. Mahoney, Friction stir welding and processing, ASM International, pp. 360 (2007).
4. Terry Khalid, An outsider looks at friction stir welding, ANM-112N-05-06 (2005).
5. S. W. Williams, Welding of airframes using friction stir, Air space Eu, 3, pp. 64 (2001).
6. C. J. Dawes, An introduction to friction stir welding and its development, Welding and metal fabrication, pp.12 (1995).
7. G. Liu, L. E. Murr, C. S. Niou, J. C. McClure and F. R. Vega, Micro structural aspects of the friction stir welding of 6061-T6 aluminium, Scripta Materlia, 37(3), pp.355-361 (1997).
8. R. S. Mishraa, Z. Y. Ma. R. S. Mishraa, Z. Y. Ma, Friction stir welding and processing.
9. Z. W. chen and S. Cui, on the firming mechanism of banded structures in aluminium alloy friction stir welds, Scripta Materialia 58(2008)417-420.
10. K. Kato, H. Tikisu and G. Ito, Mechanical properties of friction stir welded 6061 aluminium alloy, Welded international 18 (2004)95-102.
11. Z.Barlas and U. Ozsarac, Effect of FSW parameters on joint properties of AlMg3 alloy, Welding Research, vol. 91, pp. 16s-22s (2012).
12. Moneer H. Tolephih, Hatem M. Mahamood, Athra a H. Hasheem and Esam T. Abdullah, Effect of tool offset and tilt angle on weld strength of butt joint friction stir welded specimens of AA2024 aluminium alloy welded to commercial pure copper, Chemistry and materials research, vol.3, no.4, pp.49-58(2013).

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