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A STUDY OF MECHANICAL PROPERTIES PARAMETERS OF FRICTION STIR WELDED AA 6063 ALUMINUM ALLOY IN O AND T6 CONDITIONS

L.Nirmalraj , B.Saravanan , N.Thangavel

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. A specially customized Orbital Clamping Unit (OCU) was used and fixed on the Bridgeport 2216 CNC milling machine in order to weld an aluminium alloy 6063 pipe butt joint at several welding parameters. The principal advantages are low distortion, absence of melt related defects and high joint strength. This paper will investigate the effect of welding parameters on the tensile strength of joint produced by the FSW process. Several good samples of pipes joint were produced using the present experiment setting. The paper focuses on process parameters that in required for producing effective friction stir welding joint.

Keywords — Friction Stir welding, Al alloys, Mechanical properties, 6063 aluminium alloy, Friction stir welding.

I. INTRODUCTION

Aluminium 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. The Friction Stir Welding (FSW) is the state-of-the art joining process which was invented and later patented by The Welding Institute (TWI) in 2017 [1]. There are many advantages of FSW including energy savings, exclusion of consumables and shielding gases, good dimensional stability, low distortion of work sheet, enhanced metallurgical properties in the weld region, fine microstructure, possibility of welding dissimilar materials, and reduced usage of fasteners for joining multiple parts. Because of the environmental friendliness and energy efficiency, it is considered as “green technology. Friction Stir Welding is a variant of friction welding that produces a weld between two or more work pieces by the heating and plastic material displacement caused by a rapidly rotating tool that traverses the weld joint 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 [2].

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. This application of FSW on pipes can be used for

Petroleum, Petrochemical, natural gas industries, which in some studies, estimated to provide 25% and 7% cost saving for offshore and onshore construction respectively [3].

Fig.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.

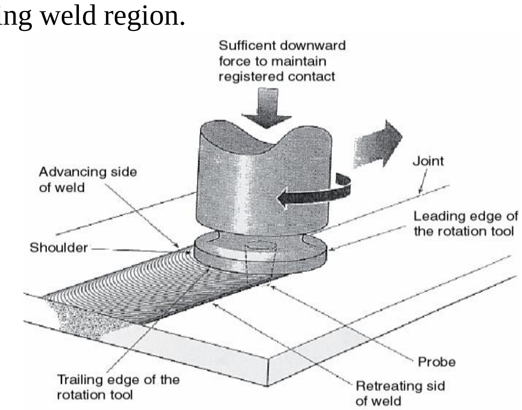

Fig.1. Friction Stir welding with a rotating tool.

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In recent times, focus has been on developing fast, efficient processes that are environment friendly to join two dissimilar materials [4]. 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.

The spotlight has been turned on Friction stir welding as a joining technology capable of providing welds that do not have defects normally associated with fusion welding processes. However, the experiment setting is the most critical part in this process especially for joining aluminium alloy 6063 pipes. This application of FSW on pipes can be used for petroleum, petrochemical, and natural gas industries which in some studies, estimated to provide 25% and 7% cost saving for offshore and onshore construction respectively [5]. This paper will study the effect of welding parameters on the tensile strength of the friction stir welded aluminium alloy 6063 pipe butt joint.

II. FRICTION STIR WELDING

Friction Stir Welding is considered to be the most significant development in metal joining in a decade. 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.

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. In Friction Stir Welding no cover gas or flux is used, thereby making the process environmentally friendly, energy efficiency

and versatility or it is a „green technology" [6]. The rotation of the pin can be unidirectional or reverse clockwise. The shortage of this process is the tool being used vulnerable to damage because it operates at a high enough temperature and therefore required to use the tool of the material is strong and heat resistant. The Pin used must have the hardness and high melting point compared to the material to be welded, in order to weld pin is not damaged and participate melt material when welding work so that the weld was better [7]. Friction stir welding can be applied to various types of joints like butt joints, lap joints, T butt joints, pipes and fillet joints with different thickness and different profile.

FSW technique was initially developed for Al - alloys, it also has great potential for welding of Mg-, Cu-, Ti-, Al alloy matrix composites, lead, some steels, stainless steels, and different material combinations, particularly those with close melting temperatures and similar behaviour such as hot workability.

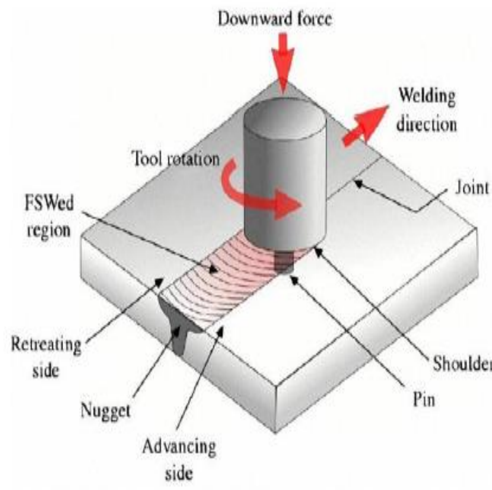

Fig.2. Schematic drawing of friction Stir welding process

Performed FSW experiments on AA7075-T6 for a number of tool shoulder diameters and tool rotational speeds and used a three dimensional, heat transfer and visco plastic flow model to simulate these welding experiments. mm/min [8]. Consequently, the appearance of the weld for different rotational speed is shown and the impact of the stress as a function of strain and the effect of different rotational speed and pin profiles on yield strength and elongation are analyzed. Experiments were conducted on AA6351 Aluminium alloy in a CNC Vertical Machining Centre. The experimental method is proposed to analyze the role of friction stir welding tool on friction stir weld formation by analyzing the material flow [9]. Material flow is analyzed without the insertion of marker material. Based on observations made in the analysis, mechanisms of friction stir weld formation; defect formation and onion ring formation are proposed.

III. EXPERIMENTAL SETUP

In this study, full-penetration friction stir welds are performed on aluminium alloy 6063 pipe for butt joint configuration as shown in Figure 2.

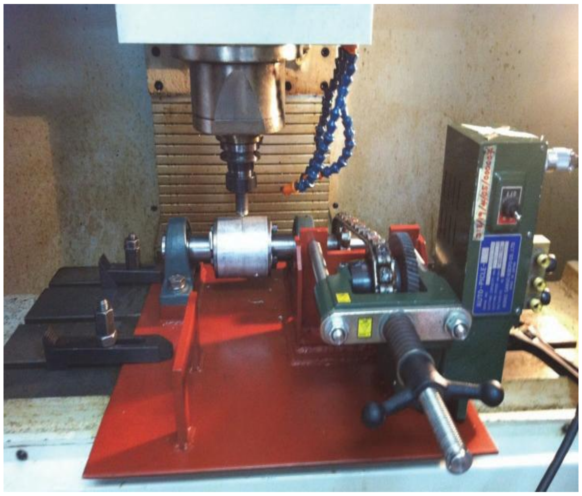

Fig.3: Orbital clamping unit for FSW experiment

The 89 mm outside diameter of aluminium alloy 6063 pipe with 5 mm nominal thickness was used in this present study. Chemical composition and mechanical properties are shown in Table 1 and 2, respectively. The tool geometry used for this study was made of high carbon steel with 20 mm diameter of shoulder, 5 mm and 3.8 mm of pin diameter and length, respectively. The position of tool was offset 6mm forward from centreline.

Table.1a. Chemical composition of aluminum alloy.

Al alloy	6063
Si	0.4-0.8
Fe	0.7 max
Cu	0.15-0.4
Mn	0.2-0.8
Mg	0.8-1.2
Cr	0.15-0.35

Table.1b. Mechanical properties of base metal

Tensile strength (MPa)	**292**
Yield strength (MPa)	**245**
% Elongation	**28.4**
Hardness	**109**

Aluminum 6063 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 [10]. 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.

IV. RESULTS AND DISCUSSIONS

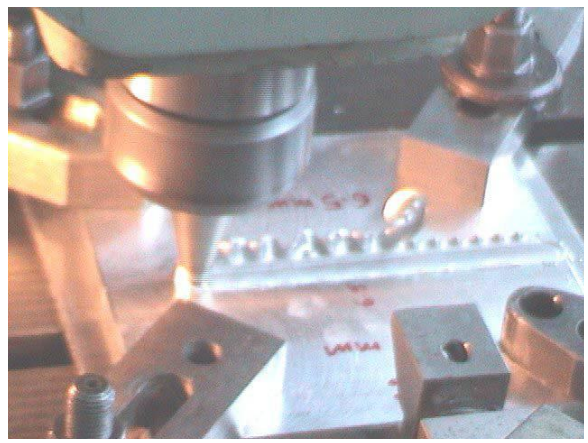

Fig.4. FSW process

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.

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 [11]. In the following sections, typically mechanical properties, such as strength, ductility, and bending are briefly reviewed.

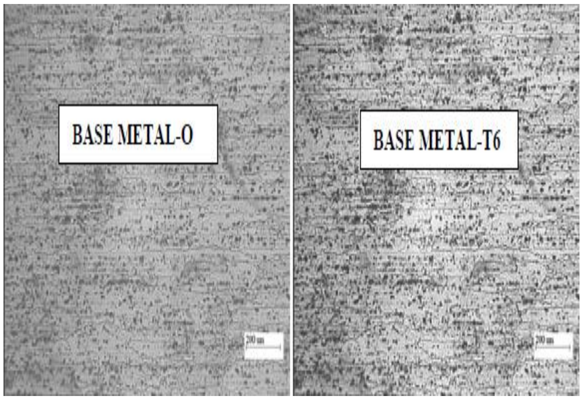

Fig.5a. Optical microstructures of base metal after heat treatment annealed and T6.

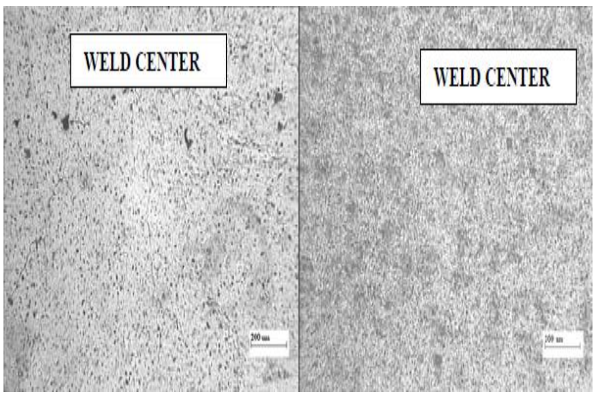

Fig.5b. Optical microstructures of weld-O and weld-T6

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

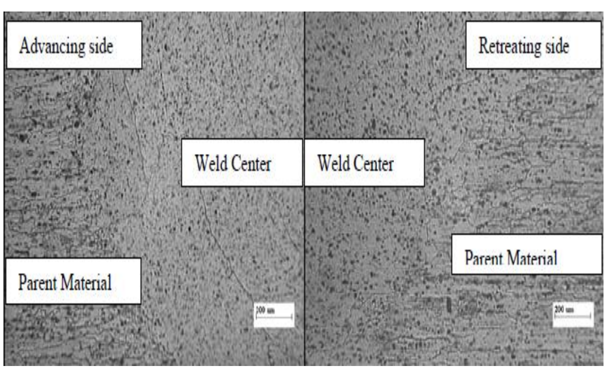

Fig.6. Optical microstructures of TMAZ in FSW.

Friction stir welding was carried out on the AA6061 aluminium alloy in different conditions i.e., in annealed condition (O) and solutionized and aged condition (T6).

FSW for pipe posed unique challenge and the orbital clamping unit (OCU) was vital in this current setting. Two categories of welding parameters were used which can be referred to in Table 3.

TABLE 3: WELDING PARAMETERS

FSW sample	Welding parameters		Remarks
	Rotation speed (rpm)	Travel speed (mm/s)	
FSW1	900	1.2	Vary in rotation speed but constant in travel speed
FSW2	1200	1.2	
FSW3*	1500	1.2	
FSW3*	1500	1.2	Vary in travel speed but constant in rotation speed
FSW4	1500	1.8	
FSW5	1500	2.4	

With same welding parameters

Visual inspection was conducted to detect for possible voids or imperfections such as crack, excessive flash, surface tunnel, wormhole and lack of penetration according to AWS D17.4. Tensile tests were performed according to ASTM E8M-06. Three tensile samples were prepared for each weld.

The tensile tests were conducted at specific parameters, by using servo controlled universal testing machine.

A. Visual Inspection

Table 4 shows the surface finishing for each FSW sample.

The FSW1 and FSW2 give smooth weld surface with some lateral flash; meanwhile FSW3, FSW4 and FSW5 show smooth weld surface condition. With the increase of rotation speed, the lateral flash was minimized while increasing the travel speeds, no such lateral flash occurred.

Therefore, it was discovered that the external surface behaviour may depend on the welding parameters as stated in the previous study [12].

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TABLE 4: WELD SURFACE FINISHING

FSW sample	Weld surface finishing	Remarks
FSW1		Smooth weld surface with lateral flash
FSW2		Smooth weld surface with lateral flash
FSW3		Smooth weld surface
FSW4		Smooth weld surface
FSW5		Smooth weld surface

TABLE 5: CROSS SECTION MACRO STRUCTURES

FSW sample	Advancing side	Retreating side	Remarks
FSW1			Defect free
FSW2			Defect free
FSW3			Defect free
FSW4			Defect free
FSW5			Crack line and very small pin hole were detected.

B. Macrostructures and weld defects

Table 5 shows the cross sectional macrostructure for five pipe specimens at different welding parameters. For FSW1 -FSW4, the specimens show defect free samples but defect formed in FSW5 sample. This may due to excessive turbulence caused by higher travel speed which affects the formation of defect. This was agreed that the higher parameters will cause excessive turbulence due to different plastic deformation degrees and temperatures [5]-[6].

C. Tensile properties.

Tensile strength may vary depending on its welding parameters [12]. The tensile strength is plotted based on actual strength. Figure 3 shows the tensile strength for each FSW sample. The increment in rotation speed (FSW1, FSW2 and FSW3) increase the tensile strength up to 126MPa then decrease to 121MPa. Similar pattern goes to sample FSW3, FSW4 and FSW5. The tensile strength increase up to 132 MPa before it starts decreasing to 114MPa.

Table 6 shows the fracture section for each FSW sample. As detected on FSW1, there was defect free as shown in Table 5 but it breaks on the weld centreline. This weak joint shows the lowest tensile strength at 104MPa. Meanwhile, the FSW2, FSW3 and FSW4 samples give better joint strength as it breaks on the base metal either on advancing or retreating side. It is a bit different from the previous study which found that the fracture location was on the retreating side and applicable for certain grade of aluminium [6]. For FSW5 sample, it is clearly observed by using the optical microscope, the hairline crack and small pin hole affect the strength of the joint as it breaks on the weld centreline. It also gives the lower tensile strength with the value of 114MPa.

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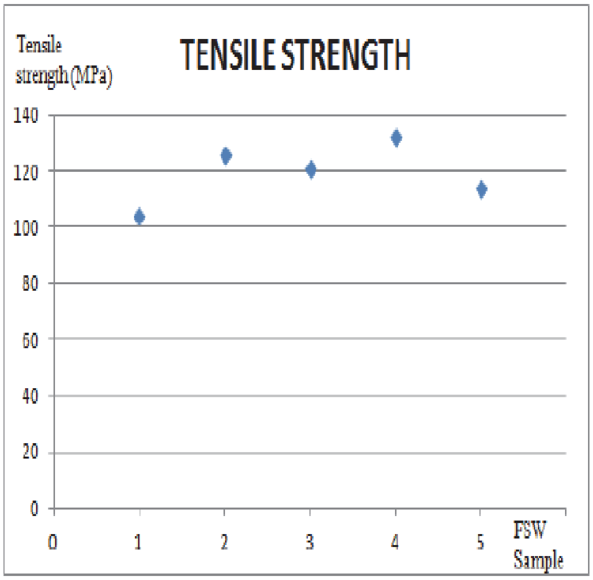
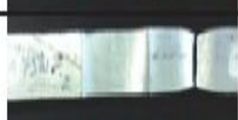


Fig.7: Tensile strength for FSW sample.

TABLE 6: FRACTION SECTION

FSW sample	Advancing side	Retreating side	Remarks
FSW1			Breaks on centerline
FSW2			Breaks on retreating side
FSW3			Breaks on advancing side
FSW4			Breaks on retreating side
FSW5			Breaks on centerline

V. DISCUSSIONS

The mechanical properties of the weld were an important factor that determines the quality of the welding connection. the tensile strength of welding results showed a tensile strength in contrast to the variation of rotation and feeding as well as the diameter of the tool shoulder. The mechanical properties of FSW welds on aluminium alloys (AA 5052) such as tensile and bending strength of the material Results of research shows the tensile strength of FSW results on Aluminium AA 5052 for the variation of rotation, feeding and two shoulder diameter of the tool achievements of the percentage of the tensile strength for base metal by 85% while the lowest tensile strength of 70MPa was obtained at 1950 rpm rotation with feeding 208 mm/min with the achievements of the percentage of the tensile strength for base metal by 26%.

VI. CONCLUSION

Research has been performed on welding friction stir welding (FSW) aluminium AA 5052 using the round (855, 1300 and 1950 rpm) and feeding (50, 135, 208 mm. An Extensive research effort that continues the progress to understanding of FSW of aluminum alloys and its influence on their microstructure and properties. Metal flow modeling may have a role to play here; though capturing this aspect of the thermo mechanical behavior remains a significant challenge.

It can be concluded that by varying the process parameters within the range:

Case I:

Tool rotation speed 1120 rpm, Welding speed 20 mm/min and Pin length of the tool 5.2mm.Tensile strength obtained is 142Mpa.

Case II:

Tool rotation speed 1400 rpm, Welding speed 25 mm/min and Pin length of the tool 5.7mm. Tensile strength obtained is 182Mpa.

From the two cases it has been observed that the maximum tensile strength obtained is 182 Mpa from case II.

We know that tensile strength of base material is 320Mpa; it means the joint efficiency is 60%.

1) High rotation speed of 1500rpm for various travel speed (1.2, 1.8 and 2.4 mm/s) gives better weld surface finishing without lateral flash.

2) High rotation speed of 1500rpm and travel speed of 2.4 mm/s cause void defect to form in the joint.

3) The increment of rotation speed will increase the tensile strength up to maximum value of 126 MPa and then starts decreasing to 121 MPa.

4) The increment of travel speed will increase the tensile strength up to maximum value of 132 MPa and then starts decreasing to 114 MPa.

5) The lowest rotation speed of 900 rpm and travel speed of 1.2 mm/s give the weakest joint strength of 104MPa while the highest rotation speed of 1500 rpm

and travel speed of 2.4 mm/s give defects in the joint with a bit higher strength of 114MPa.

REFERENCES

[1] Liu, D., Xin, R., Zhao, L., & Hu, Y. 2017. Effect of textural variation and twinning activity on fracture behavior of friction stir welded AZ31 Mg alloy in bending tests. Journal of Alloys and Compounds, 693, 808-815.

[2] R.Yuvaraj, N.Alagirisamy, R.Kandhasamy (2016), "Experimental Analysis of Nano Aluminum Metal Matrix Composite a Tribological Studies". International Journal on Applications in Mechanical and Production Engineering Volume 2: Issue 4: April 2016, pp 16-19.

[3] Zhao, Y., Lu, Z., Yan, K., & Huang, L. 2015. Microstructural characterizations and mechanical properties in underwater friction stir welding of aluminum and magnesium dissimilar alloys. Materials & Design (1980-2015), 65, 675 - 681.

[4] Nur Rusdi, M.Y. Noordin I. Sudin and D.Kurniawan. (2014), "Power Demand Calculations in Turning of Aluminum Alloy". Advanced Materials Research. 845: 786-789.

[5] Doss, M. 2012. Experimental Study of Friction Stir Welding of 6061-T1 Aluminum Pipe. International Journal of Mechanical Engineering and Robotics Research. 1(3).

[6] Miroslav M. Mijajlovi, Nenad T. Pavlovi (2012), "Experimental studies of parameters affecting the heat generation in friction stir welding process" thermal science, Vol. 16, Suppl. 2, pp. S405-S417.

[7] Akinlabi E T, Els-Botes A and McGrath P J (2011), "Effect of Travel Speed on Joint Properties of Dissimilar Metal Friction Stir Welds", in Proceedings of 2nd International Conference on Advances in Engineering and Technology (AET), January 30-February 1, Uganda.

[8] Ahmed Khalid Hussain, Syed Azam Pasha Quadri "Evaluation of parameters of friction stir welding for aluminium AA6351 alloy International Journal of Engineering Science and Technology Vol. 2(10), 2010, 5977-5984.

[9] Benyounis K Y and Olabi A G (2008), "Optimization of Different Welding Processes Using Statistical and Numerical Approaches—A Reference Guide", Advances in Engineering Software, Vol. 39, pp. 483-496.

[10] P. L. Threadgill., (2007), "Terminology in friction stir welding, Science and Technology of Welding and Joining", Vol 12 , No 4, 2007, 357- 360.

[11] Rajamanickam N and Balusamy V (2008), "Effects of Process Parameters on Mechanical Properties of Friction Stir Welds Using Design of Experiments", Indian Journal of Engineering and Materials Sciences, Vol. 15, pp. 293-299.