Friction Stir Welding on Aluminum Alloy 6063 Pipe

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Abstract

In Friction Stir Welding (FSW) process, there is a substantial amount of research done on aluminum plate but very few are found for aluminum pipe due to its tubular shape. A specially customized Orbital Clamping Unit (OCU) was used and fixed on the Bridgeport 2216 CNC milling machine in order to weld an aluminum alloy 6063 pipe butt joint at several welding parameters. This OCU will hold the work pieces together tightly, rotate them at the required constant low speed, and ensure easy removal. 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.

Introduction

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 1991 [1]. This is a solid state joining process which uses heat from frictional work to soften and join the material together through stirring process. The schematic process is shown in Figure 1 [2]. This welding technique provides many advantages such as it produces no fumes, no arc and requires no filler metal [3]. Thus, this process can be regarded as an environmental-friendly process.

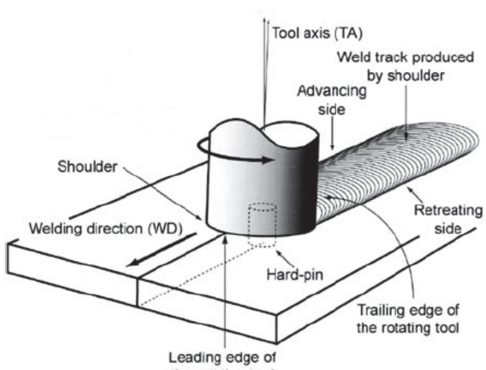


Figure 1: Friction stir welding process

However, the experiment setting is the most critical part in this process especially for joining aluminum alloy 6063 pipes. Good samples are needed before tensile testing. The Orbital Clamping Unit (OCU) was developed and fixed on the Bridgeport 2216 CNC milling machine. This OCU will hold the pipes together tightly, rotate them at required constant low speed, and ensure easy removal.

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 [4].

A substantial amount of research has been done on aluminum plate but found very few for aluminum pipe due to its tubular shape [5]-[12]. This paper will study the effect of welding parameters on the tensile strength of the friction stir welded aluminum alloy 6063 pipe butt joint.

Experimental setup

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

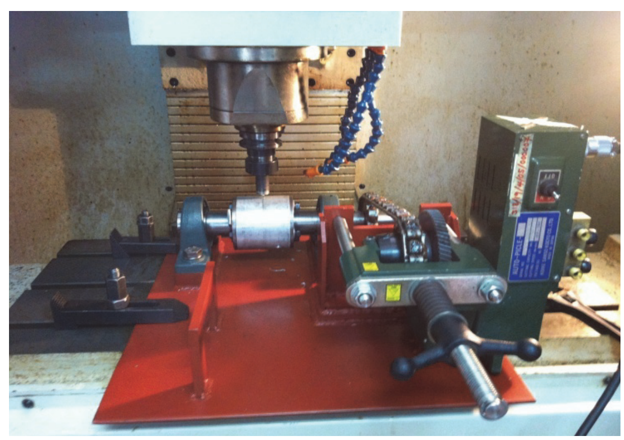


Figure 2: Orbital clamping unit for FSW experiment

The 89 mm outside diameter of aluminum 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 centerline [2].

TABLE 1: CHEMICAL COMPOSITION [13]

Element	% Present
Manganese (Mn)	0.0 - 0.10
Iron (Fe)	0.0 - 0.35
Magnesium (Mg)	0.45 - 0.90
Silicon (Si)	0.20 - 0.60
Zinc (Zn)	0.0 - 0.10
Titanium (Ti)	0.0 - 0.10
Chromium (Cr)	0.0 - 0.10
Copper (Cu)	0.0 - 0.10
Aluminium (Al)	Balance

TABLE 2: MECHANICAL PROPERTIES [13]

Property	Value
Proof Stress	50 Min MPa
Tensile Strength	100 Min MPa
Elongation	27 %
Shear Strength	70 MPa
Hardness Vickers	25 HV

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. The plunge depth and dwell time used were 4mm and 30s respectively.

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 D17.3 [14]. Tensile tests were performed according to ASTM E8M-04 [15]. Three tensile samples were prepared for each weld. The tensile tests were conducted at specific parameters, by using servo controlled universal testing machine. Macro tests were prepared based on ASTM E340 [16]. The optical microscope was used during the macro structural analysis with 10x of magnification and the etchant used was Keller's reagent.

Results and discussion

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 behavior may depend on the welding parameters as stated in the previous study [12].

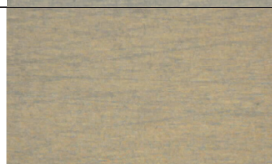
TABLE 4: WELD SURFACE FINISHING

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

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].

TABLE 5: CROSS SECTION MACROSTRUCTURES

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.

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 centerline. 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 aluminum [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 centerline. It also gives the lower tensile strength with the value of 114MPa.

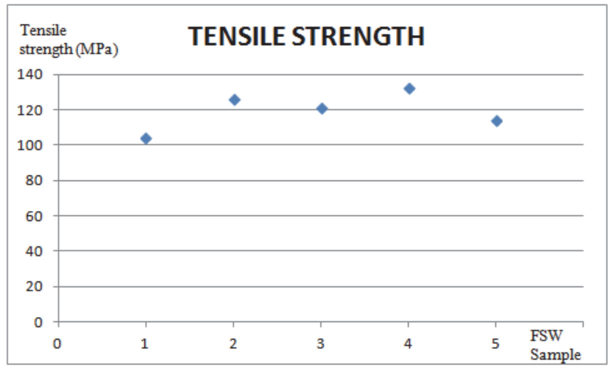
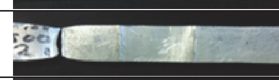
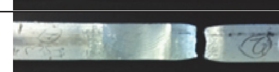
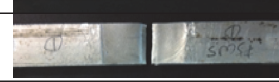


Figure 3: Tensile strength for FSW sample.

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

Conclusions

From the results of the present study, several conclusions can be drawn:

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.

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