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The Temperature and Hardness Distribution of the Friction Stir Welded AA6063 Pipe Butt Joint

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Abstract: Friction stir welding of pipe was carried out on a modified CNC Bridgeport 2216 milling machine. An auxillary orbital clamping unit was utilized with this unit in order to enable this milling machine to friction stir weld in a butt joint configuration. Several good samples were produced using several selected welding parameter combinations. In the experiment, the frictional heat generated was measured and the hardness profile was then analyzed. In this work, the aluminum alloy 6063 pipe with 89mm outer diameter with 5mm wall thickness was used.

Keywords: Friction stir welding, small diameter, aluminium pipe, temperature profile, hardness.

1. INTRODUCTION

The friction stir welding (FSW) is a solid state joining process. During welding, the frictional heat was produced from the rubbing action of the tool and materials. The weld seam will become softened and stirred together as a quality joint (Keivani *et al*, 2013). This haened below the melting temperature of the aluminum as the welded parts. This FSW produces less distortion compared to the arc welding process. There are a lot of benefits introduced by this process such as no additional weight imposed to the welded structure as it uses no filler materials, no safety issue as it produced no fumes and arc during the welding process and also no additional cost as no shielding gas required. **(Fig-1)** illustrates the FSW process (Axel *et al*, 2014).

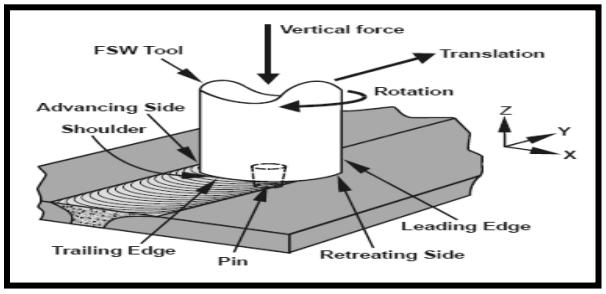


Fig-1 Friction stir welding process

Due to friction and plastic deformation of the welded parts, the temperature in the weld zone will increase thus leading to a significant microstructure transformation without typically causing phase changes and the aluminum shows no visible change due to heat (Axel *et al*, 2014; Yeong *et al*, 2008; Mishra *et al*, 2005) Threadgill *et al*, 2009). Extensive research have been conducted in both academia and industrially, covering microstructure analysis, mechanical testing, hardness test, and temperature profile, including the joining of dissimilar alloys and metals. Mostly done for plates and found a few for pipes.

Zhang *et al*, 2009 and 2011 stated that the increment in the rotating speed and the decrement in the travel speed could increase the stirring effect, thus improving the friction stir welding quality. The microstructure transformation, the metallurgical and mechanical properties of the welded part is determined by the affecting temperatures due to stirring motion. This effect is already mentioned in several studies which conclude that the heat input (temperature) dominated the weld properties (Peel *et al*, 2003; Gratecap, 2008; Simar *et al*, 2008). As mentioned in a study by (Zeng *et al*, 2006 and Ismail *et al*, 2014,), the mechanical properties can be assessed through hardness and tensile measurements. In this present study, the temperature and hardness distribution on the friction stir welded aluminum alloy 6063 pipe joint was analyzed.

2. MATERIALS AND METHODS

2.1 Temperature Profile

The AA6063 pipes have a dimension of an outer diameter with an outside diameter of 89mm, 5mm wall thickness, and 40mm length. These pipes were fixed onto the orbital clamping unit (OCU) to hold tightly and rotate slowly at the required travel speed. This OCU was then mounted onto the bed of the milling machine as shown in **(Fig.2)**. The FSW tool was manufactured from H13 hot work tool steel.

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Fig-2 The OCU was mounted on the bed of the milling machine

Five welding parameter combinations were selected in this study. In the experiment, the FSW tool was offset to 6mm forward of the centerline, plunge at 4mm and dwell time was set to 30s in order to get full penetration of weld. These parameters are shown in **(Table-1)**. All welded samples were inspected according to AWS D17.3 standard acceptance level.

An infrared (IR) thermometer model DT-8859 was used to measure the temperature at the rotating tool. The same method was used by Lammlein *et al*, 2011. This IR thermometer is shown in Figure 3. The IR thermometer was calibrated to the emissivity of the rotating tool due to the outer surface of aluminum pipe was too reflective to give a better temperature reading as stated by Lammlein *et al*, 2011. The welding parameters used are shown in **(Table-1)**.



Fig-3 Infrared thermometer

Table-1: Friction stir welding parameters

FSW samples	Welding parameters	
	Rotation speed (rpm)	Travel speed (mm/min)
FSW#1	900	72
FSW#2	1200	72
FSW#3	1500	72
FSW#4	1500	108
FSW#5	1500	144

The temperatures were recorded in full weld cycle for each sample by the distance of 1.5 m away pointing at the rotating tool. In every 20 mm the pipe rotates, 3 readings of temperature were recorded and an average value were taken at each position for each sample. A schematic diagram of tool setup is shown in **(Fig-4)**.

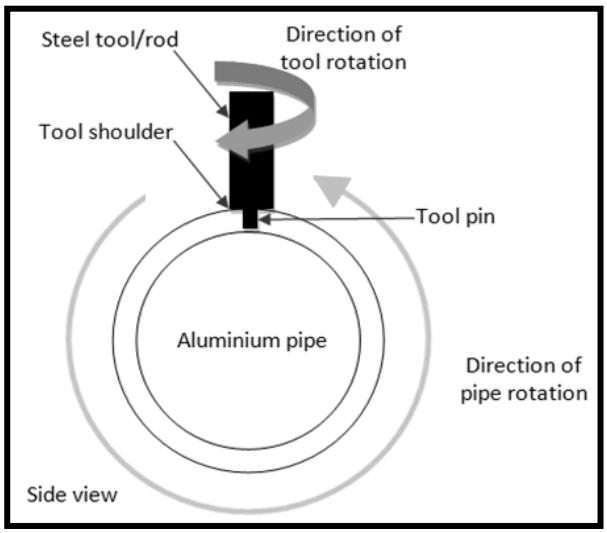


Fig-4 The H13 hot work tool steel setup

2.2 Hardness Test

The hardness distribution was examined using ASTM E18 as guidance. The hardness tester model AFFRI 206 RTD was used in this experiment setting. The hardness testing parameters were shown in **(Table- 2)**.

Table-2: Hardness testing parameters

Testing Equipment	AFFRI 206 RTD	Load	100kg
Rockwell scale	HRB	Temperature	23ºC
Indentor type	1.5875 mm ball	Type of ball	Steel

The hardness specimen was prepared with dimension of 20mm x 60mm as shown in **(Fig-5)**.

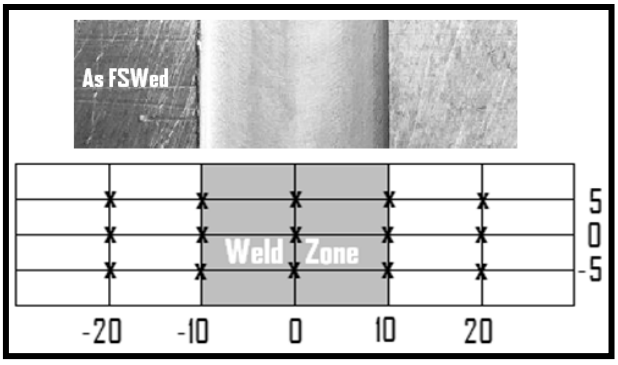


Fig-5 Hardness testing points inside and outside the weld zone

3. RESULTS AND DISCUSSION

3.1 Temperature Profile

Fig 6 and 7 shows the temperature profile measured at the rotating tool for a complete weld cycle of each weld sample. As shown in **(Fig 6 and 7)**, the measured temperature increased with the increment of rotation speed. The same alies when increasing the travel speed.

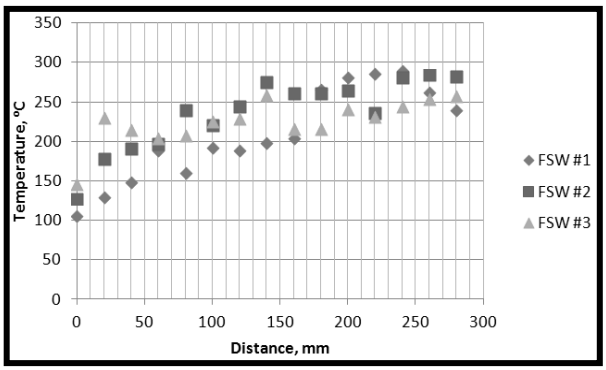


Fig-6 Temperature profiles measured at the rotating tool at varying rotational speed and constant travel speed

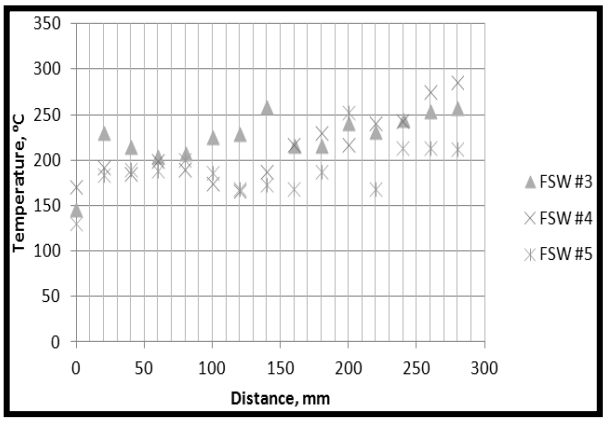


Fig-7 Temperature profiles measured at the rotating tool at varying travel speed and constant rotational speed

However, FSW#3 and FSW#5 showed a reverse pattern when increased the rotation and travel speed respectively. This is due to contact between the tool's shoulder and the outer surface of pipe in which related to the pipe eccentricity. The pipe eccentricity affected the surface contact for heat generation during welding (Yeong *et al*, 2008; Lammlein *et al*, 2011; Gercekcioglu *et al*, 2005). The measured temperature varied from 106.4°C to 289.1°C. In order to complete full weld cycle, the rotating tool starts and stops at the same point which further increased the temperature, thus secondary heating occurred as shown in both **(Fig 6 and 7)** respectively.

3.2 Hardness

Fig 8 and 9 show the measurement of the hardness across the welded joint for all welded samples. Friction contact between the tool's shoulder and outer surface of pipe and the occurrence of plastic deformation will further increased the temperature thus affecting the hardness in the weld zone. An increment in rotational speed caused the hardness to increase before it droed at the highest rotational speed. Whereas an increment in travel speeds, the hardness value droed. The plastic deformation due to stirring process droed hardness value.

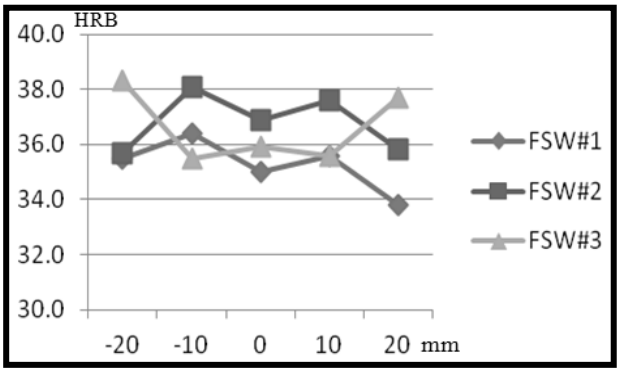


Fig-8 Hardness reading at varying rotational speed and constant travel speed

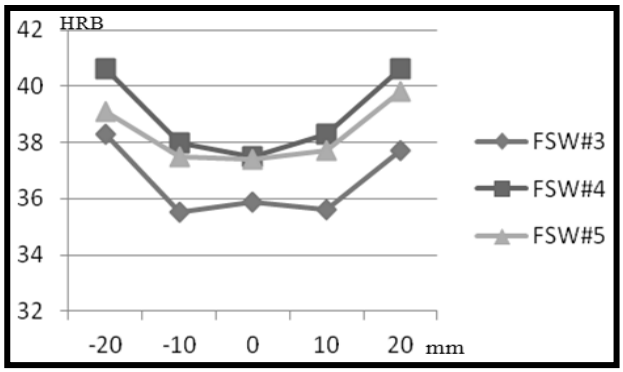


Fig- 9 Hardness reading at varying travel speed and constant rotational speed

4. CONCLUSION

In this study, the temperature and hardness distributions across the friction stir welded joints were determined experimentally. The measured temperature ranged between 106.4°C to 289.1°C. This temperature was based on the rotating tool and not the aluminium pipe which it would give higher readings. The hardness values ranged between 35 HRB and 45.6 HRB on the weld zone which vary due to differences in rotation and travel speeds.

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REFERENCES:

ASTM E18, standard test method for Rockwell hardness and Rockwell superficial hardness of metallic materials, ASTM International. 1-14.

AWS D17.3, (2010) "Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Alications", American National Standard. 1-42.

Fehrenbacher, A., N. A. Duffie, N. J. Ferrier, F. E. Pfefferkorn, M. R. ZinnG, (2014). "Effects of tool-workpiece interface temperature on weld quality and quality improvements through temperature control in friction stir welding", Department of mechanical engineering, University of Wisconsin, USA, 1-31.

Gratecap, F., G. Racineux, S. Marya, (2008). "A Simple Methodology to Define Conical Tool Geometry and Welding Parameters in Friction Stir Welding," 7th International Friction Stir Welding Symposium, Awaji Island, Japan, TWI, Published on CD. 143-158.

Gercekcioglu, E., T. Eren, K. Yildizh, N. Kahraman, E. Salamci, (2005). "The friction behavior on the external surface of the friction stir welding of AA6063-T6 tubes", 5th Int Conf on Tribology, 225-228. Kragujevac (Serbia).

Hwang, Y-M., Z.-W. Kang, Y.-C. Chiou, H.-H. Hsu, (2008). Experimental study on temperature distributions within the workpiece during friction stir welding of aluminum alloys, International Journal of Machine Tools & Manufacture 48, 778–787.

Ismail, A., M. Awang, (2014). Surface hardness of friction stir welded AA6063 pipe, MATEC web of conferences, 13, 04025, 1-5. Kuala Lumpur.

Ismail, A., M. Awang, S. H. Samsudin, (2015). "The Influence of Process Parameters on the Temperature Profile of Friction Stir Welded Aluminium Alloy 6063-T6 Pipe Butt Joint", Mechanical and Materials Engineering of Modern Structure and Component Design, Switzerland Vol. 70 43-249.

Keivani, R., B. Bagheri, F. Sharifi, M. Ketabchi, M. Abbasi, (2013). "Effects of pin angle and preheating on temperature distribution during friction stir welding operation", Trans. Nonferrous Met. Soc. China 23, 2708−2713.

Lammlein, D. H., B. T. Gibson, D. R. DeLa, C. Cox, A. M. Strauss, G. E. Cook, (2011). "The friction stir welding of small-diameter pipe: an experimental and numerical proof of concept for automation and manufacturing", Proc.IMechE Vol.000, Part B: J. Engineering Manufacture, 1-16.

Mishra, R. S., Z. Y. Ma, (2005). "Friction Stir Welding and Processing," Materials Science and Engineering, vol. R 50, 1–78.

Peel, M., A. Steuwer, M. Preuss, P. J. Withers, (2003). "Microstructure, Mechanical Properties and Residual Stresses as a Function of Welding Speed in Aluminum AA5083 Friction Stir Welds," Acta Materialia, vol. 51, 4791–4801.

Simar, A., Y. Brechet, B. de Meester, A. Denquin, T. Pardoen, (2008). "Microstructure, local and global mechanical properties of friction stir welds in aluminium alloy 6005A-T6," Materials Science and Engineering A, vol. 486, no. 1–2, 85–95.

Threadgill, P. L., A. J. Leonard, H. R. Shercliff, P. J. Withers, (2009). "Friction Stir Welding of Aluminium Alloys," International Materials Reviews, vol. 54, no. 2, 49–93.

Zhang, Z., H. W. Zhang, (2009). "Numerical studies on controlling of process parameters in friction stir welding", Journal of Materials Processing Technology, 209: 241−270.

Zhang, Z., J. T. Chen, Z. W. Zhang, H. W. Zhang, (2011)."Coupled thermo-mechanical model based comparison of friction stir welding processes of AA2024-T3 in different thicknesses", Journal of Materials Sciences, 46: 5815−5821.

Zeng, W. M., H. L. Wu, J. Zhang, (2006). Effect of tool wear on microstructure, mechanical properties and acoustic emission of friction stir welded 6061 aluminum alloy, Acta Metallurgica Sinica, 19(1), 9-19.