MATEC Web of Conferences **13**, 04025 (2014)
DOI: 10.1051/matecconf/20141304025

Surface Hardness of Friction Stir Welded AA6063 Pipe

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Abstract. The external surface hardness of friction stir welded aluminum alloy 6063 pipe joint was investigated in this paper. The 89mm of outside diameter pipe with 5mm of wall thickness was used as test pipe piece for this experiment on closed butt joint configuration by utilising Bridgeport 2216 CNC milling machine and orbital clamping unit specially designed to cater for this task and function. Several welded samples were produced on varying process parameters which were successfully joined by using a non-consumable tool with a flat shoulder and a cylindrical pin.

1 Introduction

Friction stir welding (FSW) is a solid state joining process which involves mechanical contact (friction and stirring process) to join the adjoining sections of the pipes. The heat generated from the frictional contact of a non-consumable tool with a flat shoulder and a small cylindrical pin to soften (not melting) the adjoining sections of pipes and stirred (joined) the sections together are shown in Figure 1.

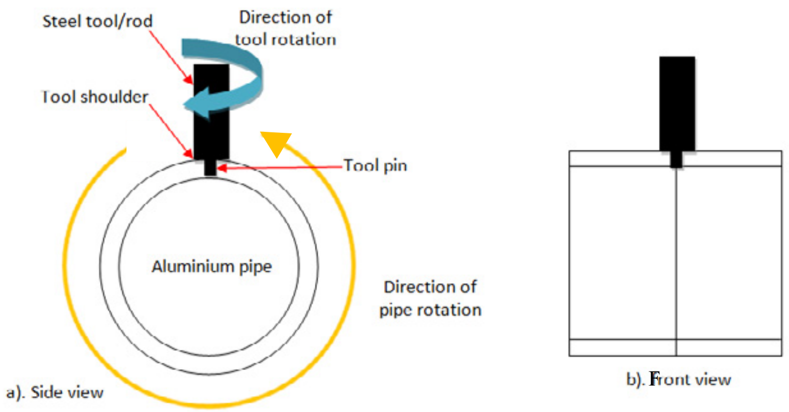

Figure 1. Friction stir welding of pipe

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This process was invented by Wayne Thomas from The Welding Institute in 1991 [1]. This welding technique was initially developed for aluminum to overcome the problems associated with traditional arc welding process [2]. Since then, the process has rapidly evolved and has been used in many applications, which related to steel, stainless steel and titanium. This process was considered a environmental-friendly as it produced no arc and no fumes, besides that requires no filler metal and shielding gas. FSW is suited for flat panel and tubular shape due to advancement of the technology nowadays. Many researches were conducted on flat panels but a few established for tubular shape such as pipe [3-10] for various studies including micro-hardness.

There are different procedures applied to measure large, small, hard, soft, thin and thick metal parts [11]. The prediction of materials transformation can be made by assessing the hardness of these internal and external surface condition. As mentioned by Zeng [12], the mechanical properties can be assessed by hardness and tensile measurement on as-welded parts. Based on the study conducted on 2195-T8 aluminum grade [13], the hardness nearby the interface (weld center) was approximately 35% less than base materials hardness. Besides that, the micro-hardness in thermo-mechanically affected zone (TMAZ) gives the hardest value with an average of 89.4HV. The same condition was found in the lower part [14]. This paper will study the external surface hardness condition of friction stir welded aluminum alloy 6063 pipe butt joint.

2 Experimental Setup

The 89mm of outside diameter aluminum alloy 6063 pipe with 5mm of wall thickness is used as the test pipe piece for this experiment on closed butt joint configuration by utilizing Bridgeport 2216 CNC milling machine and orbital clamping unit as shown in Figure 2.

Figure 2. Experimental setup

The tool geometry used for this study was made of high carbon steel with geometry dimension as shown in Figure 3. The position of tool was offset 6mm forward from the centerline. The plunge depth and dwell time were 4mm and 30s, respectively [15].

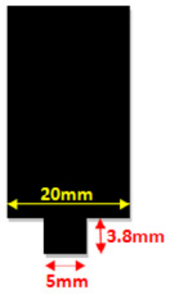


Figure 3. Tool geometry

The welding parameters used may vary in rotation speed and travel speed as shown in Table 1. Surface hardness was assessed based on ASTM E18 [16], standard test method for Rockwell hardness and Rockwell superficial hardness of metallic materials. The parameter setting for Rockwell hardness testing can be referred to Table 2. Testing points on as-welded sample can be referred to Figure 4.

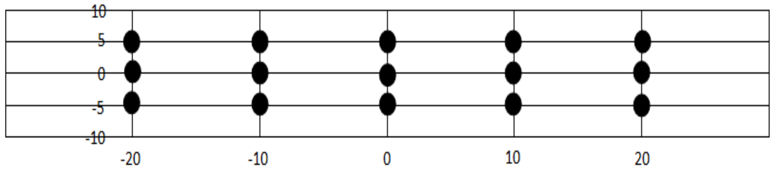
Table 1. Welding parameters

FSW sample	**Welding parameters**		**Remarks**
	Rotation speed (rpm)	**Travel speed (mm/s)**	
FSW 1	900	1.2	Vary in rotation speed but constant in travel speed
FSW 2	1200	1.2	
FSW 3*	1500	1.2	
FSW 3*	1500	1.2	Vary in travel speed but constant in rotation speed
FSW 4	1500	1.8	
FSW 5	1500	2.4	

Note: *similar welding parameter

Table 2. Rockwell hardness testing parameters

Rockwell scale	HRB	**Load**	100 kgf
Testing Equipment	AFFRI 206 RTD	**Temperature**	23°C
Indentor type	1/16" ball	**Type of ball**	Steel



* All dimension in mm

Figure 4. Testing points on as-welded sample

3 Results and Discussion

During the welding, the plastic deformation occurred thus affecting the hardness of the surface profile. This is shown in Figure 5 where FSW 1 and FSW 2 provide convex shape hardness profile across the surface of as-welded sample, increase gradually and then show decrement in hardness. Meanwhile, the rest of the three samples such as FSW 3, FSW 4 and FSW 5 showed a concave shape in hardness profile as it decreases gradually before increasing to the highest value. The increment of welding parameters will give higher readings of hardness. These welding parameters do affect the hardness of the surface profile, quite similar pattern found in [1] where hardness depends on the welding parameters and the distance from the weld center although the aluminum grade used was different. The hardness ranges between 35 HRB and 40.6 HRB. The surface under the tool pin (weld center) gave the lowest hardness reading due to stirring of pin tool which caused excessive turbulence, giving different plastic deformation degrees and temperatures [4-5].

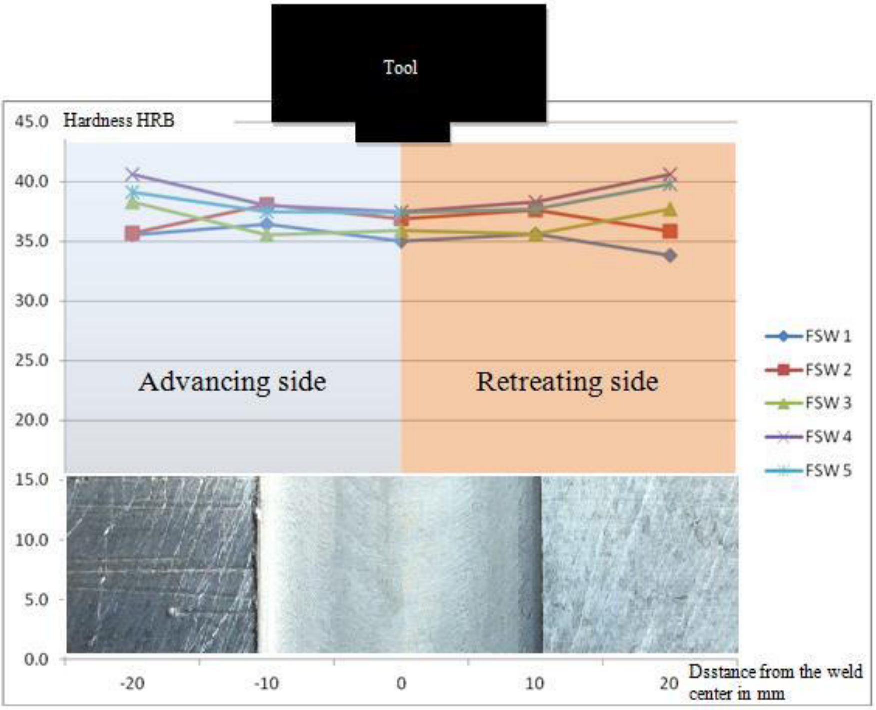


Figure 5. Hardness testing results

4 Conclusions

Several conclusions can be drawn from this study as follows:

1. The weld center of each sample (stirred zone) gives the lowest hardness ranges from 35 HRB to 37.5 HRB at different welding parameters.
2. The surface below the flat shoulder gives reading range from 35.5 HRB to 38.3 HRB, a bit higher compared to weld center (stirred zone).
3. The surface hardness increases to a maximum of 36.9 HRB before decreasing to 35.9 HRB with the increment of rotation speed.
4. The lowest hardness of 35 HRB at the lowest rotation speed of 900rpm.
5. The surface hardness increases to a maximum of 37.5 HRB before reducing to 37.4 HRB with the increment of travel speed.
6. The highest hardness of 37.5 HRB at travel speed of 1.8mms^{-1}.

5 Acknowledgement

The authors would like to acknowledge the Universiti Kuala Lumpur and Universiti Teknologi PETRONAS for providing the required facilities and assistance.

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