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The Effects of Welding Parameters on Macro and Micro-Structure of Friction Stir Welded Aluminium

Azman Ismail[1,2*], Mokhtar Awang[2], Fauziah Ab Rahman[1], Puteri Zarina Megat Khalid[1], Bakhtiar Ariff Baharudin[1], Mohd Afendi Rojan[3], Darulihsan Abdul Hamid[4]

[1]Universiti Kuala Lumpur, Malaysian Institute of Marine Engineering Technology, Lumut, Perak. MALAYSIA.
[2]Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak. MALAYSIA.
[3]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra, Perlis. MALAYSIA.
[4]Universiti Kuala Lumpur, Malaysia Italy Design Institute, Cheras, Kuala Lumpur. MALAYSIA.

Email: azman@unikl.edu.my

Abstract. Friction stir welding (FSW) is considered as state-of-the-art technology for joining aluminium alloys (AA). Several welding parameters with different rotational and travel speed combinations are used to produce good friction stir welded AA6063 pipe butt joint. The weld quality is then evaluated by optical microscope through observations of the macro and micro-structure. The different welding parameters give finer grain structure on the weld nugget zone instead of irregular size of grain structure on the thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ). Thus, it would be useful for predicting mechanical performances (fracture) of FSW pipe butt joints.

1. Introduction.

Friction stir welding (FSW) is an established solid-state joining process introduced in 1991 in the United Kingdoms. Based on previous literature, this FSW technology has become very promising in automotive, shipbuilding, pipeline and space technology [1]. The heat input generated during this friction stir welding process is mainly controlled by these two welding parameters thus affecting the microstructural changes of the friction stir welded joints. The heat input and plastic deformation influence the formation of a zone in the microstructure such as weld nugget zone (WNZ), thermo-mechanically affected zone (TMAZ), heat affected zone (HAZ) and base metal (BM). Recrystallization refine grains used to be found in weld nugget zone [2]. These microstructure changes occur during the cool down of the weld [3]. The mechanical properties of friction stir welded joint are dependent on the welding parameters [4][5]. Thus, the mechanical performance due to microstructural changes should be evaluated accordingly. The purpose of the present study is to discuss the effect of the welding parameters on the microstructure changes in 6063 aluminum alloys.

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2. Experimental procedures

The material under investigation is a 6063-aluminum alloy of pipe structure. Aluminum pipe with an outside diameter of 89mm, 100mm long and 5mm of wall thickness was friction-stir welded by employing various welding parameters as shown in Table 1. The dwell time and the plunge depth was set to 25 s and 4 mm respectively for all specimens.

Table 1: Friction stir welding parameters

Specimen No.	Tool Rotational speed (RPM)	Pipe Travel speed (mm/s)
1	1000	3
2	1000	4
3	1000	5
4	1300	3
5	1300	4
6	1300	5
7	1600	3
8	1600	4
9	1600	5

The cylindrical type of H13 high carbon steel tool was utilized and characterized by 20mm of shoulder diameter, 5mm of pin diameter and 4mm of pin length. The welds were performed by offsetting the tool 6mm forward the centerline. The arrangement of this setting is as shown in Figure 1. The finished product is as shown in Figure 2.

Figure 1 Experiment setting

Figure 2 Finished product

An electrical discharge machine (EDM) wire cut was employed for specimens sectioning and was then cool- mounted in order to minimize the effect of post heat treatment on the specimens.

For microstructural analysis purpose, the specimens were then polished, and etched with 1% hydrofluoric acid (HF) etching reagent (1 mL HF, 100 mL distilled water, with 10 minutes of immersion) to reveal the metallurgical structure. The analysis of this macro image revealed characteristic features of these aluminum alloys. The observation was done under an optical microscope (OM). The 10x and 100x power magnification were used for macro and micro images respectively.

3. Results and discussion

A macro image of each specimen is shown in Figure 3. The differences between each zone for each specimen are shown in Table 3.

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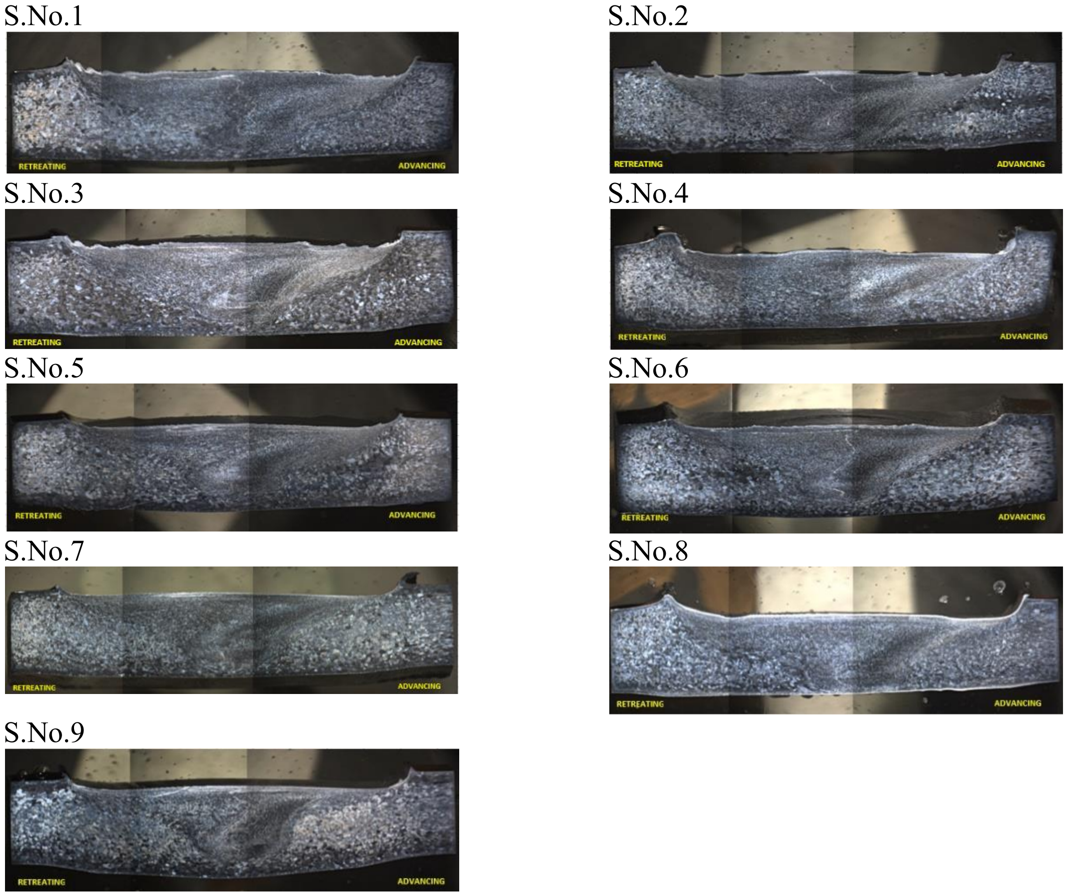
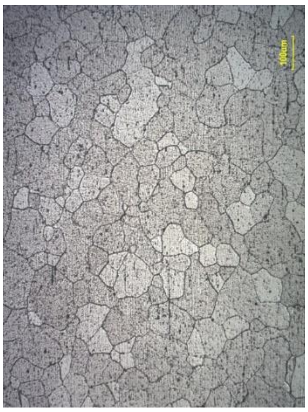
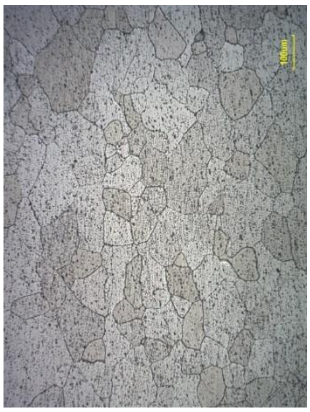


Figure 3: Macro images of specimen (10x magnification)

Based on Figure 3, macro images of FSW show the advancing side on the right and the retreating side on the left for all nine specimens. Regardless of the welding parameters, the weld nugget showed approximately symmetrical patterns which were similar in diameter to the pin tool. With the increment of welding parameters, the grain structure in the weld nugget was much smaller in size and equiaxed (finer grain) when compared to other zones.

This rapid solidification at below melting temperature gave an initial finer grain within this weld nugget. The nugget is intensely recrystallized and categorized by finer grains. The finer grain structure favored the increase of strength thus preventing fracture within this zone [1][6]. For thermo-mechanically affected zone (TMAZ) and heat affected zone (HAZ), the grain size was much larger than in the weld nugget zone and smaller than in the base metal of this aluminum alloy. There was a high tendency for a fracture to occur within this zone either on the advancing or retreating side. This is due to different microstructural structures at the beginning into the HAZ and into the TMAZ which might be characterized by lower stiffness with respect to the base metal.

Table 3: Differences between zones (100x Magnification)

	Heat Affected Zone (HAZ)	Thermo-Mechanically Affected Zone (TMAZ)	Weld Nugget Zone (WNZ)
S.No.1			
S.No.2			
S.No.3			
S.No.4			

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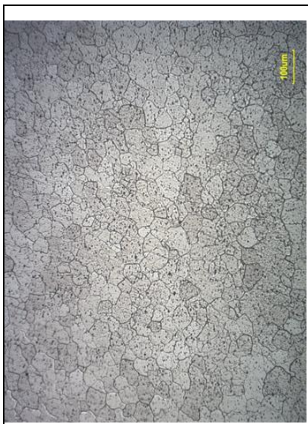
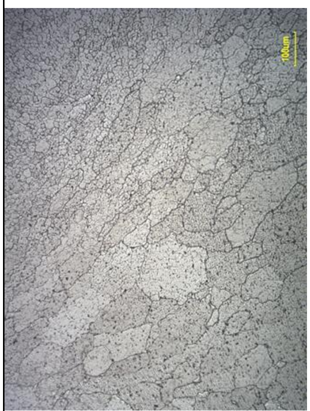
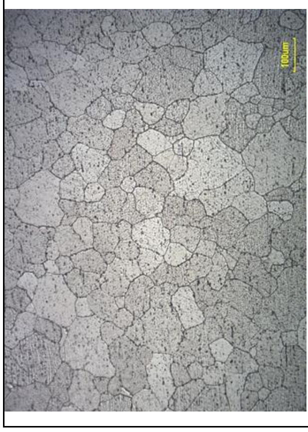
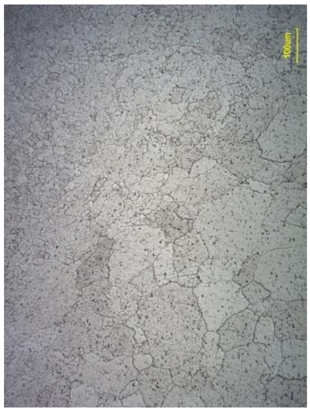
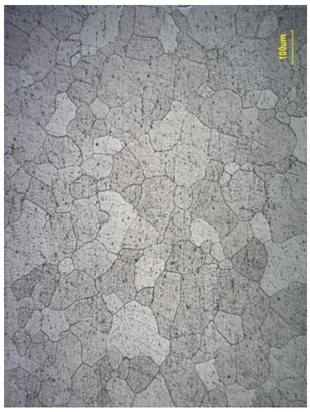




S.No.5



S.No.6

S.No.7

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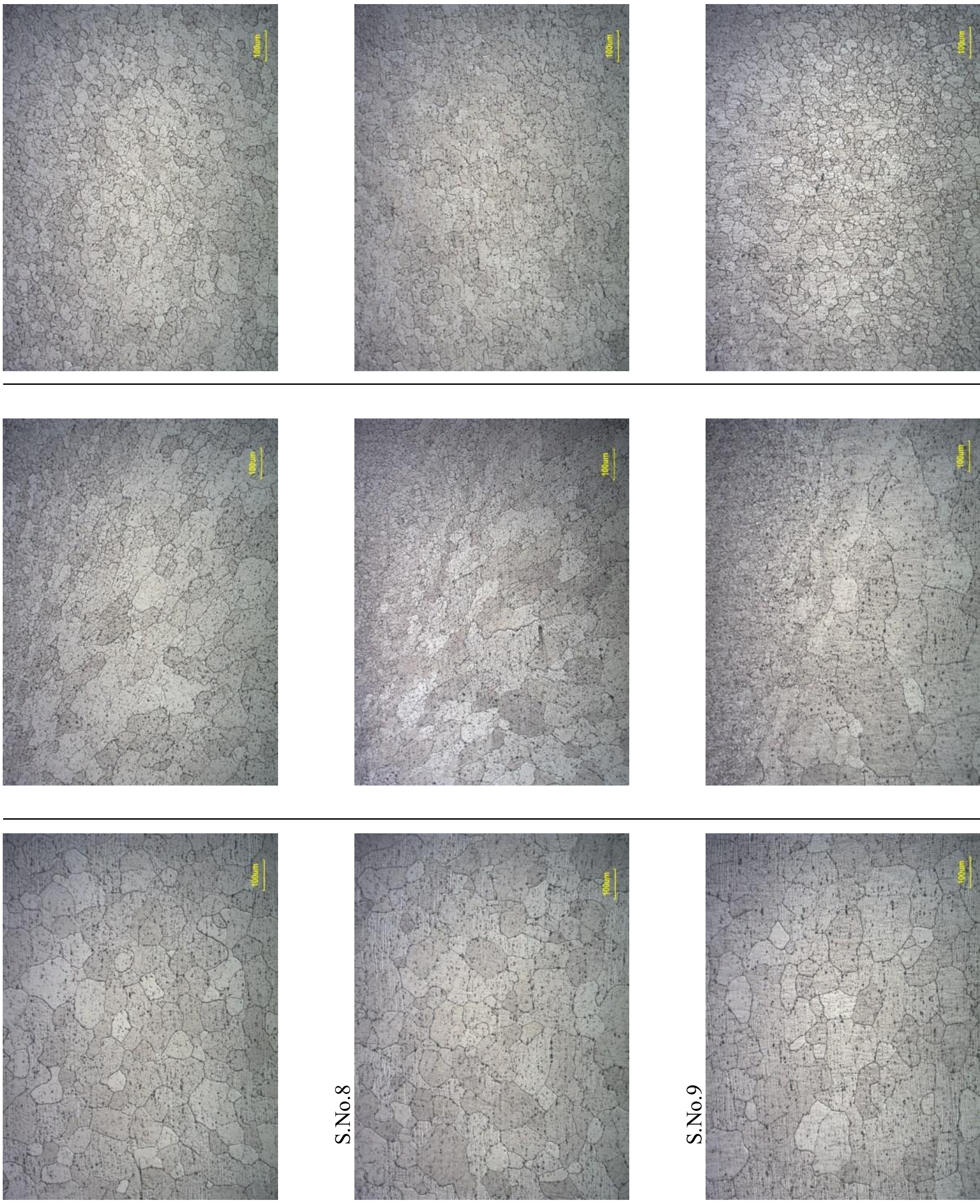

S.No.8

S.No.9

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4. Conclusion

In the present study, the effect of welding parameters on macro and micro- structure of 6063 aluminum alloys pipe has been fully described. All pipe specimens were successfully friction stir welded with a defect-free joint. These macro and micro images were useful for predicting mechanical performances (fracture) of FSW joints. It was underlined that the different welding parameters gave finer grain structure on the weld nugget zone.

5. Acknowledgement

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