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Friction Tir Welding Using Round Welding Tool Probe on Aluminium Alloy AA6061

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Abstract: This research project focuses on investigating the mechanical properties and microstructure of a 3 mm thick aluminum alloy AA6061 joint fabricated using FSW. The project conduct to find the relationship between rotary speed and feed rate in friction stir welding by determining the mechanical properties and microstructure of the aluminum alloy AA6061 after the welding process and identifying the optimal parameters to produce the best and strongest joint. The projected methodology employs a series of process iterations with varying parameters. Tensile tests, microhardness tests, and microstructural analysis are conducted to observe and collect the corresponding mechanical and microstructure properties. Subsequently, the obtained results are carefully evaluated. The experimental findings indicate that selecting suitable parameters leads to high mechanical strength, consistent microhardness, and fewer defects.

Keywords: Friction Stir Welding (FSW), Joint, Microstructure, Mechanical Properties, Aluminum Alloy AA6061

1. Introduction

Welding is a technique used to join materials like metals or thermoplastics by melting them and allowing them to solidify, creating a fused connection. It differs from other methods such as brazing and soldering, which don't involve melting the base metal. Welding often involves adding a filler material to create a molten pool, known as a weld pool, that cools and forms a strong bond, potentially stronger than the base material. Welding can be accomplished with or without the application of heat, using different energy sources like gas flame, electric arc, laser, electron beam, friction, or ultrasound. It requires a shield to prevent contamination or oxidation of the filler or molten metals. Welding can be performed in various conditions, including open air, underwater, or even in space. However, it carries risks, such as burns, electric shock, visual impairment, inhalation of hazardous gases and fumes, and exposure to intense UV radiation [1].

Friction-stir welding (FSW) is a widely used technique in industries such as automotive, transportation, marine, and aerospace. It offers several advantages, including low welding temperature and heat input, elimination of melting, prevention of alloy element evaporation loss, and avoidance of

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solidification-related challenges. FSW is a solid-state joining process that employs a non-consumable rotating tool with a specially designed pin and shoulder. This tool is plunged into the contact surfaces of two metal pieces, generating heat and creating a softened region near the FSW tool. As the tool moves along the length, it mechanically mixes and bonds the softened metal without melting the components. The elevated temperature allows for the metal to be joined using mechanical pressure exerted by the tool, similar to joining clay or dough. FSW is commonly used for aluminum, particularly extruded aluminum and non-heat treatable alloys, as well as in applications where strong welds are needed without the need for post-weld heat treatment [2].

2. Material and Method

The objective of this study is to examine the mechanical and microstructural properties of a sample. For the experiment, an aluminum alloy plate of AA6061 with dimensions of 100 mm x 50 mm x 3 mm was selected. The chosen alloy composition typically consists of approximately 97.9% to 98.8% aluminum (Al), 0.8% to 1.2% magnesium (Mg), 0.4% to 0.8% silicon (Si), 0.7% iron (Fe), 0.15% to 0.4% copper (Cu), 0.15% manganese (Mn), and 0.25% chromium (Cr) [3]. Friction stir welding will be employed for the experiment, utilizing a mild steel tool with a round probe. The welding parameters for the tool include a shoulder length and diameter of 20 mm, as well as a probe length of 2.5 mm and diameter of 6 mm.

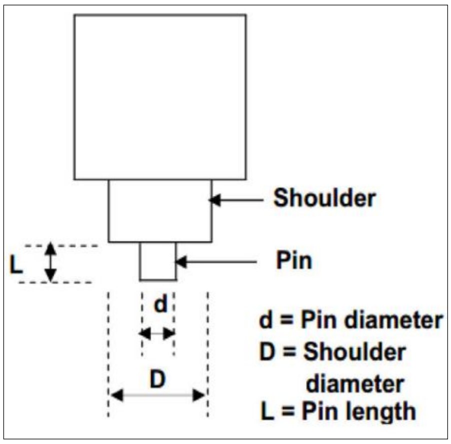


Figure 1 Geometry of Welding Tool

There are 5 different parameter use for this experiment:

Workpiece No.	Input Parameter	
	Spindle Speed (rpm)	**Feed rate (mm/min)**
1	1055	14
2	1320	14
3	1640	14
4	1930	14
5	2620	14

There are few type of equipment and machine what will be use in this experiment and research study. All selected equipment is needed to be evaluate the workpiece mechanical and microstructure property of aluminum alloy 6061. The equipment used in this study is:

i. PINNACLE Conventional Vertical Milling Machine
ii. YAMAZAKI MAZAK VCN-410-II CNC Milling Machine
iii. EDM Wire Cut (Mitsubishi RA90)
iv. Universal Testing Machine
v. SHIDMADZU Microhardness Vickers
vi. NIKON ECLIPSE LV150NL Digital Microscope Image Analyser
vii. JOEL JSM-6380LA Scanning Electron Microscope

Process of friction stir welding will be conducted by using PINNACLE Conventional Vertical Milling Machine. Workpiece will be weld using butt joint and will be hold to prevent displacement during plunging process. Figure 2 show the setup for friction stir welding.

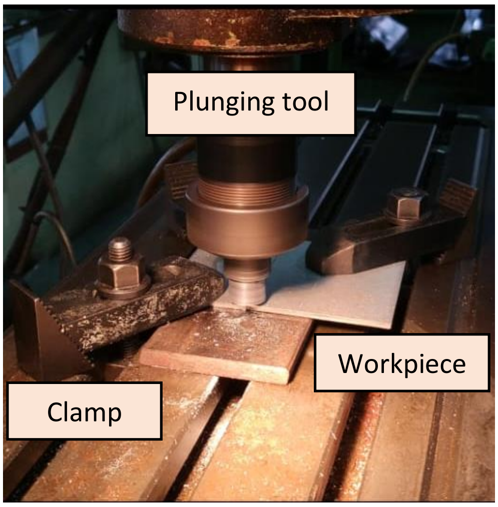


Figure 2 Horizontal clamp use to hold workpiece.

After welding workpiece, in preparation sample for mechanical & microstructure analysis the workpiece will undergo cutting process into 2 type of sample which is 'dog bone' sample for tensile test and small square with a dimension of 2 mm x 2 mm by using YAMAZAKI MAZAK VCN-410-II CNC Milling Machine and EDM Wire Cut (Mitsubishi RA90).

Figure 3 EDM Wire Cut (Mitsubishi RA90)

Figure 4 YAMAZAKI MAZAK VCN-410-II CNC Milling Machine

Universal Testing Machine and SHIDMADZU Microhardness Vickers will be used to determine the mechanical properties of aluminum alloy AA6061 which is tensile test result and Hardness Vickers (HV).

Figure 5 Universal Testing Machine

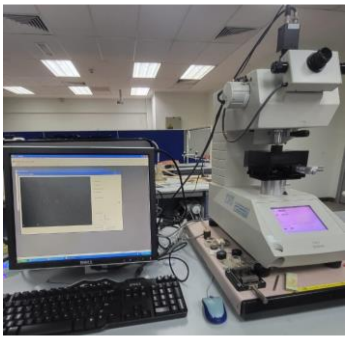


Figure 6 SHIDMADZU Microhardness Vickers

Microstructure analysis will be using NIKON ECLIPSE LV150NL Digital Microscope Image Analyser to analyse grain structure of AA6061 after etching process. Next, JOEL JSM-6380LA Scanning Electron Microscope is to analyse fractography of AA6061 at tensile fracture area.

Figure 7 NIKON ECLIPSE LV150NL Digital Microscope Image Analyser

Figure 8 JOEL JSM-6380LA Scanning Electron Microscope

3. Result and Discussion

This chapter shows the experiment result obtained from conducting mechanical and microstructure analysis.

3.1 Mechanical Analysis

Table 1 shows the result for tensile test. Table 2 to Table 6 shows the result of hardness test. Table 1 shows significant variations in maximum load, maximum stress, and elongation at break among different samples. Sample 1, with a spindle speed of 1055 RPM, achieves the highest values for maximum load and maximum stress, while sample 4, with a spindle speed of 1930 RPM, has the maximum elongation at break.

It's important to note that matching the spindle and feed rates is crucial for achieving good weldments, as indicated in Table 1. Combining high spindle speed with low feed rate or low spindle speed with high feed rate leads to better welding performance. However, sample 3 deviates from the expected results, showing significant differences in maximum load and maximum stress compared to the other samples.

The Vickers hardness test will apply a load of 0.98 N to indent the weld joint surface using a Vickers diamond pyramid indenter. Each indentation will last for 10 seconds to ensure consistent testing conditions. The test will be conducted at three vertical points along the weld joint: top, middle, and bottom regions.

By performing the microhardness test at these points, valuable insights can be gained about the hardness distribution across the weld joint. The hardness values obtained at each point will help identify the characteristics of different regions within the joint, such as the nugget zone and the thermo-mechanically affected zone. Measuring the hardness trends (in HV) at each point provides information about the microstructure and its influence on hardness.

Table 1 Tensile Test Result

Sample No.	Parameter		Maximum Load (kN)	Maximum Stress (MPa)	Elongation @ Break (mm)
	Spindle Speed (RPM)	Feed Rate (mm/min)			
1	1055	14	1.92	106.57	1.97
2	1320	14	0.75	41.63	1.69
3	1640	14	0.08	4.32	0.44
4	1930	14	0.60	33.18	2.89
5	2620	14	0.38	21.30	0.41

Table 2 Hardness Test Result of 1055 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Top	59.778	59.671	59.7242	51.9904
Middle	61.4385	61.3133	61.3759	49.2303
Bottom	63.099	60.9483	62.0237	48.2073

Table 4.6 Hardness Test Result of 1320 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Top	59.04	58.2111	58.6256	53.9577
Middle	63.099	61.4958	62.2974	47.7846
Bottom	63.6525	62.9556	63.304	46.277

Table 4.7 Hardness Test Result of 1640 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Top	61.623	59.306	60.4645	50.7256
Middle	60.885	61.1308	61.0079	49.8259
Bottom	59.9625	62.7731	61.3678	49.2432

Table 3 Hardness Test Result of 1930 RPM

Point	Horizontal Length (µm)	Vertical Length (µm)	Average Length (µm)	Hardness (HV)
Top	58.1175	57.1162	57.6169	55.8635
Middle	66.789	63.6855	65.2373	43.5749
Bottom	64.0215	66.7877	65.4046	43.3522

Table 4 Hardness Test Result of 2620 RPM

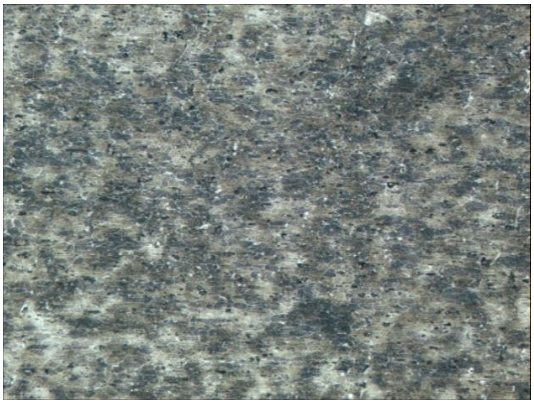
Point	Horizontal Length (µm)	Vertical Length (µm)	Average Length (µm)	Hardness (HV)
Top	60.885	56.7513	58.8181	53.605
Middle	63.6525	62.9556	63.304	46.277
Bottom	64.575	62.0432	63.3091	46.2696

3.1 Microstructure Analysis

In optical microscope (OM), among the five samples, it is observed that samples with rotational speeds of 1640 RPM, 1930 RPM, and 2620 RPM exhibit larger grain boundary sizes and fewer refined grains compared to samples with rotational speeds of 1055 RPM and 1320 RPM. The presence of large grain boundary sizes suggests the occurrence of dislocation, which refers to the movement of crystalline imperfections within the grains. Dislocations are caused by the generation of sufficient stress and thermal energy during welding [4].

Furthermore, the three samples with larger grain boundary sizes exhibit a less clear appearance of refined grains during the etching process. This is attributed to insufficient etching time, as all samples were etched for only 2 minutes. Insufficient etching time can prevent the full development and clear visibility of equiaxed grains.

On the other hand, samples with rotational speeds of 1055 RPM and 1320 RPM demonstrate finer and clearer grain boundaries. The grain size in these samples is smaller compared to samples with higher rotational speeds (1640 RPM, 1930 RPM, and 2620 RPM). The smaller grain size indicates that the two samples experienced less dislocation movement, leading to the formation of more grain boundaries. However, it is noted that sample 1055 RPM exhibits a more refined distribution and orientation of grain boundary compared to sample 1320 RPM. This suggests that the combination of sufficient stress, thermal energy, and reduced dislocation movement in the 1055 RPM weld sample contributes to higher strength and mechanical properties [5].



(a)

(b)

Figure 9 (a) Magnification 100X; (b) Magnification 200X on Grain Structure of 1055 RPM Sample

Meanwhile, on scanning electron miscroscope (SEM) or fractography analysis it is observed that samples with rotational speeds of 1055 RPM, 1640 RPM, and 1930 RPM exhibit dimple fractures with favourable characteristics. These dimples are well-defined, rounded, and uniformly distributed across the surface, indicating high energy absorption and better ductility. Among these three samples, the 1055 RPM sample shows the most promising dimple characteristics in terms of shape and size. Additionally, the distribution of dimples in the 1055 RPM sample is uniform and deeper dimples indicate high in ductility, suggesting good bonding and the ability to withstand higher tensile stress and yield strength during the tensile test compared to the 1640 RPM and 1930 RPM samples.

In contrast, the fracture surfaces of the 1320 RPM and 2620 RPM samples exhibit a patterned fracture appearance. The dimple sizes vary, and there are regions with poor integration of the metal, suggesting a potential cause for brittle fracture. The cooling rate experienced during the friction stir welding (FSW) process also a possible factor influencing the dimple fracture behaviour.

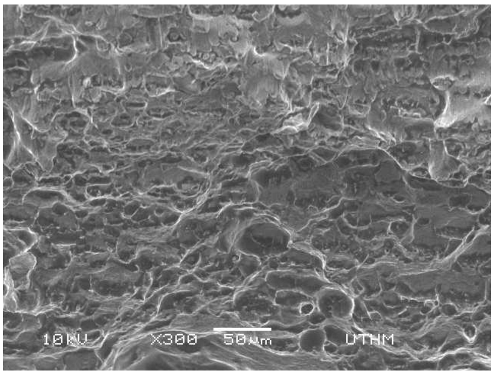


Figure 10 Dimple fracture of 1055 RPM

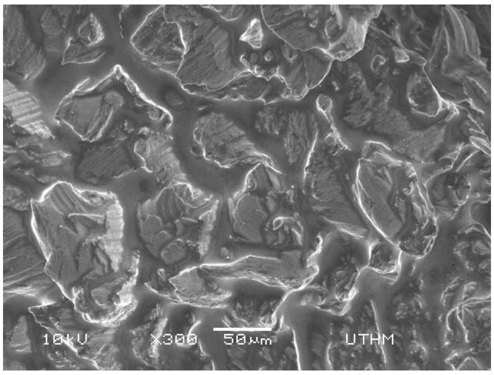


Figure 11 Fail fracture of 1320 RPM

4. Conclusion

In a study on friction stir welding (FSW) of aluminum alloy AA6061, the relationship between spindle speed and feed rate was investigated to achieve strong and high-quality weld joints. Matching the spindle speed and feed rate improved the mechanical strength of the weld joint. The sample welded at 1055 RPM demonstrated superior mechanical properties with a high maximum load, maximum stress, and elongation at break. However, microhardness alone was not enough to determine overall strength.

Scanning electron microscope (SEM) analysis showed that the sample welded at 1055 RPM had smaller and more uniform dimples, indicating good ductility and energy absorption. Based on the comprehensive analysis, the optimal parameter combination was determined to be a spindle speed of 1055 RPM and a feed rate of 14 mm/min, which resulted in better and stronger weld joints.

To further enhance the FSW process for aluminum alloy, it is recommended to implement heat treatment to improve forgeability and strength. Choosing a welding tool material that is stronger and harder than the workpiece material can also have a positive impact. Increasing the sensitivity and precision of the milling machine used for FSW allows for more precise adjustment of process parameters, leading to improved weld quality and performance.

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