

Effect of Square Head Tooltip and Joining Speed on Aluminium Alloy AA6061 in Friction Stir Welding

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Abstract

Friction stir welding (FSW) is a solid-state joining process that gained significant attention in recent years due to its advantages over traditional welding techniques. FSW utilizes non-consumable rotating tool to generate frictional heat which mechanical stirring to create a defect-free weld. In this particular study, square tooltip and aluminum alloy AA6061 as workpiece are the material used. The aim is to investigate the effect of different welding parameters, specially the welding speed of 1055 rpm, 1320 rpm, 1640 rpm, 1930 rpm, and 2620 rpm, while maintaining a constant feedrate of 14 mm/min. Tensile testing are performed to assess the mechanical properties of material including strength and ductility as the process were subjected tensile forces until failure occurred. As for Vickers hardness was employed to assess the hardness distribution in 3 different regions of welded area. Microstructure analysis are done by optical microscopy allowed for visualize of grain boundaries, orientations and potential defect present in the welded area. For scanning electron microscopy (SEM) was employed of more detailed microstructure analysis which able to generate dimple boundaries and intermetallic compounds. By varying the rotational speed of tool, different results in terms of mechanical properties and microstructure are obtained.

1. Introduction

Friction Stir Welding (FSW) is a solid-state welding process that has found widespread use in the shipbuilding, railroad, and aerospace industries because of its low defect and lack of melting. Frictional stir welding can be described as a welding process operation where fabrication process of two piece of metal fused together by frictional welding which by melting the material by friction process. The metals are not melted, instead they are stirred or mixed.

The tools enable the friction and pressed into the workpiece where frictional heat is generated through pressure and rotation. Due to the heat, the material become deformable without reaching the melting point. This welding joining method in which the metals being joined are not molten which means that the grain structure and mechanical properties of the parent metal can be preserved in the weld zone. The process requires continuous and simultaneous movement within the tools.

Therefore, rotating tools both stir the metal and form strong joints between the metal pieces. The fact that this method of welding does not require the use of any gas or flux contributes to the fact that it is more beneficial to the environment. In addition, one of the benefits of friction stir welding is that it may be utilized on several types of joints, such as butt joints, fillet joints, and lap joints. Because it can weld metals that are typically difficult to weld, such as aluminum alloy, copper, and titanium, friction stir welding is a technique that is

frequently used in the production of lightweight structures. It is necessary to do research into the various kinds of materials that are utilized so that friction stir welding may be improved effectively. This improvement can be accomplished when the speed of the tooltip satisfies the parameters.

2. Illustrations

For this experiment, mild steel used as a tooltip which mild steel have better mechanical strength properties. It is also having better conductivity for friction stir welding on aluminum alloy workpiece Thus, this type of material commonly used due to its low-cost material and common used in industry. For the fabrication process, lathe machine used to fabricate the tooltip.



Fig. 1 HARRISON M300 Lathe Machine

Figure 2 displays a conventional vertical milling machine with two process parameters, spindle tool rotating speed and feed rate, which significantly contributes to heat input and influence joint welding quality. A milling machine holder holds a welding tool with a shank, shoulder, and pin that is rotated along its longitudinal axis.



Fig. 2 Conventional vertical milling machine

Table 1 Tooltip Dimension

Parts	Dimension (mm)
Length of tool body	50
Length of shoulder	20
Diameter of shoulder	20
Length of probe	5
Probe size	5 x 5

As for tensile test, it is for determining a material's resistance to breaking under severe tension, tensile testing is the standard method. The results of tensile tests are useful for multiple of purposes, including quality control and predicting how a material will respond to stress. When the tensile force is no longer applied to the sample, it corresponds to where it was before the load was applied. Hooke's Law is no longer valid when the stress increases, and permanent or plastic deformation develops.



Fig. 3 *Tensile test machine*

To conduct standard indentation testing, common approach in micro hardness testing, an indenter is pressed into the surface of aluminum alloy AA6061 with specific weight and for a a predetermined duration. This controlled application of force creates an indentation on the surface of the material, which serves as a measured able indicator of its hardness.



Fig. 4 *Vickers micro hardness machine*

Optical microscopy methods can be used to study a material's microstructure. This study used optical microscopy (OM) to get topographic data. During materials performance tests and failure testing, optical microscopy can discover microstructure changes that may cause degradation or failure.



Fig. 5 *Scanning Electron Microscopy*

Scanning electron microscope (SEM) creates an image by projecting and scanning a focused stream of electrons across a surface. Electrons in the beam clash with the sample, generating signals that may be analyzed to determine the surface's structure and composition. SEMs use a focused beam of high-energy electrons to create distinct signals on solid materials.

3. Results and Discussion

This shows the experimental results obtained from the friction stir welding with microstructure testing and microstructure testing.

3.1 Tensile testing

Table 1 Tensile result

Sample No.	Welding Parameter		Maximum Load (kN)	Elongation Break (mm)	Maximum Stress (MPa)	Maximum Strain (%)
	Spindle Speed (rpm)	Feed Rate (mm/min)				
1.	1055	14	2.69	2.96	149.71	7.372
2.	1320	14	0.36	2.07	19.36	4.356
3.	1640	14	0.26	0.58	14.22	1.806
4.	1930	14	1.74	2.45	96.93	7.289
5.	2620	14	2.83	4.48	157.23	12.971

Based on table 1, it can be observed that optimal parameters are achieved at a spindle speed of 2620 rpm with feed rate of 14 mm/min. Additionally the maximum elongation observed at the speed of 2620 rpm, feed rate 14 mm/min while the second-tier parameter are observed at a spindle speed of 1055 rpm and feed rate of 14 mm/min. Based on the results, it becomes apparent that higher spindle speed are well-suited for lower feed rate while lower feed rate are not suitable when paired with lower spindle speed.

3.2 Optical Microscopy



Fig. 6 200x 1320 RPM



Fig. 7 200x 1640 RPM



Fig. 8 200x 2620 RPM

The microstructure of sample of rotating speed of 1640 rpm and 2620 rpm shows consistent size of grain. This is due of less dislocation movement during the welding resulting it creates larger and more grain boundary. While samples of rotating speed of 1320 rpm show the unbalance size of grain this is due to unstable movement during welding process. The grain size increases due to diffusion across grain boundaries where the material left above recrystallization temperature or extended period of time during welding

3.3 Vickers Hardness

Table 2 Sample Vickers hardness 1055 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Upper	64.575	64.233	64.404	44.7098
Middle	65.8665	65.1454	65.5059	43.2182
Bottom	64.944	62.4082	63.6761	45.7378

Table 3 Sample Vickers hardness 1320 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Upper	62.73	61.130	61.9304	48.3526
Middle	63.2835	62.7731	63.0283	46.6827
Bottom	63.2835	64.233	63.7582	45.62

Table 4 Sample Vickers hardness 2620 RPM

Point	Horizontal Length (μm)	Vertical Length (μm)	Average Length (μm)	Hardness (HV)
Upper	60.7005	57.6637	59.1821	52.9477
Middle	62.5455	60.7658	61.6557	48.7845
Bottom	62.5455	62.4082	62.4768	47.5105

3.4 Fracture Analysis (SEM)

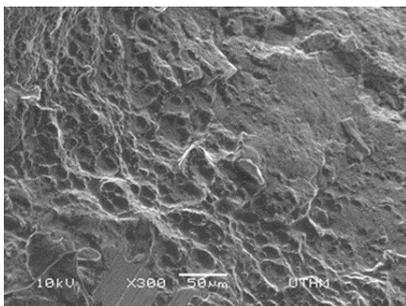


Fig. 9 300x 1320 RPM

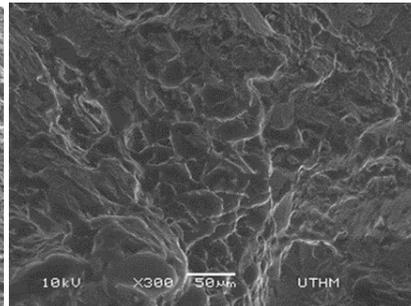


Fig. 10 300x 1930 RPM

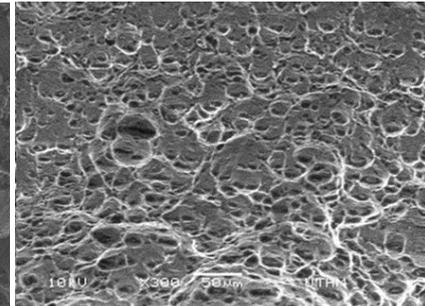


Fig. 11 300x 2620 RPM

The results of sample rotating at 1320 rpm and 1930 rpm, it shows that there was an asymmetry in the distribution of dimples fracture size. This result posed a challenge in evaluating the severe fracture processes using dimples in middle size range as compared to samples rotating at 1690 rpm and 2620 rpm. As a result, large dimple with more complicated structure arose from coalescence of pores, while smaller dimples were directly related to constant size of grains inclusions in the fracture. This phenomenon can be attributed to the favorable integration of the welded area, indicating that heating rate during welding was well-controlled. The uniform grain dimple size and distribution shows evidence that the samples possess higher tensile strength with low ductility also they are capable of withstanding high levels of stress or load without undergoing significant deformation

4. Conclusions

Recommended speed of 2620 rpm shows best speed of friction stir welding. Higher spindle speed also increased the heat input and rise in the stir zone temperature. The spindle speed of 2620 rpm shows the highest ultimate tensile strength, 157.23 MPa. Based on weld quality, the spindle speed of 2620 rpm ensures sufficient heat input for proper material flow and solidification process without excessive plastic deformation and voids. The speed of 2620 rpm shows the smaller grain and dimples structure size from the other sample which is smaller grain size generally lead to improve ductility and toughness in aluminum alloy material. Finer grain size enhances the material strength and resistance to deformation. Vickers hardness test, rotating speed of 2620 rpm has the

higher value from the specimen the other specimen which it has average value of hardness of 52.9477 HV for upper point, 48.7845 HV for middle point and 47.5105 HV.

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