IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

Effect of tool shoulder diameters on surface quality of friction stir welded joints of aluminum alloy 6061

To cite this article: N C Maideen *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **932** 012114

IOP Conf. Series: Materials Science and Engineering **932** (2020) 012114 doi:10.1088/1757-899X/932/1/012114

Effect of tool shoulder diameters on surface quality of friction stir welded joints of aluminum alloy 6061

N C Maideen[1], S Budin[1], Dzullijah Ibrahim[1] and A Shahrol Azlan[1]

[1] Faculty of Mechanical Engineering, Universiti Teknologi MARA, Cawangan Pulau Pinang, Jalan Permatang Pauh, 13500 Pulau Pinang, Malaysia

Email: normariah@uitm.edu.my

Abstract. In friction stir welding process, shoulder diameter of stirring tool plays an important role. The role is to provide enough soften region along the process to produce a good quality of weldment. In this work, three variations of stirring tool shoulder diameter are produced which are stirring tool 1 (16mm), stirring tool 2 (20mm), and stirring tool 3 (24mm). Reconfigured milling machine (Cheng Yin – CY-GH 260) is used to performed friction stir welding process using the fabricated stirring tool. The stirring tools are made of H13 steel (chromium-molybdenum) with constant pin height of 3mm, and pin diameter of 5mm. Welding parameter used are 1270 RPM for rotating speed and 248 mm/min for welding speed. Then, all stirring tools are used to joined two similar plates AA 6061 with butt joint. The surface quality is determined from physical appearance, surface roughness, and welding strength of AA 6061 welded samples using fabricated strring tools (16mm, 20mm, and 24mm). From the result, smallest diameter stirring tool 1 (16mm) produced the best surface quality of weldment. Stirring tool 1 produced a free defect sample, smoothest surface with surface roughness value of 1.92 µm, and highest welding strength (119.28 MPa). However, the wear rate of the stirring tool 1 is the highest recorded from the stirring tool 1 material deposited at the sample.

1. Introduction

Stirring tool is one of the important parameters that will influence the quality of the weldment joint in Friction Stir Welding (FSW) process. Essentially, the tool is in cylindrical-shape and consist of a shoulder and a protruding pin located at the center of the shoulder. Liu et. al., mentioned that tool materials for FSW of high softening temperature alloys must exhibit excellent properties at temperatures more than 900 ◦C [1]. In addition to the requirements of strength, fatigue, and some fracture toughness at elevated temperatures, tool materials must also be resistant to both mechanical and chemical wear. On the other hand, tool geometry plays important roles in the rate of heat generation, transverse force, torque and thermo-mechanical environment experienced by the tool [2]. The tool geometry and motion of the tool will affect the flow of plasticized material in the workpiece. S Budin et. al. have recommeded that tapered tool produced highest tensile strength weldment compared to cylinder and triangle tool [3]. Other important factors of tool are shoulder diameter, shoulder surface angle, pin geometry (shape and size) and nature of tool surface. Sahu et. al have stated that with the increase of shoulder diameter, keeping the other process parameters constant, there is an increase in mechanical properties and peak temperature [4]. Ramesh Babu et. al. have studied the effect of tool shoulder diameter on AZ31B alloy sheets of various thicknesses and the result shows that the best tool shoulder was beyond 18mm but less than 24 mm for variation in the process parameters in 6mm thick plate [5].

IOP Conf. Series: Materials Science and Engineering **932** (2020) 012114 doi:10.1088/1757-899X/932/1/012114

With the significant effect of stirring tool, this work was conducted to specifically study the effect of shoulder diameter on surface quality of friction stir welded AA6061 (5mm thick) using reconfigured milling machine (Cheng Yin – CY-GH 260). Surface quality was determined based on physical appearance of welded sample using fabricated three variations of shoulder diameter, surface roughness values, and correlation with welding strength from fabricated samples.

2. Methodology

2.1. Materials
Plates of AA6061 aluminum alloy with dimension of 125x30x6 mm were used as base material. Chemical composition and mechanical properties of base material are given in Table 1. Butt joint is performed to two pieces of base material.

Table 1. Chemical composition of AA 6061.

Element	Mg	Si	Cu	Zn	Ti	Mn	Cr	Al
Amount (%)	0.85	0.68	0.22	0.07	0.05	0.32	0.06	97.7

2.2. Tool design
All the designed stirring tools were fabricated using H13 steel and heat treated using hardening technique. Physical propoerties of H13 steel are shown in Table 2. Dimensional and geometrical characteristics of tool used in this work are shown in Table 3. Figure 1 shows the fabricated tools.

Table 2. Physical properties of stirring tool (material: H13).

Hardness, (Rockwell C)	Ultimate tensile strength (MPa)	Yield strength (MPa)	Modulus of elasticity (GPa)	Thermal conductivity at 2000C (W/m-K)
50-55	1990	1665	210	24.3

Table 3. Dimensional and geometrical characteristics.

Geometry	Material	Diameter (mm)	Pin height (mm)	Pin diameter (mm)
Straight cylinder	H13 Steel	24, 20, 16	3	5

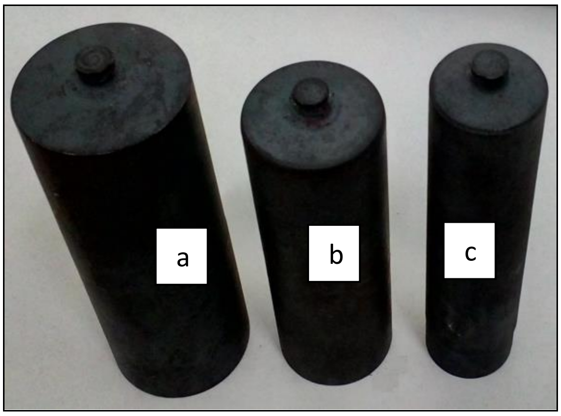


Figure 1. Fabricated tools after heat treatment. Diameter (a) 24mm, (b) 20mm, (c) 16mm

IOP Conf. Series: Materials Science and Engineering **932** (2020) 012114 doi:10.1088/1757-899X/932/1/012114

2.3. Welding parameters and experimental setup
A reconfigured milling machine (Cheng Yin- GH260) was set-up to performed friction stir welding process. In this experiment, rotational speed (1270 RPM) and welding speed (248 mm/min) were set constant. Figure 2 shows the setup of the tool pin profile to performed FSW process using reconfigured milling machine [3].

Figure 2. Setup of tool pin profile to performed FSW process [3].

2.4. Design evaluation
For design evaluation, the samples produced from FSW were tested and compared for its physical appearance of sample and surface roughness value. For physical appearance of sample and physical appearance of stirring tool wear, the picture of weldment was captured using low power microscope. For surface roughness, Mitutoyo surface roughness tester (SURFTEST SJ-210) was used.

3. Results and discussion

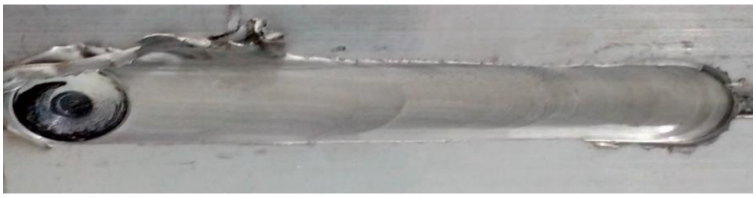
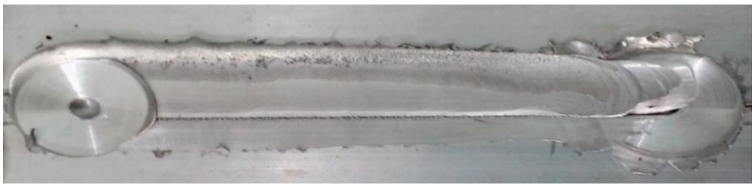
3.1. Physical appearance of samples
Table 3 shows physical appearance of weldment. From the result, it shows that all fabricated stirring tool with variable diameter (24, 20, and 16mm) for reconfigured milling machine were successfully joint by FSW technique. The best three samples of AA6061 was successfully welded using three different diameter is shown in Figure 3.

Sample welded using stirring tool 1 show free defect on the weldment but there are continuos burr at the end of the weldment, while sample welded by stirring tool 2 show lesser burr and a thin line visible on the weldment due to incomplete weldment between the sample. Weldment from stirring tool 3 produce more burr along the weldment line compared to stirring tool 1 and 2. Thin line also visible on the weldment due to incomplete weldment between the sample. Both thin line due to incomplete weldment in sample of stirring tool 2 and stirring tool 3 occurs at advancing side. These incomplete weldment will become weakest point in the joint that leads to failure of the joints. The weakest point is supported by the weldment strength value gather from the samples. Weldment strength was measured using 50kN universal testing machine. Weldment strength for stirring tool 1 is 119.28 MPa, stirring tool 2 is 49.42 MPa, and stirring tool 3 is 54.25 MPa. From the result, physical appearance and weldment strength factors are closely related. Free defect weldment from sample produced by stirring tool 1 produce highest welding strength.

Futhermore, from observation, there is stirring tool material deposited on the weldment at finishing point for weldment of stirring tool 1 and stirring tool 2. It shows that, stirring tool 1 and stirring tool 2 is wear during the process. Due to smaller diameter (16 and 20 mm), surface area for friction is less compared to 24mm diameter. Thus, soften region of sample is also less, resulting higher friction occurs at the finishing point that finally wear the rotating tool. Tool material deposited on the weldment is worsed for stirring tool 1 (16 mm). From the physical appearance, stirring tool with diameter 16mm is better compared to the other two (20 mm and 24 mm). This is because, strength of the weldment is more important than any other criteria (tool wear and burr).

IOP Conf. Series: Materials Science and Engineering **932** (2020) 012114 doi:10.1088/1757-899X/932/1/012114

Table 4. Physical appearance of AA6061 weldment from FSW.

Stirring tool pin diameter	Physical appearance
Tool 1 16 mm	
Tool 2 20 mm	
Tool 3 24 mm	

3.2. Surface roughness

In measuring surface roughness of weldment, one sample was devided into three section which are start section, intermediate section, and end section. Mitutoyo (SURFTEST SJ-210) was used to measure the surface roughness. The surface roughness value was based on Ra value and was measured for every 20mm surface distance. Three repetitive value of Ra was taken for each samples at each sections. The average readings of Ra value are shown in Figure 3. From Ra value, it is known that at starting section, stirring tool 2 and stirring tool 3 produce roughest surface of weldment. The quality of surfaces keep improving until ending section of weldment. This is because, initially, heat generated around the pin is insufficient to effectively soften the region. Effective soften region will actually produce a better surface finish that reflect lower Ra value.

Stirring tool 1 shows a different scenario. Starting section starts with better surface roughness with lowest value (1.92 µm). As the welding progress, rougher surface produced at intermediate section before ends the weldment. Since stirring tool 1 is lowest diamenter, it is understood that when the welding progress, heat generated around the region may not be effective as compared to starts region. It is also related with the welding speed. Effective soften region unable to constantly remains as welding speed take place. In average, stirring tool 1 produce a better surface (1.92 µm) compared to the other stirring tool (tool 2:Ra-6.81 µm and tool 3:Ra-4.46 µm).

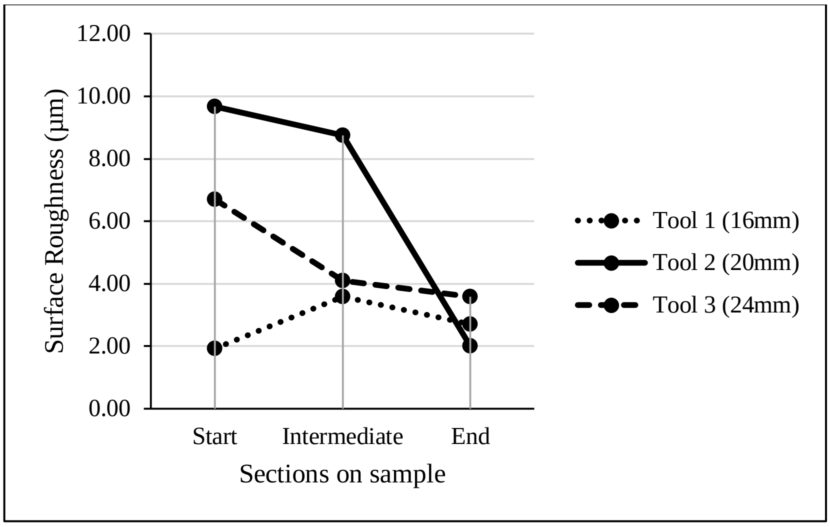


Figure 3. Surface roughness value of AA6061 samples.

4. Conclusions

Three different diameter of stirring tool were produced (tool 1: 16mm, tool 2: 20mm, tool 3:24mm). The best three friction stir welded samples of AA6061 were chosen to be analysed and discussed the result based on its surface quality. Surface quality is determine based on sample's physical appearance, surface roughness value, and correlate with welding strength.

In this work, all three fabricated stirring tools were successfully able to performed FSW process. From the results, smallest diameter of stirring tool (16mm) produced better surface quality of weldment compared to the other two stirring tool (20mm and 24mm). Stirring tool 1 able to produce a free defect weldment with highest welding strength (119.28 MPa). Stirring tool 1 also produced lowest surface roughness value which is 1.92 µm. However, stirring tool 1 facing higher wear rate compared to the other two tools. In contrast, this finding is contradict with Sahu et. al. [4] where the recorded highest tensile strengh was obtained from 24mm houlder diameter. Thus, further study shall be carried out to identify the gap and issue of wear rate can also be addressed.

5. References

[1] Liu F C, Hovanski Y, Miles M P, Sorensen C D, and Nelson T W 2017 *J. Mater. Sci. Technol.*, **34**(1) 39-57
[2] Khourshid A M and Sabry I 2013 *International Journal of Mechanical Engineering and Robotics Research* **2**(3) 233-241
[3] Budin S, Maideen N C, and Sahudin S 2019 *IOP Conf. Series: Materials Science and Engineering* **505** 012089
[4] Sahu P K and Pal S 2014 *5th Int. 26th All India Manuf. Technol. Des. Res. Conf. (AIMTDR 2014)* 12- 17
[5] Ramesh Babu S, Pavithran S, Nithin M, and Parameshwaran B 2014 *Procedia Engineering* **97** 800–809

Acknowledgements

The author would like to thank Universiti Teknologi MARA Cawangan Pulau Pinang for offering a good facility for this research as well as funding for this project.