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Effect of Different Size of Tool Pin Diameter for Butt Joint Between Aluminium and Aluminium by Friction Stir Welding (FSW)

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Abstract: Aluminum alloy finds its applications in various sectors of engineering. This paper discusses the investigation of mechanical properties of butt weld joints using Friction Stir Welding (FSW) of aluminum alloy A1100 having 200 x 75 x 6 mm thick sheets each. An experiment was conducted with three different tool pin size diameter which is 3.00 mm, 5.00 mm and 7.00 mm, and the rotational speeds used was 990 rpm and traverse speed 27 mm/min using conventional milling machine. The experimental results are evaluated by visual inspection and tensile test methods and the defect existing in this process such as poor welded joint surface, flash defect, lack of penetrations, weld discontinuities, and irregular material flow due to insufficient tool force downwards onto the specimen. The results shows that specimen C with diameter tool pin of 3.00 mm obtain the highest peak force of 934.13 N, tensile stress 17.49 MPa, elongation of 1.89 mm which is 6.33 %, and yield strength of 13.94 MPa and for specimen B with diameter tool pin of 5.00 mm, it shows that the peak force is 564.59 N, tensile stress 13.03 MPa, elongation of 1.48 mm which is 5.94 % and yield strength of 8.42 MPa. For specimen A, the specimen failed due to the incomplete fusion of material during the welding process and cannot undergo the tensile test. From this result, it can be concluded that the most suitable tool pin is 3.00 mm and mechanical properties of the weld is indeed influenced by the size of tool pin diameter.

Keywords: Friction Stir Welding, Aluminium-Aluminium, Mechanical Properties, Defects

1. Introduction

Friction stir welding (FSW) is a relatively new solid-state welding method in which there is no melting of the material. It was developed on the year of 1991 and now is being increasingly used in the welding of aluminium alloy. There are no voids and cracking in the weld, no distortion of the work piece, no need of filler materials, no costly weld preparation required, and no shielding gas is

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required during FSW process. Aluminium alloys find wide applications in aerospace, automobile industries, ship building, train wagons and trams, offshore structures and in bridge constructions due to its light weight and higher strength to weight ratio.

FSW is a clean and environment friendly process because there are no harmful effects like arc formation, radiation, and release of toxic gas. It works by generating frictional heat from the stirring action of rotating tools pin that raises the temperature of the material above the recrystallization temperature yet below melting point but enough to soften the material and enables the material to flow plastically around the pin and join the interfaces together.

Most researchers have found that there is a correlation between Tool Rotational Speed and Feed Rate to the Mechanical Properties and Microstructure of the Friction Stir Welding. Tool Rotational Speed affects the rate of softening metals while the Feed Rate affects the flow of the material. The types of metal or material used for the welding will affect the end result of experiments because different type of metal used in the welding method will yield different mechanical properties of the friction stir weld. Owing this information, this study aims to investigate the effect of different size of tool pin diameter to the mechanical properties of the material.

2. Materials and Methods

2.1 Materials

10 sheets plates of Aluminium Alloy A1100 of 6mm in thickness were ordered with the required dimension (200mm x 75 mm x 6 mm). The experiments were conducted on the aluminium alloy A1100 because of its low thermal conductivity, malleability and delicate material. A carbon steel AISI 4340 also known as Carbon Steel 705 pin tool is been used in this experiment. AISI 4340 alloy steel is a heat treatable and low alloy steel containing chromium, nickel and molybdenum. It has high toughness and strength in the heat treated condition. The type of tool pin used is Conical Pin.

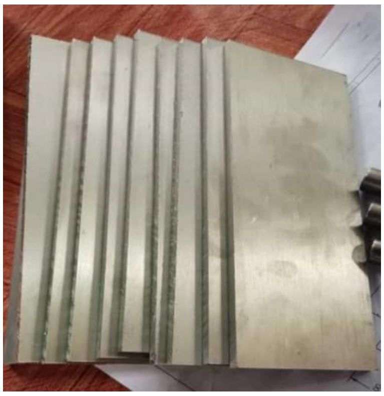

Figure 1: Aluminium A1100 (200 mm x 75 mm x 6 mm)

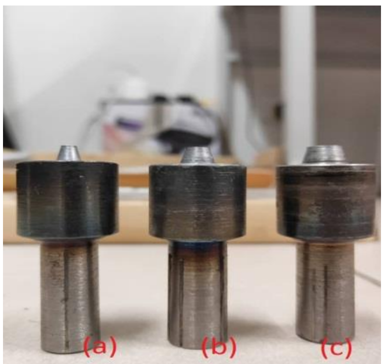

Figure 2: Conical Pin with different Diameter (a) 3 mm, (b) 5 mm, (c) 7 mm

2.2 Process Parameter

This experiment is performed with conventional milling machine HWACHEON (see figure 2.3) by taking size of pin diameter as variable and tool rotational speed and traverse speed as constant. Table 2.2 shows details regarding FSW process parameter and tools.

Figure 3: HWACHEON Milling Machine

Table 1: Process Parameter

Pin Size Diameter (mm)	Tool shoulder diameter D(mm)	Pin Length ,h(mm)	Shoulder Length (mm)	Tool Rotational Speed (RPM)	Traverse Speed (mm/min)
3	20	5	20	990	27
5	20	5	20	990	27
7	20	5	20	990	27

2.3 Welding Process

As for working principle of this friction stir weld method consists of the pin tool penetration and rotation, the direction of welding and the advancing and retreating side. Figure 4 virtually show how the process is run and the welding operation illustration.

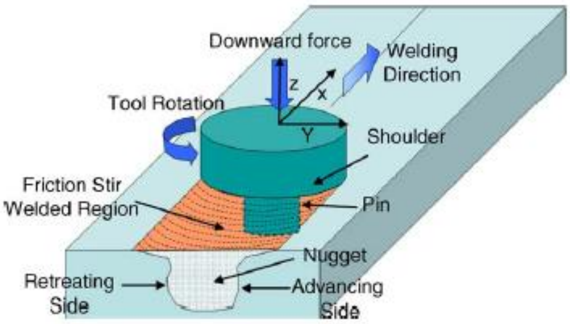

Figure 4: Working Principle of FSW

The experiments were conducted on the Aluminum alloy 1100. Before the welding, the weld surface of base material is cleaned. Friction stir welding is done by holding the plates to be welded securely so that the plates stay in place and do not fly away due to the welding forces. The rotational motion of the spindle is started and the tool is then got in contact with the surface of the plates and the pin is penetrated to a predetermined depth in between the surfaces of the plates to be welded. The tool is given some time as it rotates in contact with the surfaces to soften the material due to the frictional heat produced. This time is called as dwell time, and after the dwell time the forward motion is given to workpiece which formed the weld. The welded joints are shown in Figure2.5 and Figure 2.6.

Figure 5: Welding by FSW

Figure 6: Friction Stir Welded Plate

2.4 Visual Inspection

Visual test has been finished by perception on the physical appearance of the welded joint. Perceptions involve for the front and rear of trailing development, the progressing and withdrawing side, and furthermore the blended of material. Visual inspection was performed to evaluate physical attributes of the friction stir weld that help provide confirmation that proper operating conditions were maintained during fabrication. These attributes include flash, misalignment, discontinuities, cracks, and lack of penetration. Remarks were noted on the specimens.

2.5 Tensile Test

The tensile tests are done on the fabricated welds according to the standards given by the ASTM (American Society for Testing of Materials). The welded plates were first sectioned according to the tensile specimen test dimension standards and the testing was conducted on the Universal Testing Machine (UTM). Figure 7 and Figure 8 shows the machine and tensile testing of welded specimen.

Figure 7: Victor Universal Testing Machine

Figure 8: Tensile Tested Specimen

3. Results and Discussion

3.1 Visual Test

The visual test survey was carried out by using naked human eye. Specimen welded with diameter pin size 3.00 mm with tool rotational speed of 990 rpm and traverse speed of 27 mm/min obtained the highest weld trail quality. Even though the surfaces still quite rough and there still have severe flash defect and lack of penetration, the weldment can be seen to be better than previous specimen. The specimen welded with tool pin size diameter 5.00 mm and 7.00 mm obtained the lowest weld trail quality where misalignment was also occurred in it.

Figure 9: Specimen A with Pin Tool Diameter of 7 mm

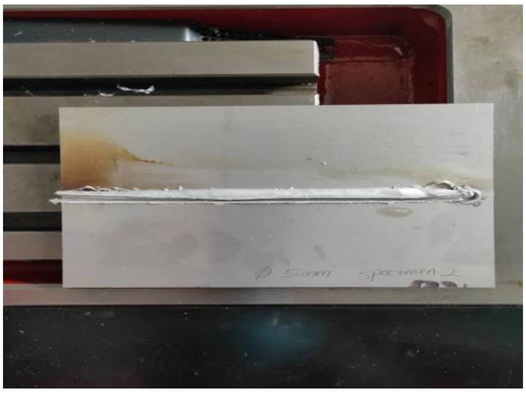

Figure 10: Specimen B with Pin Tool Diameter of 5 mm

Figure 11: Specimen C with Tool Pin Diameter of 3 mm

3.2 Tensile Test

Two out of three specimens were tested by Tensile Test where for specimen A, the specimen failed due to the incomplete fusion of material during the welding process and cannot undergo the tensile test. For Specimen B and C, the specimen was tested at three part of the weldment which is at the beginning of welding, at the middle and at the end of welding. Full data was recorded from the experiment in the Table 2.

Table 2: Tensile Test Result

Specimen	Tool Pin Diameter (mm)	No of parts	Force @Peak (N)	Tensile Stress (MPa)	Elongation @ Peak (mm)	Elongation Percentage @ Peak (%)	Yield Strength Rp0.2 (MPa)
A	7	3	-	-	-	-	-
		2	-	-	-	-	-
		1	-	-	-	-	-
		Average	-	-	-	-	-
B	5	3	681.53	15.69	1.95	6.95	9.38
		2	598.25	12.91	1.45	5.78	8.65
		1	413.98	10.48	1.04	5.09	7.23
		Average	564.59	13.03	1.48	5.94	8.42
C	3	3	1059.82	18.32	2.16	7.62	16.51
		2	992.43	17.85	1.94	6.26	13.53
		1	750.14	16.29	1.56	5.12	11.78
		Average	934.13	17.49	1.89	6.33	13.94

3.2.1 Tensile Stress Result

The result shows that Specimen C with diameter tool pin of 3.00 mm obtain the highest Tensile Stress 27.21 MPa, For Specimen B with diameter tool pin of 5.00 mm, it shows that the Tensile Stress 8.96 Mpa. Both specimens used the same parameter for the tool rotational speed which is 990 rpm and traverse speed 27 mm/min. Tensile stress at Specimen C is higher than Specimen B about 134.00 %. This shows that Specimen C can resist more stress or force compare to Specimen B. Graph below shows the comparison between Specimen B and Specimen C about Tensile Stress versus Diameter Pin.

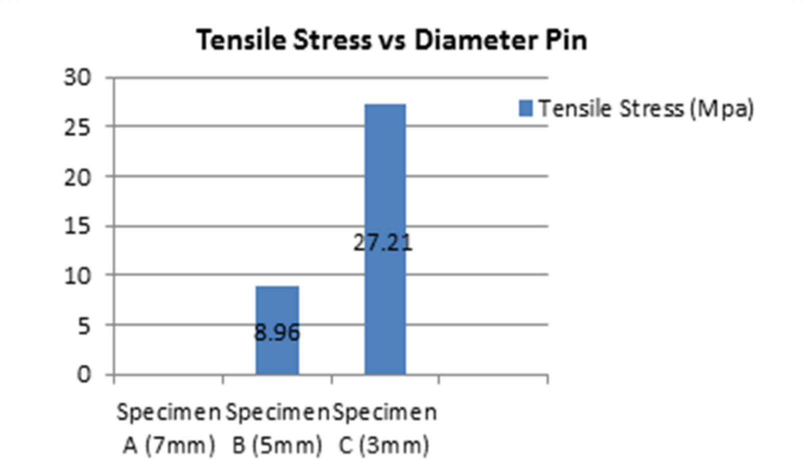

Figure 12: Graph of Tensile Stress vs Diameter Pin

3.2.2 Elongation Result

For elongation part, Specimen C with diameter tool pin of 3.00 mm obtains the highest elongation which is 1.89 mm. For Specimen B with diameter tool pin of 5.00 mm, it shows that the elongation was 1.48 mm. Both specimens used the same parameter for the tool rotational speed which is 990 rpm and traverse speed 27 mm/min. Elongation for Specimen C is higher that Specimen B about 127.00 %. This shows that, Specimen C was more ductile compared to the Specimen B. Graph below shows the comparison between Specimen B and Specimen C about Elongation versus Diameter Pin.

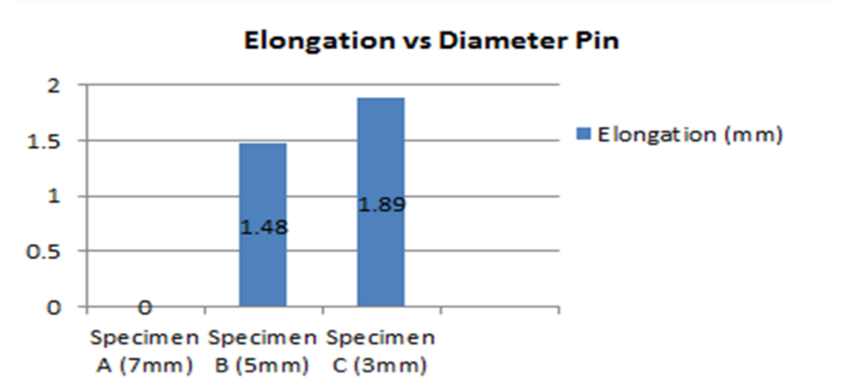

Figure 13: Graph of Elongation vs Diameter Pin

3.2.3 Yield Strength Result

For yield strength part, Specimen C with diameter tool pin of 3.00 mm obtains the higher value of yield strength which is 13.94 MPa. For Specimen B with diameter tool pin of 5.00 mm, it shows that the yield strength was 8.42 MPa. Both specimens used the same parameter for the tool rotational speed which is 990 rpm and traverse speed 27mm/min. This shows that, Specimen C can withstand more stress before started permanent deformation compared to the Specimen B. Graph below shows the comparison between Specimen B and Specimen C about Yield Strength versus Diameter Pin.

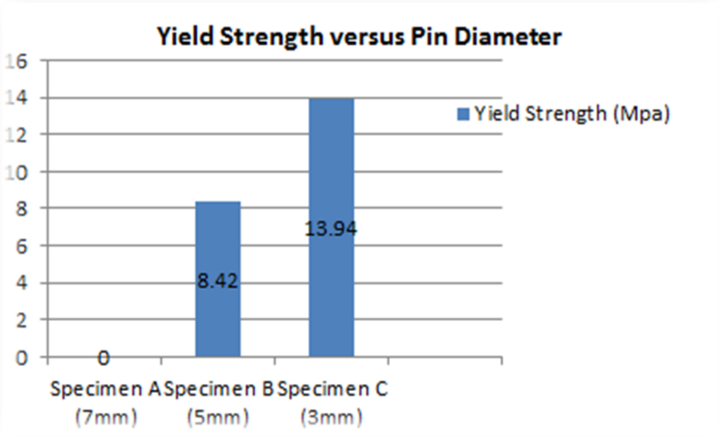

Figure 14: Graph of Yield Strength vs Pin Diameter

4. Conclusion

The results of inspections show that the entire specimen has several defects and problem during the welding process. The weldment has many defects and discontinuities that can be seen such as poor welded joint surface, severe flash at the side of welded joint, crack at cross section of weldment and lack of penetration. The problem causing all those flaws is the insufficient tool force downwards onto the specimen. Lacking of force will produce insufficient heat during mixing of material. On the other hand, it reducing the strength of the material as the fusion between materials is incomplete.

Two out of three specimens can be proceeding for Tensile Test where for Specimen A the specimen break at the cutting process and cannot perform the tensile test. For Specimen B and C, the specimen was tested, and the results shows that Specimen C with diameter tool pin of 3.00 mm obtain the highest peak force of 934.13 N, tensile stress 17.49 MPa, elongation of 1.89 mm which is 6.33 %, and yield strength of 13.94 MPa. For Specimen B with diameter tool pin of 5 mm, it shows that the peak force is 564.59 N, tensile stress 13.03 MPa, elongation of 1.48 mm which is 5.94 % and yield strength of 8.42 MPa. From this result, it can be concluded that the most suitable tool pin is 3.00 mm and mechanical properties of the weld is indeed influenced by the size of tool pin diameter.

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