Effect of FSW Heating Base Temperature on Tensile Strength and Hardness of AA 1100 Welds

Syamsul Hadi[1,a], Agus Setiawan [1,b], Pipit Wahyu Nugroho[1,c], Adi Dwi Hermansyah[1,d], and Anas Nur Alfisahri[1,e]
[1]Department of Mechanical Engineering, State Polytechnic of Malang, Jl. Soekarno Hatta 9, Malang 65141, Indonesia
[a] syamsul.hadi@polinema.ac.id,[b] agus.setiawan@polinema.ac.id, [c] pipitwn@gmail.com, [d]dwiadhy1998@gmail.com, [e]anasalfisahri0@gmail.com

***Abstract*—The research objective was to determine the effect of heating base temperature on tensile strength and hardness of AA 1100 welds in Friction Stir Welding (FSW). The research methodology includes preparing work pieces of size 150 mm x 100 mm x 3.6 mm from aluminium alloy AA1100 series, making work piece clamps that are suitable for the milling machine used, preparing heating plates 500 Watt for FSW, preparing tools from AISI-H13 material with a shoulder diameter of 20 mm and pin size of M5 x 3.4 mm for FSW, the implementation of FSW with a rotating speed of 1750 rpm and translation speed of 10 mm/minute, preparing hardness test specimens, preparing tensile test specimens refers to ASTM E8-13a, and data analysis of hardness test and tensile test results. The FSW results show that the hardness value increases with the increase in the width of the heating plate linearly for a temperature of 200°C from 10 mm to 30 mm which indicates better conditions, meanwhile decreases at a temperature of 175°C for heating plate width from 10 mm to 20 mm, but increases to 30 mm which is different for the temperature of 250°C and temperature of 300°C which have increased from 10 mm to 20 mm, but decreases towards 30 mm, and than the correlation between AA 1100 tensile strength and surface hardness of 3 heating plate widths is shown with the function of tensile strength, σ (MPa) = -0.9699 x surface hardness (HV) + 102.01.**

Keywords*—*Friction Stir Welding, AA1100, AISI-H13, rotating speed, translation speed, surface hardness.

I. Introduction

In the manufacturing industry, aluminium is widely used as a material for component manufacturing. The development of welding in the world is very rapid, from conventional to non-conventional welding, namely welding with the help of machines, these developments are continuously being improved to reduce the increasing pollution. Friction Stir Welding (FSW) is a type of Solid State Welding (SSW) where 80% of the FSW melting temperature is obtained from the friction between the tool and the workpiece. The melting temperature of the tool material must be higher than the workpiece to which it is joined so that the tool is not attached to the work piece. This method produces a smaller Thermo mechanically Affected Zone (TMAZ) area compared to flame arc welding. FSW was discovered at The Welding Institute (TWI) by Wayne Thomas in 1991. In FSW, a tool in the form of a cylindrical shoulder equipped with a rotating pin and immersed between two welded plates which has been applied to the FSW method for aluminium.

In FSW of HDPE (high-density polyethene) sheet welding joints with backing plate temperature (30, 70, 110, and 150 °C), tool rotation speed (2200, 2300, and 2400 rpm) and welding speed (30 mm/minute) obtained that the backing plate temperature effected tensile strength and homogeneity of HDPE welded joints. The tensile strength of the weld joint is 28.52 MPa or 95.07% compared to the tensile strength of HDPE material obtained on the backing plate at a temperature of 150 °C and a rotating speed of 2300 rpm [1]. In previous studies, improvements in post-weld yield strength, corrosion resistance and fatigue strength were achieved with FSW on aluminium alloys for shipbuilding [2]. It has been investigated by FSW for the tool force, torque and welding temperature of AA 5083-H321 for 6 mm thickness has been noted [3]. On the AA5083 monolithic plate, a technique of modified friction stir channeling has been applied in making the channel [4]. Between the Modification of the Friction Stir Channeling (MFSC)

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and the FSC, it is obtained that the comparison of the fabrication channel produced using MFSC shows better results than the FSC process [5]. The MFSC technique has been used in two geometric tools in the form of an upward conical pin and straight cylindrical pin to construct a channel on the AA 5083 monolithic plate [6]. Between MFSC and FSC there is a main difference in the tilt angle [7]. Titanium alloy fusion welding has problems in solidification such as porosity, segregation and grain structure in the form of columns which can be solved using FSW [8]. The microstructure changes resulted from FSW improved the mechanical properties of TS (tensile Strength), elongation, and weld hardness with an efficiency of 98.84% [9]. As a result of dynamic recrystallization, in the stir zone, the micro hardness value of the Sc-modified AA2519 extrusion joints increased from 86 $HV_{0.1}$ to about 110-125 $HV_{0.1}$ depending on the welding parameters [10]. FSW on AA 6061-T6 shows that the peak temperature value of 300 °C occurs when t = 3 s [11]. Samples that were subjected to post-weld heat treatment occurred the formation of hardening particles with grain refinement which could increase the strength of the material [12]. The microhardness values of the HAZ zone of the parent metal AISI 304 and AISI 316 plates of 75 x 75 x 2 mm are higher than that of the FSW weld zone [13]. The AA 6061-T6 pipe can be welded with FSW with a maximum welding efficiency of 61.7% for its TS using a rotating speed of 630 rpm and a translation speed of 1 (mm/sec) [14]. The joining of different plates AA2024 and AA6061 with a thickness of 5 mm was carried out with FSW which resulted in minimum hardness in the HAZ AA6061 and the weld failed during the tensile test [15]. FSW on AA 6063 with tool rotational speed of 2700-5400 rpm, translation speed of 12-17 mm/minute, and tool shoulder diameter of 17-22 mm produce weld tensile strength increasing with rotational speed and decreasing with translation speed because frictional heat is directly proportional to the tool rotational speed [16].

II. Research Methodology

FSW research on AA 1100 material with heating plates was carried out at the Mechanical Workshop and Material Testing Laboratory, Department of Mechanical Engineering, State Polytechnic of Malang in early 2020.

The FSW research flow chart for temperature and heating plate width variations is shown in Figure 1.

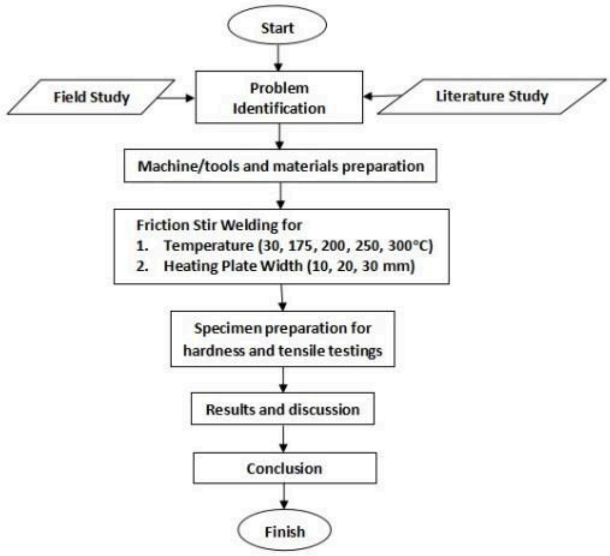

Figure 1. The FSW research flow chart for temperature and heating plate width variations

The arrangement of the FSW tool against the workpiece, heater, and workpiece clamp/jig is shown in Figure 2.

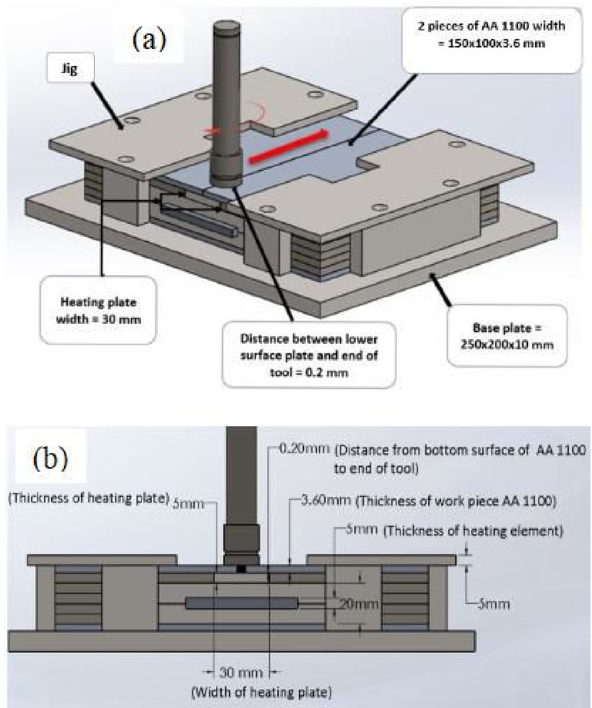

Figure 2. The arrangement of the FSW tool against the workpiece, heater, and workpiece clamp: (a) isometric view, and (b) front view

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The distance between the bottom surface of the workpiece and the tip of the tool (plunge depth) for the optimal value is 0.25 mm [17]. The determination of the plunge depth of 0.2 mm is sufficient in FSW for the AA 1100.

A. Materials

The material used is an experiment with aluminium alloy AA 1100 which is welded with FSW with the composition shown in Table 1.

Table 1. Chemical composition of AA 1100 in (%wt) [18]

Element of AA1100						
Al	Be	Cu	Mn	Zn	Si, Fe	Other elements
Min. 99.0	Max. 0.0008	0.05 ÷0.2	Max. 0.05	Max. 0.1	Max. 0.95	Max. 0.2

The tool material was selected from AISI-H13 material with a shoulder diameter of 20 mm and a pin size of M5 x 3.4 mm whose dimensions and shape are shown in Figure 3.

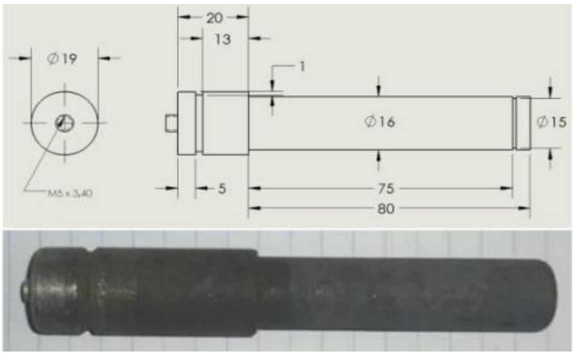

Figure 3. Tool dimensions and shape

B. Method

The FSW process is carried out by heating the base plate with the help of an electric heater 500 W with different heating plate widths (10, 20, and 30 mm) at a tool rotating speed of 1750 rpm with a translation speed of the tool at 10 mm/minute. The AA 1100 FSW process carried out with a milling machine and heating plate is shown in Figure 4.


Figure 4. FSW process condition of AA1100 with milling machine and heating plate

The 500 W heating plate used to research the effect of heating temperature and heating plate width variations in the FSW process is shown in Figure 5.


Figure 5. The 500 W heating plate used to research the effect of heating temperature variations with heating plate width variations in the FSW process

The important supporting pieces of equipment in research other than milling machines, including thermometer gun, temperature control, type K thermocouple-wire are shown in Figures 6 to Figures 8.


Figures 6. Thermometer gun

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Figures 7. Temperature control

Figures 8. Type K thermocouple-wire

The result of the FSW weld on the AA 1100 plates is shown in Figure 9.

Figure 9. The result of the FSW weld on the AA 1100 plates

The microhardness test of FSW weld results carried out with a microhardness tester is shown in Figure 10.

Figure 10. Micro hardness tester

The results of the welds from the FSW process prepared for the formation of tensile test specimens using a milling machine/manually following the ASTM E8-13a standard is shown in Figure 11.

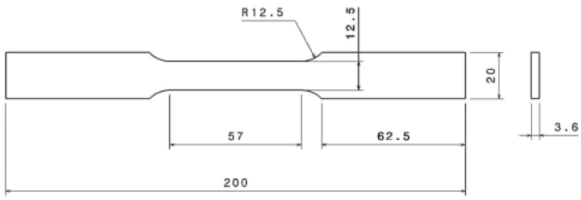

Figure 11. ASTM E8-13a standard dimension for tensile test

The tensile test specimens before and after withdrawal are shown in Figure 12.

Figure 12. The tensile test specimens before and after withdrawal

III. Results and Discussion

The results of the hardness test in the AA 1100 weld area from the FSW are shown in Table 2.

Table 2. The results of the hardness test in the AA 1100 weld area from the FSW

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	Heating Plate Temperature (°C)	Heating Plate Width (mm)	Surface Hardness (HV)				
			1	2	3	4	Average
Rotating Speed 1750 rpm and Translation Speed 10 mm/minute	30	0	57.7	59.2	63.4	60.6	60.2
	175	10	56.4	46.7	57.7	49.4	52.6
		20	59.4	42.4	55.3	46.5	50.9
		30	60.7	67.3	61.5	66.5	64.0
	200	10	49.6	45.9	47.0	47.7	47.6
		20	46.0	56.7	47.0	56.2	51.5
		30	55.6	55.6	56.7	54.5	55.6
	250	10	46.1	44.9	45.2	45.8	45.5
		20	55.9	52.1	55.3	55.8	54.8
		30	54.8	50.5	52.7	52.5	52.6
	300	10	56.5	51.1	54.7	52.9	53.8
		20	59.6	65.0	59.6	65.0	62.3
		30	60.8	56.4	60.7	56.5	58.6

The correlation between the surface hardness and heating plate width of the AA 1100 weld with the FSW process is shown in Figure 13.The FSW results show that the surface hardness value increases with the increase in the width of the heating plate linearly for a temperature of 200°Cfrom 10 mm to 30 mm which indicates better conditions, decreases at a temperature of 175°C for heating plate width from 10 mm to 20 mm, but increases to 30 mm which is different for the temperature of 250°C and temperature of 300°C which have increased from 10 mm to 20 mm, but decreases towards 30 mm.

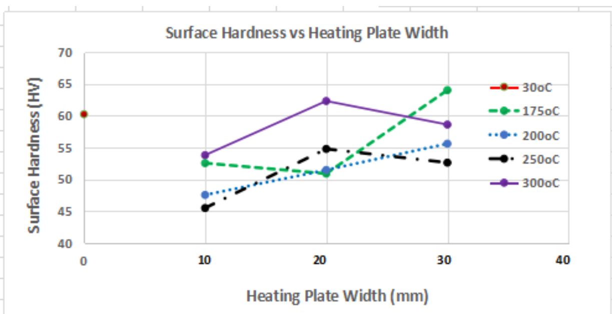

Figure 13. Correlation between the surface hardness and heating plate width of the AA 1100 weld with the FSW process

The results of the hardness test and tensile test of the AA 1100 weld with the FSW process are shown together in Table 3.

Table 3. The results of the hardness test and tensile test of the AA 1100 weld with the FSW process

	Heating Plate Width (mm)	Surface Hardness (HV)	Surface Hardness Average (HV)	Tensile Strength (MPa)	Tensile Strength Average (MPa)
Rotating Speed 1750 rpm and Translation Speed 10 mm/minute	10	45.5	52.0	62.6	50.3
		47.8		53.8	
		52.6		40.1	
		53.8		52.2	
		60.2		42.9	
	20	50.9	55.9	54.6	45.7
		51.5		38.9	
		54.8		49.7	
		60.2		42.9	
		62.3		42.3	
	30	52.6	58.2	55.2	49.4
		55.6		52.6	
		58.6		53.4	
		60.2		42.9	
		64.0		42.9	

The tensile strength and elongation of the tensile test results for the AA 1100 material was 106.79 MPa and elongation 1.53% AA as a result of FSW at a heating temperature of 200°C.

The ratio between the minimum AA 1100 weld tensile strength compared to the base metal is (45.7 : 106.79) x 100% = 42.81%.

The relationship between the surface hardness values and the tensile strength for the three heating plate widths combined using the trend line of each curve is shown in Figure 14.

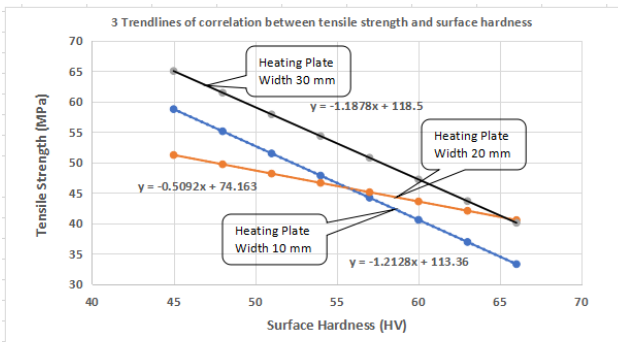

Figure 14. The relationship between the surface hardness values and the tensile strength for the three heating plate widths

The relationship between the tensile strength and surface hardness of the welds from the AA 1100 results from the FSW process is shown in Figure 15.

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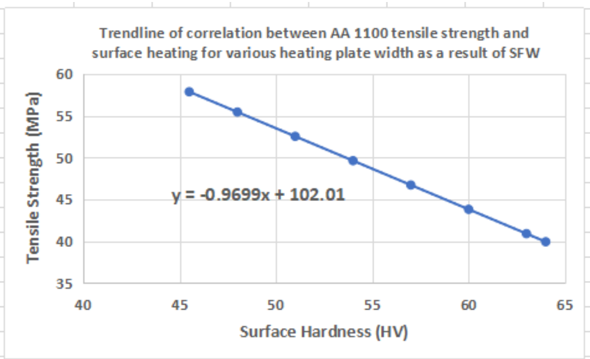

Figure 15. Relationship between the tensile strength and surface hardness welds from the AA 1100 results from the FSW process

The resulting equation of FSW in the relation of tensile strength and surface hardness of AA 1100 welds is shown as formula (1).

$$\sigma \text{ (MPa)} = -0.9699 \times \text{(HV)} + 102.01 \qquad (1)$$

IV. Conclusion

The conclusions from Friction Stir Welding experimental for AA 1100 materials can be drawn are as follows:

1. The surface hardness value increases with the increase in the width of the heating plate linearly for a temperature of 200°C from 10 mm to 30 mm which indicates better conditions,
2. The surface hardness value decreases at a temperature of 175°C for heating plate width from 10 mm to 20 mm, but increases from 20 mm to 30 mm,
3. The surface hardness value for the different temperature of 250°C and temperature of 300°C which have increased from 10 mm to 20 mm, but decreases towards 30 mm,
4. The ratio between the minimum AA 1100 weld tensile strength compared to the base metal is 42.81%, and
5. The correlation between AA 1100 tensile strength and surface hardness for 3 heating plate widths is shown with the function of tensile strength, σ (MPa) = -0.9699 x surface hardness (HV) + 102.01.

The suggestions to improve the conclusion are as follows:

1. Future work of tensile test specimens is done with a milling machine and finely sanded without any scratches or traces of 2 AA 1100 plates welded by the FSW process, and
2. In order to reduce the initial defects and the final defects of welding, preferably before starting the FSW, the tool has touched the metal being welded, AA 1100 is held (rotating in place) for 5 minutes, then the FSW welding process starts after the translation movement is complete at the end of the welding, the workpiece is not immediately removed, but is left natural cooling (allowed to natural) to a temperature of 200°C, then the weld can be removed from the clamp/jig.

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