



# Analysis of The Joint Mechanical Properties of Resulting from The Friction Stir Welding Method Using Variations in The Rotational Speed of The Tool on Aluminum 1100

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**Abstract.** The need for aluminum material as the main material in the production process of the transportation and construction industry is increasingly needed because aluminum is a light metal that has high ductility, is resistant to rust, and is a good conductor of electricity. The problem is that aluminum has poorer weldability than steel in the fusion welding process. Next, to overcome this problem, use the friction stir welding (FSW) method, which uses a connection process without filler and without melting the parent metal. The metal joining process using the friction stir welding method is carried out in the solid phase below the melting point temperature. This research aims to determine the effect of tool rotational speed and material translational motion on the mechanical properties and corrosion rate of joints welded using the friction stir welding method. The results of the research show that the higher the tool rotation, the more heat it produces and the better the connection, where variations in tool rotational speed of 2500 rpm and material translational movement of 43 mm/min produce mechanical properties of maximum tensile strength of 101.85 MPa, strain. 3.45% and modulus of elasticity 29.52 GPa. Furthermore, good corrosion resistance test results were also produced at the highest tool rotation of 2500 rpm, namely 1.22 mm/y, this is because higher rotation results in maximum density and agitation.

**Keywords:** Friction Stir Welding, Metal Joining, Aluminum 1100.

## 1 INTRODUCTION

Aluminum is more widely used today in various industries because of its low weight (density 2.7 g/cm<sup>3</sup>), high corrosion resistance, excellent formability, high toughness at cryogenic temperatures, has a cubic face-centered crystal structure (FCC), high thermal and electrical conductivity, and relatively cheap. Additionally, Al has excellent recyclability [1]. Friction Stir Welding (FSW), as a solid object welding process, can achieve the joining of metals below the melting point or in the metal plastic stage with the help of non-consumable tools [2]. Compared with welds made by fusion welding processes, friction stir welds have a more homogeneous grain structure and better mechanical properties such as tensile strength, hardness, and toughness [3]. Currently,

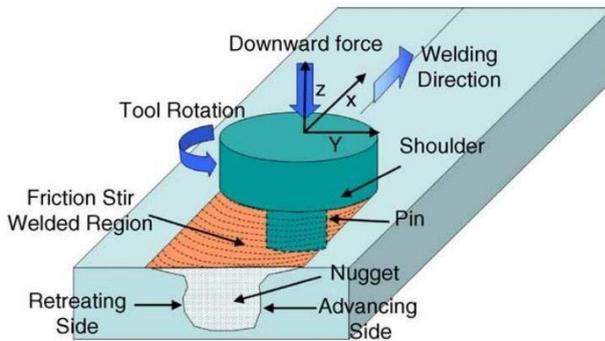
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FSW has become one of the aluminum alloy joining processes that is widely used in industry [4,5,6]. Even considering hard metals such as steel, FSW still does not reach the same feasibility on aluminum alloys [7,8]. The limitations of friction stir welding on steel are as follows: (a) tools with very high resistance are required to weld steel [9].

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a solid-state joining technique, and it was initially applied to aluminum alloys [10,11]. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint (Figure 1). The tool serves two primary functions: (a) heating of workpiece, and (b) movement of material to produce the joint. The heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in ‘solid state’. Because of various geometrical features of the tool, the material movement around the pin can be quite complex [12]. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains [13–16]. The fine microstructure in friction stir welds produces good mechanical properties.



**Fig. 1.** Schematic Drawing of Friction Stir Welding [17]

Studied the effect of high rotational and feeding speed on the ultimate tensile strength of stir welded AA1100 aluminum alloy. The rotational speed was set at 1500 RPM, 2500 RPM and 3500 RPM with a feeding speed of 10 mm/min, 30 mm/min and 50 mm/min. The highest ultimate tensile strength was measured at 1500 RPM and 50 mm/min with a welding efficiency of about 81% [18]. The effect of welding speed (with advancing speed in the range 40–460 mm/min) on the mechanical and microstructural properties of AA6082 were studied in the present paper. A strong variation in the nugget mean grain size was observed by increasing the advancing speed from 40 to 165mm/min up to a plateau corresponding to no further variations by increasing the speed up to 460 mm/min. The yield strength was recorded to increase strongly from the lower speeds to 115 mm/min and after starts to decrease by increasing the advancing speed, the ductility of the material followed the same behavior but restarted to increase after 165 mm/min. The material welded with the advancing speed of 115 mm/min exhibited the best fatigue properties and the higher fatigue limit, while a very narrow

similar behavior in the low cycle regime, differing strongly by decreasing the stress amplitude up to the fatigue limit, was observed in all the configurations. The SEM observations of the fatigue specimens, welded at 115 mm/min, showed that at higher stress amplitude levels the cracks initiate at the surface of the welds. By decreasing the stress amplitude, the cracks initiate by the internal defects [19]. Al–Zn–Mg alloy AA7039 was successfully friction stir welded employing different process parameters in order to investigate their influence on microstructure and mechanical properties of developed joints. Following conclusion can be drawn from the present work. The ultimate tensile strength, % elongation, energy absorbed and joint efficiency decrease with increase in welding speed and all above joint performance parameters increase with increase in rotary speed [20]. The aim of this research is to determine the effect of tool rotational speed and material translational motion on the mechanical properties and corrosion rate of joints resulting from friction stir welding methods. the strong one.

## 2 EXPERIMENT SET UP

In this study, the variables were the rotational speed of the tool 800, 1600, 2500 rpm and the translational motion of the material was 43 mm/min. The material used in the tool for friction stir welding process is AISI H13 steel. AISI H13 steel is the most frequently used hot working tool steel. This steel has excellent strength, wear resistance and toughness properties as well as a high melting point. Judging from the properties of AISI H13 steel, this type of steel is suitable for making friction stir welding tools. In the manufacture of friction stir welding tools in order to increase the toughness of the tool, a heat treatment process is carried out on the tool to be used.



Fig. 2. Design Tool Friction Stir Welding.

The material used in this study is aluminum series 1100. Specimen production begins with cutting the 1100 series aluminum plate to be welded and used as a test specimen. Aluminum plate sheets are cut using a cutting machine into sizes of 150 mm x 100 mm.

Then a tensile test is carried out to determine the properties produced by the tensile test, namely:

1. Maximum tensile strength ( $\sigma$ )

It is the maximum stress that can be borne by the material before fracture occurs. In brittle materials, where the maximum stress is at the same time the fracture stress (breaking point). Formulated [21]:

$$\sigma = P/A_o \tag{1}$$

Where:

$\sigma$  =Maximum tensile strength (MPa,N/mm<sup>2</sup>)

P =Maximum load (N)

$A_o$  = Cross-sectional area (mm<sup>2</sup>)

2. Maximum strain (e)

Measured as the addition of the measured length after a break with the initial length. Formulated:

$$e = (\Delta L/L_o) \times 100\% \tag{2}$$

$$e = (L_i/L_o) \times 100 \tag{3}$$

Where:

e = strain (%)

$L_i$ = initial length (mm)

$L_o$  = length after fracture (mm)

3. Modulus of elasticity (E)

Is the stiffness of a material on the stress-strain graph, the stiffness modulus can be calculated from the slope of the linear elastic line. Formulated:

$$E = \sigma/e \tag{4}$$

Where:

E = Modulus of elasticity (GPa,KN/mm<sup>2</sup>)

$\sigma$  = Maximum tensile strength (MPa,N/mm<sup>2</sup>)

e = Strain (%)

Tensile testing can show several phenomena of ductile and brittle fracture, brittle fracture has different characteristics from ductile fracture, namely no or very little plastic deformation occurs in the material. and the formation of the specimen according to the ASTM E8 standard to test the mechanical strength of the welding results, namely in the form of a tensile test [22].

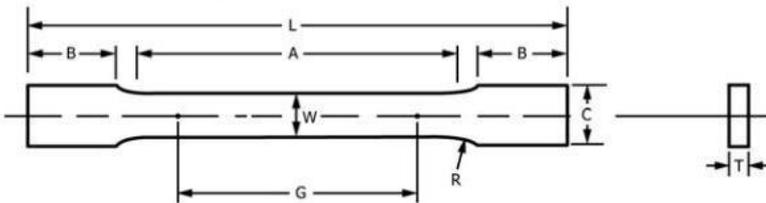


Fig. 3. Standard ASTM E8/E8M-22 Tensile Testing Specimens [22]

**Table 1.** Dimensions Standard Specimens [22]

Dimensions Standard Specimens	
	Sheet-type, 12,5 mm [0.500 in.] wide
	mm [in]
G—Gauge length	50.0 ± 0.1 [2.000 ± 0.000]
W—Width	12.5 ± 0.2 [0.500 ± 0.010]
T—Thickness	thickness of material
R—Radius of fillet, min	12.5 [0.500]
A—Length of reduced parallel section, min	200 [8]
L—Length of reduced parallel section, min	57 [2.25]
B—length of grip section, min	50 [2]
C—with of grip section, approximate	20 [0.750]



**Fig. 4.** Test sample specimens resulting from friction stir welding using 3 variations with 9 test samples.

The friction stir welding process is carried out using a universal milling machine with the following procedure:

Prepare the milling machine and other supporting equipment, install the friction stir welding tool on the chuck tool, install the specimen on the installation that has been prepared, carry out friction stir welding as many as specified variation, cleaning the milling machine that has been used, giving a code or mark on each specimen that has been made.



Fig. 5. Proses friction stir welding

### 3 RESULTS AND DISCUSSIONS

#### 3.1 Tensile Test Results Using Variations of the Rotate Speed Tool

Tensile testing was carried out in order to determine the effect of tool rotational speed on the values of maximum tensile strength, maximum strain and elastic modulus of the welding results using the friction stir welding method.

Table 2. Visual Inspection of Welded Joints.

No	Tool Rotate Speed	Material Translation Motion	Welding Result
1.	800	43	<p>WELDING DIRECTION</p> <p>TOOL ENTRY HOLE</p>
2.	1600	43	<p>FLASH DISABLED</p>
3.	2500	43	<p>ARISING THE SURFACE</p>

Based on the observation results of the welding results, it can be seen that in the welding process using the friction stir welding method there are still defects. The type of defect that occurs is that there is a hole where the pin exits or enters from the friction

stir welding tool, there are imperfect welding results or a rough surface caused by decreased temperature, there is flash defect due to too deep depth plunge during welding causing the shoulder to press excessively. Too much for the material, there is a defect where the results of stirring by the friction stir welding pin tool comes out to the surface due to the lack of pressure by the shoulder on the surface of the material.



Fig. 6. After the Tensile Test.

Table 3. Table of Tensile Test Results.

Results of Tensile Tests					
Sample No.	Research variable		Tensile Strength ( $\sigma$ )	Strain ( $e$ )	Modulus of Elasticity (E)
	Tool Rotate Speed	Material Translation Motion			
	(rpm)	(mm/min)	(MPa)	(%)	(GPa)
	Parent Metal		125	20	68
1.	800	43	75,15	3,05	24,63
2.	1600	43	89,64	2,76	32,47
3.	2500	43	101,85	3,45	29,52

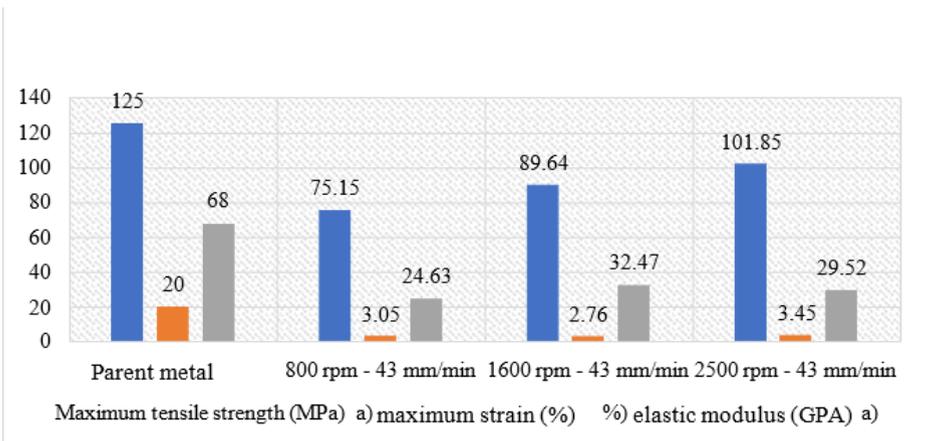
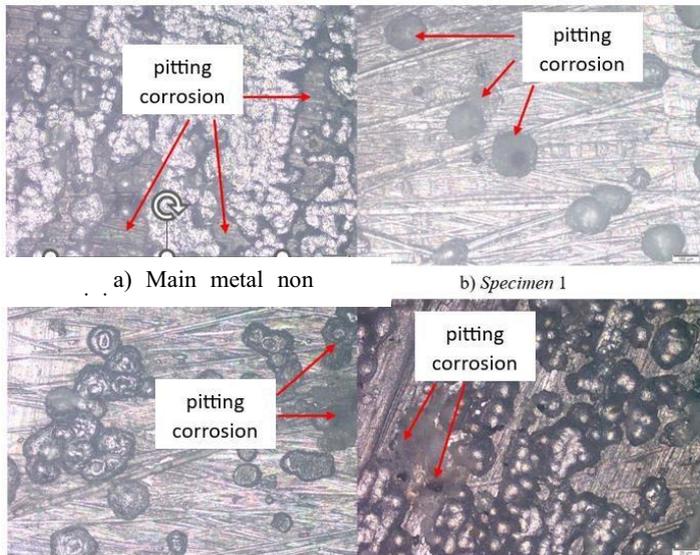


Fig. 7. Graph of Tensile Test Results.

From the results of the tensile tests that have been carried out on specimens 1 to 3 using variations into the rotational speed of the tool 800, 1600, 2500 rpm and material

translational motion of 43 mm/min, it shows that the maximum tensile strength, maximum strain and elastic modulus values are below the tensile strength value. The parent metal which reaches 125 MPa, 20% and 68 GPa. The highest maximum tensile strength, maximum strain and elastic modulus were obtained by specimen 3 of 101,85 MPa, 3.45% and 29.52 GPa using a variation of the tool rotation speed of 2500 rpm while the maximum tensile strength, maximum strain and the lowest elastic modulus were obtained by specimen 1 of 75.15 MPa, 3.05% and 24.63 GPa using a variation of the tool rotation speed of 800 rpm. This can be caused by temperature differences during the welding process, because when the temperature during the welding process is too low, the stirring carried out by the pin tool will not be optimal causing defects in the welding results and ultimately reducing the value of maximum tensile strength, maximum strain and modulus of elasticity from the connection. The high temperature is generated by the friction between the pin and shoulder of the friction stir welding tool and the material to be joined. The temperature value generated during the welding process with the friction stir welding method plays an important role in its mechanical properties.

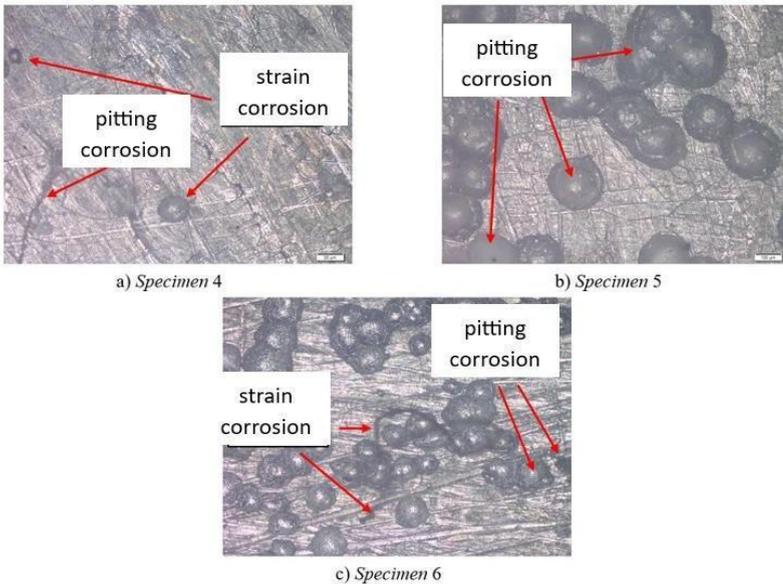
### 3.2 Results of Microstructure Observations Using Variations in Tool Rotational Speed



**Fig. 8.** Results of microstructure observations using a tool rotation speed of 800 rpm.

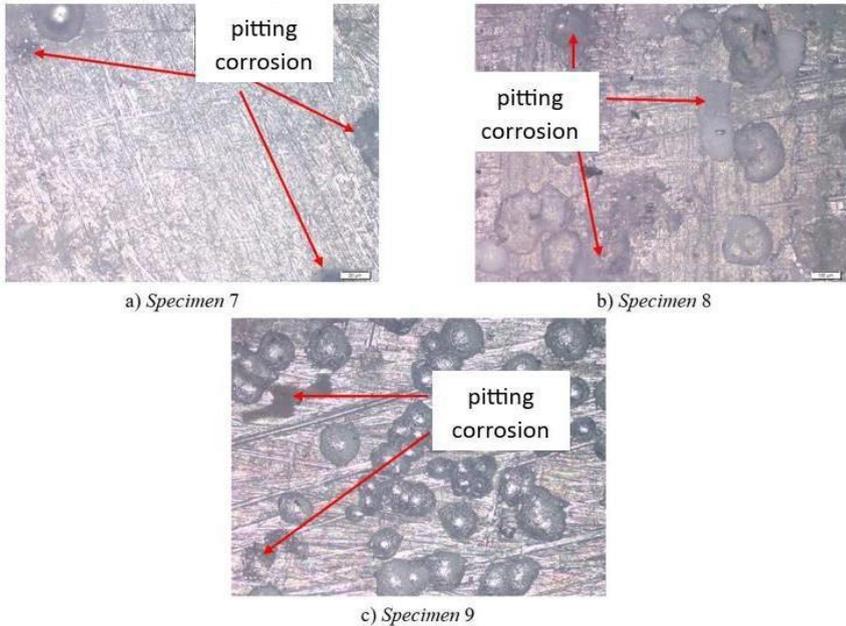
Based on the corrosion rate test results data and microstructure observations above, it shows that variations in tool rotational speed and material translational motion can influence the corrosion rate. The value of the corrosion rate of the base metal without welding is greater than the specimen resulting from welding using the friction stir welding method. The lowest corrosion rate value was obtained by specimen 1 at 1.53

mm/y using variations in welding tool rotational speed of 800 rpm and material translational movement of 43 mm/min. From the results of observations of the microstructure, it can be seen that the corrosion that occurs in joints resulting from welding using the friction stir welding method is pitting type corrosion. Pit corrosion is also known as pit corrosion because it is local corrosion in the form of small holes (pits) with a depth of their diameter and close to each other. When calculated in percentage terms, the weight loss is very small, but the consequences of this damage are quite large [23]. Meanwhile, the corrosion that occurs on the parent metal is a uniform type of corrosion. Uniform corrosion indicates damage to all or part of the protective metal layer so that the thickness of the metal will evenly decrease/wear out.



**Fig. 9.** Results of microstructure observations using a tool rotation speed of 1600 rpm.

From the test results as well as calculating the corrosion rate and observing the microstructure using a variation of tool speed of 1600 rpm. It can be seen that the largest corrosion rate value was obtained by specimen 6 of 2.25 mm/y using a material translational motion variation of 82 mm/min, while the lowest corrosion rate value was obtained by specimen 4 of 1.46 using a material translational motion variation of 43 mm/y. This is in line with the results of observations of the microstructure, where specimen 6 has more surface defects in the form of black spots which occur due to corrosion [24]. The results of microstructure observations on specimens 4 & 6 show the presence of strain corrosion. Strain corrosion can occur due to tensile stress which results in cracking.



**Fig. 10.** Results of microstructure observations using a tool rotation speed of 2500.

In order to find out more about the influence of tool rotational speed and material translational motion on the corrosion rate, the same thing was done on specimens 7 to 9 where welding used a variation of tool rotational speed of 2500 rpm. The data obtained shows that specimen 7 has a low corrosion rate value, namely 1.22 mm/y, while specimen 9 has a high corrosion rate value, namely 2.06 mm/y. From the results of observations of the microstructure, the type of corrosion that occurs is pitting corrosion.

From the tensile test results, the maximum tensile strength value for specimens 1 to specimen 9 tends to decrease compared to the maximum tensile strength, maximum strain and elastic modulus of the parent metal. Apart from decreasing the value of maximum tensile strength, changing the translational motion of the material towards a faster direction can also reduce the ductility and increase the stiffness of the material that has undergone the welding process. The rotational speed of the tool and the translational motion of the material have an important role in stirring the material and generating heat in the welding area so that it can influence the mechanical properties of a joint. When the rotational speed increases and the translational motion of the material decreases the possibility of mixing of the deformed material in the welding zone will increase and this can improve the mechanical properties of the welding joint. However, on the other hand, defects in the welding results can also affect the mechanical properties of the welding joint.

Based on the results of the analysis of corrosion test results using the friction stir welding method, it shows that the lowest corrosion rate was obtained by specimen 7 of 1.22 mm/y using a variation of welding tool rotational speed of 2500 rpm and material translational movement of 43 mm/min. Meanwhile, the highest corrosion rate was

obtained by specimen 3 at 2.32 mm/y using variations in welding tool rotational speed of 800 and material translational movement of 82 mm/min. The temperature produced during the welding process using the friction stir welding method by varying the rotational speed of the tool and the translational motion of the material not only affects the mechanical properties, but also the corrosion rate. This is possible, because the heat-affected zone has better corrosion resistance than other areas [25]. These results can also show that resistance to corrosion in the welding part increases when the tool rotational speed increases and translational motion decreases.

## 4 CONCLUSION

From the welding results of the friction stir welding method using variations in the rotational speed of the tool as well as data from the tensile test analysis results, it can be concluded as follow : the largest value was obtained by specimen 3 with a maximum tensile strength value of 101.85 MPa, maximum strain 3.45% and a modulus of elasticity of 29.52 GPa. The low translational motion of the material and the high rotational speed of the tool will generate sufficient heat during the welding process so that the material can be mixed optimally in the welding results so that it affects these values.

Corrosion test results show that there are different types of corrosion. The type of corrosion found on the base metal is uniform corrosion, while on seam joints, pitting and strain corrosion are found. The value of the lowest corrosion rate obtained by specimen 7 was 1.22 mm/y. The test results show that resistance to corrosion increases when the tool rotation speed increases.

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