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Varied Corner Joint Design Alumunium 6061 uing Friction Stir Welding

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Abstract. The object of this research was aluminum 6061 with 150 mm length, 50 mm wide, and 10 mm thick. The probe utilized is one of with simple design was made from hardened EMS 45. The observed aspect was microstructure in a specific temperature that would affect of the strength the material. Apart from the microstructure, the observation also covered the macrostructure and the temperature. The analysis of the result also involved several tests including hardness test, x-ray, and tensile test.The determined parameter for this research was the feed rate speed that ranged from 6 mm/min, 8 mm/min, 10 mm/min, 15 mm/min, and 30 mm/min and varied corner joint (Corner-Butt 45, Corner-Butt, and Corner-Lap 45). The rotation speed varied set at 1000 rpm, 1500 rpm, and 2000 rpm. The heat generated,the acquisition data was then calculated.The experiment is highest value of tensile test was 163 MPa, acquired from Corner-Butt joint 45 with 10 mm/min feed rate speed. It was verified by the heat temperature that ranged from 300-420o C and clarified by its micro and macrostructure..

1. Introduction

Friction Stir Welding (FSW) is a solid phase joining technique on fabrication industry. Good quality single sided and double sided butt, "T", and lap joints. Invented in 1991, and was originally used to produce butt joints of aluminum alloys [1].

FSW is a solid-state, hot-shear joining process which a rotating tool with a shoulder and terminating in a threaded pin. It moves along the butt surfaces of two rigidly clamped plates placed on a backing plate as shown in Fig. 1.

The shoulder position is firm contact with the top surface of the work-piece. The heat generated by friction on the shoulder and lesser extent on the pin surface softens the material being welded. During FSW, heat is generated by friction between the tool and the work-piece through plastic deformation. The fraction of the plastic deformation energy is stored within the thermomechanically processed region in the form defect densities increment.[2]

FSW does not require any filler materials. The heat is generated from the friction between the spindle (probe) with the stationary work-piece. The probe spinning on a constant rotation speed is pressed onto the work-piece and then moved along the welding track. That friction will generate 0,8 melting point of the material [3]. The probe must have higher hardness value and melting point than the work-piece. FSW is applicable for similar or dissimilar metal such as steel with stainless steel or aluminum

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with brass. FSW has become an efficient option of welding method for the same or dissimilar aluminum alloys, especially those which are difficult or impossible to be welded by the conventional fusion welding.

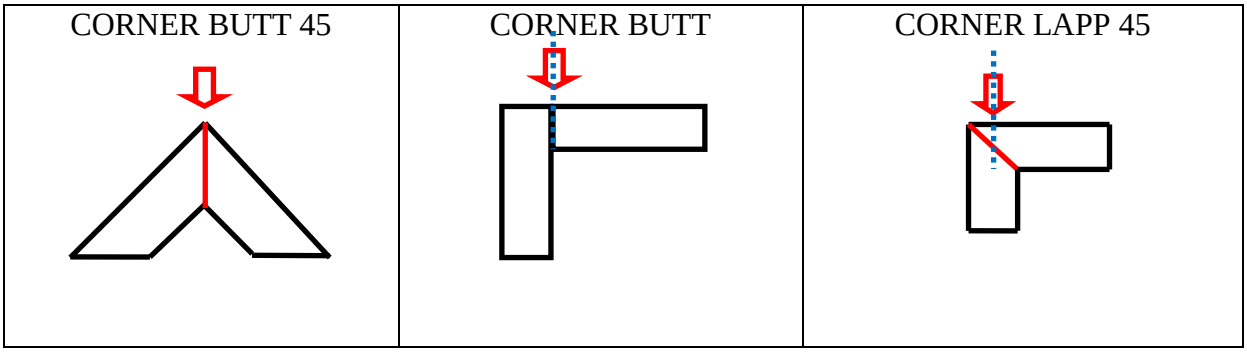


Figure 1. Varied Corner- Joint design using Friction Stir Welding technique process

The shoulder position is firm contact withthe top surface of the work-piece. The heat generated by friction on the shoulder and lesser extent on the pin surface, softens the material being welded.During FSW, heat is generated by friction between the tool and the work-piece through via plastic deformation. The fraction of the plastic deformation energy is stored within the thermomechanically processed region in the form defect densities increment.[2]

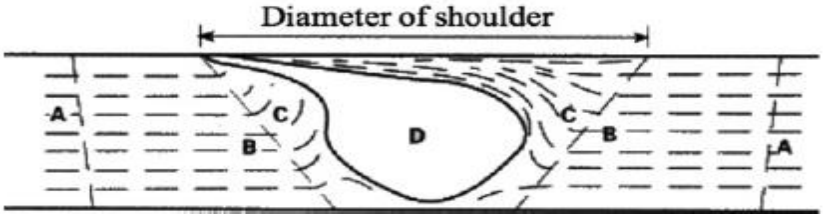


Figure 2. Schematic cross-section a typical FSW weld : (A) base metal, (B) heat affected zone, (C) thermomechanically affected zone, and (D) nugget Zone [2]

In the present study A356 and 6061 aluminum alloys were joined by friction stir welding under different tool rotation and trversing speed. It has been found, that interface microstructure within the weld nugget is dominated by retreating side alloy as the signature of Si rich particle distribution is quiet evident for all the samples [3].

Friction Stir Welding (FSW) is new technique for aluminum alloys joining. This non-consumable electrode technique makes use the heat generated by the rotating tool. Its deformation at the welding zone thereby affects the joint formation material into the solid state.The FSW has become an efficient option of welding method for the same or dissimilaraluminum alloys, especially those which are difficult or impossible to be welded by the conventional fusion welding without any hot crackings, blowholes or distortions[4].

The FSW has become an efficient option of welding method for the same or dissimilar aluminum alloys. The especially those which are difficult or impossibleto be welded by the conventional fusion welding without any hotcrackings, blowholes or distortions [5,6].

In the Journal Friction stir welded T-joints optimization [5]. The one of conclosions said, the joint improving may be achieved by using 1000 rpm, 3.90 mm of probe depth and a shoulder/probe 2.5 diameters ratio. The welding does not speed in a significant effect on the joint mechanical behaviour using the optimized parameters. It is shown in table 1.

Table 1. Level of the level parameters[6]

levels of the selected parameters.

Parameters	Unit	Level 1	Level 2	Level 3
A Tool rotational speed	rpm	490	1000	1500
B Welding speed	mm/min	76	216	360
C Shoulder/probe diameters ratio (D/d)	–	2 (12/6)	2.5 (15/6)	3 (18/6)
D Probe depth	mm	3.50	3.70	3.90

The welding corner welds, needs to have a fillet in order for the weld piece to achieve high enough rigidity. To be able to create this fillet additional material needs to be supplied into the weld. The additional material then needs to be mixed with the weld and shaped into a fillet. Because of the 90 degree angle of the weld piece and the shaping of the fillet it is not possible to have a rotating Shoulder.This is a stationary Shoulder is needed to be able to create a corner weld. When trying to create a corner weld with normal FSW without wire feeding the Shoulder will cut into the weld piece creating a non-rigid weld as seen Fig.3[7].
Conducted experiment with two combinations modes T-lap and T-Butt-lap joints, special clamping joint was used. As shown in fig 3. [8]

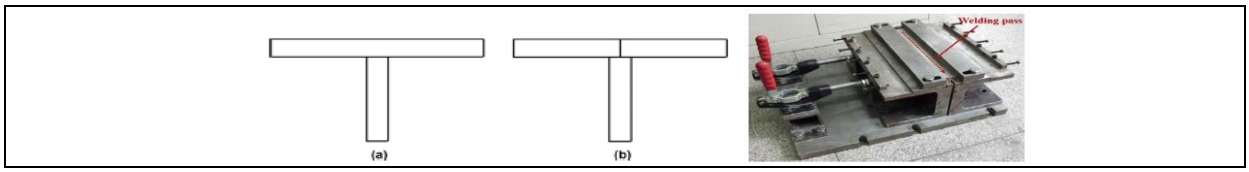


Figure 3 . T-lap , T-Butt-lap joints , and special clamping fixture [8]

The same experiment with three combinations modes T-lap, T-butt-lap, and, T-double Butt joints is listed in fig.4 [9]

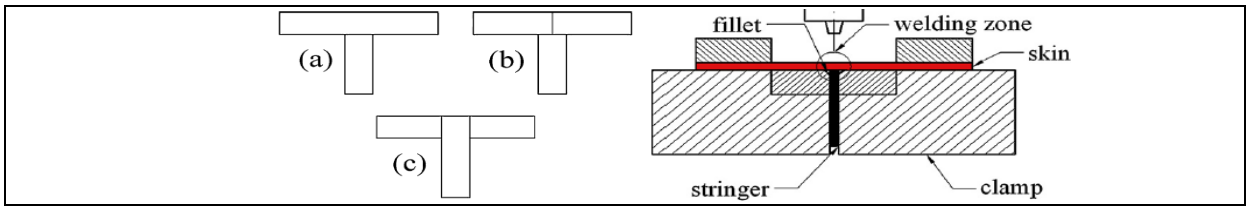


Figure 4. T-lap, T-butt-lap,T-double butt, and FSW process [9]

Aluminum alloys weldments with T-configurations are increasingly important in transport area. The especially in aerospace and airplane,shipbuilding, and car body etc. For example, T-lap joints areextensively used in back supported cars seats , bridge structuresand supported frames for pressure vessels . The one of the special features of T-joints that the stiffness and the tensilestrength of the skin can be reinforced remarkably by the stringerwithout significant increase in weight. Nowadays, T-joints are used tobe fabricated by fusion welding, extrusion and rivet connection[10].
T-welded joint, using FSW, is generally comprise of a skin and a stringer. T-joint welds are extensively used in supportingframes for pressure vessels, and bridge structures, etc. In fusion-welded T-joints of aluminum alloys, high residual stress and significant distortion are difficult to avoid. Althoughwelding distortion could be mitigated by using pre-deformation,thermal tensioning, or using optimized welding sequences, but thesemethods are time-consuming and costly[11].
Therefore, based on that model, Equation 1 expresses power (Q) generated during FSW depending on the rotational speed (Z) and the tool shoulder diameter (D), considering that the shear yield stress (Wy), the friction coefficient (P), the contact pressure (p) and the slip rate (G) are uniform throughout the interface. [12, 13]

$$Q = \frac{2}{3}\pi[\Omega\,(\delta\,\tau_y \;+\; (1-\delta)\mu\,.p\,(\frac{D}{2})^3 \qquad (1)$$

The Fig. 5 shows the effect of different rotational speeds on the recorded welding thermal cycles. The thermocouples were placed on the mid-plane of the plate on the advancing side (AS). It is 10 mm away from the weld center. It can be seen the peak temperature increases from 252 to 330 °C with the rotational speed increasing from 400 rpm to 1000 rpm. Moreover, the typically elevated-temperature over 150 °C exposure time t150 chronological increases from 57 to 100 s as the rotational speed increases from 400 rpm to 1000 rpm.[14].

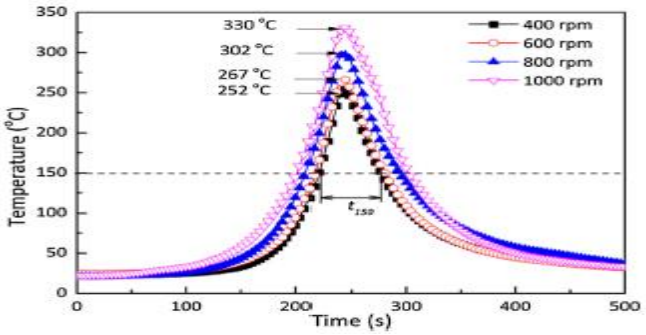


Figure 5. The welding thermal cycle of the joint produce [14]

Table 2. Level of the level parameters [14a]

Identification	Shoulder Diameter (mm)	Rotational Speed (rpm)	Welding Speed (mm/min)	Tool Tilt Angle (°)
D10	10	514	98	1,5
D12	12			
D14	14			
D16	16			

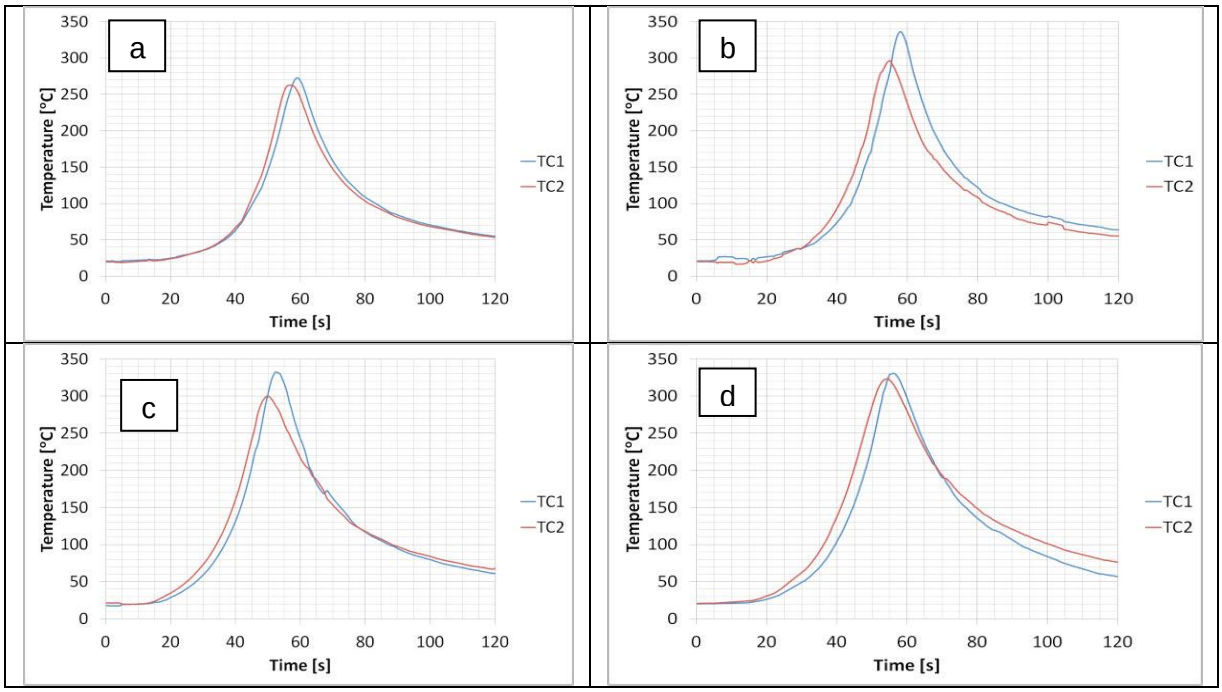


Fig.6. Thermal cycle of FSW welded : a(D10), b(D12),c(D14),d(D16)

During welding, thermal cycles were acquired using two K-type thermocouples. The thermocouples were positioned at 1 and 2 mm from the edge of the weld bead respectively TC1 and TC2, the advancing side of the joint and near of the half length of the specimen, with a distance between them of 5 mm, as is seen in Figure 6. The thermocouples were placed in machined holes of 1 mm in diameter and 1.5 mm in deep.[14a]
Reported that the grain size in the nugget region was decreased when the friction heat input was decreased. As a result, reductionin the workpiece surface roughness value caused decreases inheat generation, resulting in further grain refinement[15].with increasing the travel speed, which is attributed to the decreased heat input. Accordingly, the presentstudy introduced lower heat generation due to the effects of the lowerworkpiece surface roughness, the small size of the welding tool dimensionsand the welding speed being relatively high; therefore, the possibilityof welding tool erosion was taken into consideration.Oxidisation of the Al–Al welded joints is expected [15].

2. Experimental procedures

The base material for this research was Aluminum 6061 with 150 mm length, 50 mm wide, and 10 mm thick. Aluminum 6061 is a compound metal of pure aluminum with silicon (Si) and magnesium (Mg). The rotating tool of a probe was made a medium carbon steel EMS 45 with hardening process. The function of this probe is a liquefy and compound on base materials in the welding area.

Tabel 3. Chemical composition of 6061 aluminum alloy (wt.%).

Compositions	Mg	Si	Cu	Mn	Fe	Cr	Ti	Zn	Al
Content	0.9	0.6	0.25	0.086	0.18	0.1	0.192	0.01	Bal

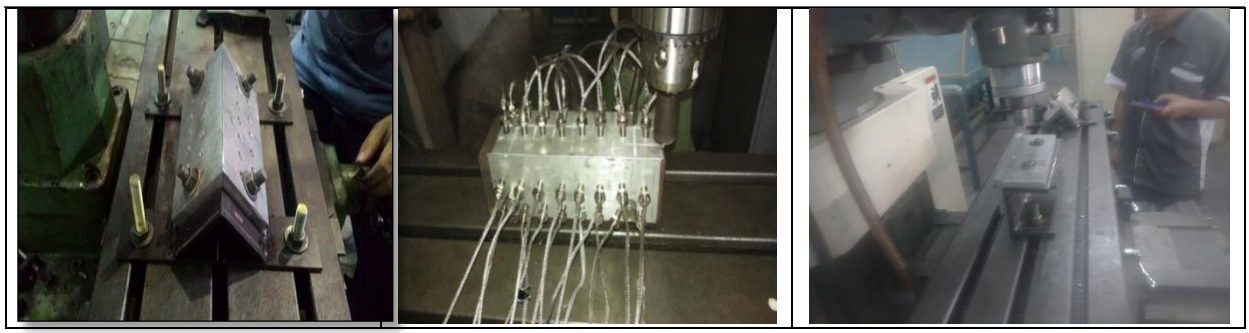


Figure 7. Varied joint design Corner butt 45, Corner Lap 45, and Corner butt joint angle

Fig. 8 shows that the varied Corner design needs to be securely attached to the jig fixture with bolts to avoid any movement since zero movement during FSW process will establish higher success rate. Aluminum 6061 was perforated for the thermocouple to measure temperature distribution.
Below is the probe design for Corner- Butt joint FSW using 10 mm thick aluminum 6061 with 45o joint angle. The probe was made of hardened medium carbon steel.

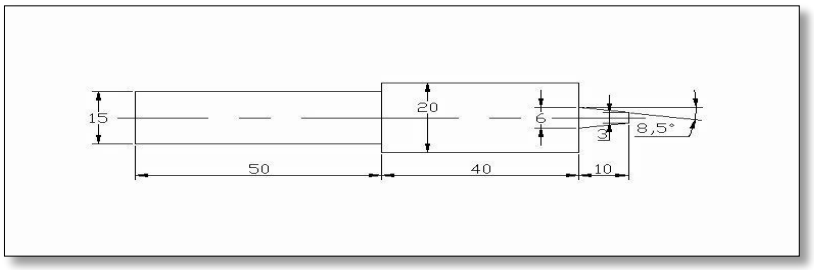


Figure 8. Rotating Tool/Probe Design

3. Result and Discussion

3.1. Visual Comparison

Figure 10 is the result of corner butt joint FSW on aluminum 6061 with 45o joint angle using 2000 rpm spindle rotation and 10 mm/min,15 mm/min,30 mm/min feed rate speed variation.

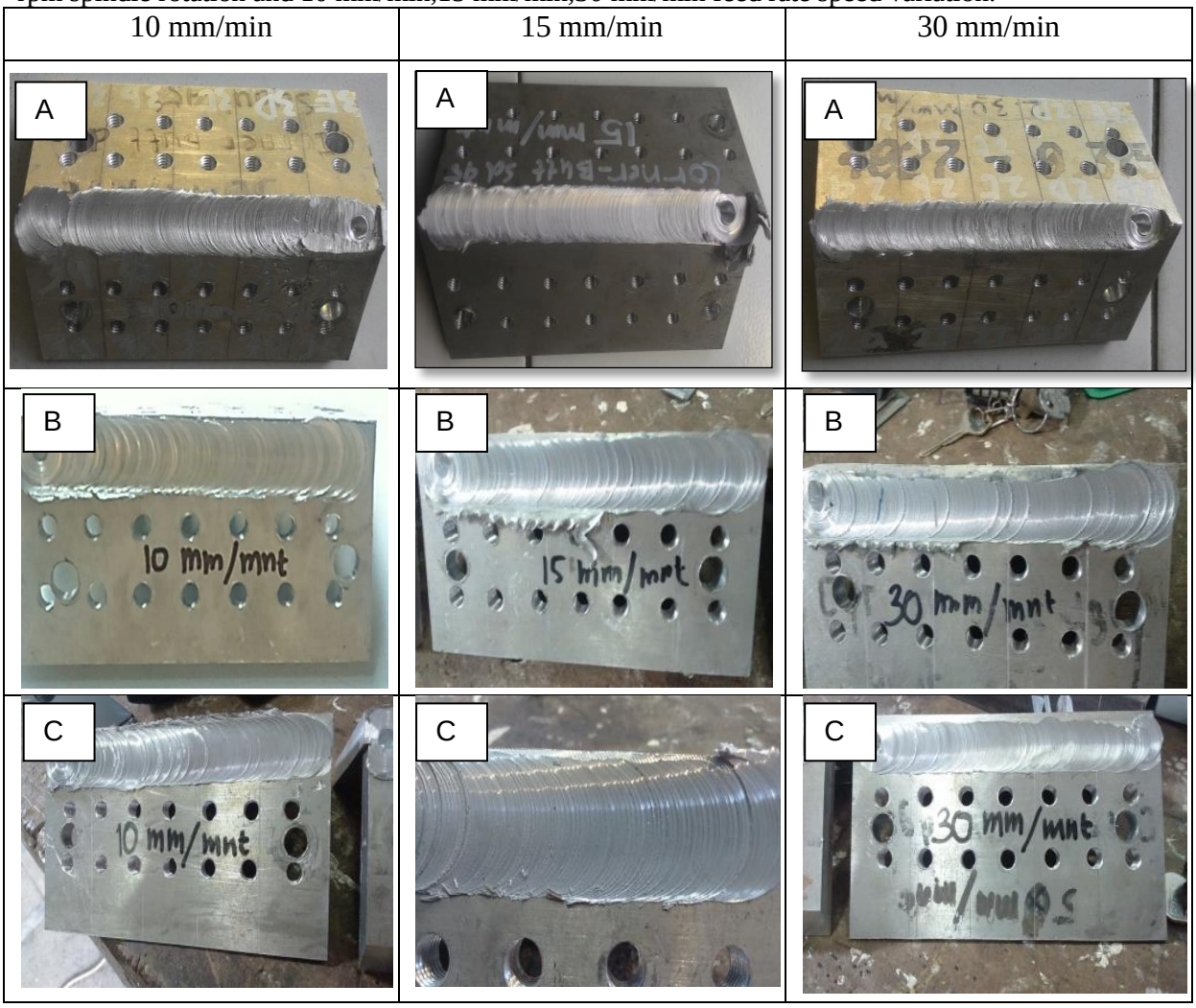


Figure 9. A123) Corner Butt 45, B123) Corner Lap 45, C123) Corner Butt FSW result with 10 mm/min, 15 mm/min, and 30 mm/min feed rate speed

a. 10 mm/minute feedrate speed

The result is visually satisfying where a well-welded line along the welding track is established on the upper surface. The process took 15 minutes, long enough to form sufficient homogenous plastic state material around the welding zone. On such composition, the pin probe could then stir more effectively to create a better joint. Moreover, Si (silica) as the alloying substance could support the welding with its flowability so that the welded surface is more delicate.

b. 15 mm/minute feedrate speed

The result shows less satisfying visual quality compared to the first try. The upper surface on the welding area looks rough because of lower temperature distribution and shorter duration of welding. Because of those factors, the homogenous plastic state was not entirely met so that the joint quality is not as good as the one with lower feedrate speed.

c. 30 mm/minute feedrate speed

The result is visually poor because the plastic state was not formed so that the welded surface looks even rougher. The uneven temperature distribution caused by shorter time spent for the welding,

which was only 5 minute, resulted in very low plastic state material on the welding zone. The pin probe's stir was then ineffective. Eventually, the joint is replete with blowhole and porosity.

3.2. Welding temperature graph
10 mm/mi feedrate speed
The temperature distribution during welding was measured with data logger. Fig. 8 shows that there are 3 temperature measurements record. From the first record, the peak temperature reaches 4340C. In this temperature, form plastic state could easily be formed so that the pin probe could stir the material well. As a result, the joint quality was at its finest without any blowhole. FSW on this speed created joint with flat surface and satisfying visual characteristic. The lowest peak temperature recorded is 220 0C. Such temperature measurement was done 30 mm from the shoulder on the base metal (Fig. 11).

15 mm/min feedrate speed
The temperature distribution was recorded from different spots on the base material. The graph on fig. 10 shows more consistent temperature distribution during the time spent for the welding. The peak temperature is 3220C. With that heat, plastic state material was formed, yet less homogenous so the pin probe was in effective in stirring. Consequently, the joint created was not really satisfactory and blowholes could possibly be present because of insufficient heat. FSW requires 0.8 melting point as its ideal heat [3] and this feedrate speed could not reach such temperature (fig. 11).

30 mm/min feedrate speed
When the probe/tool was plunged onto it, the temperature slowly increased. It took 500 seconds to reach 3110C as its peak temperature. However, such number is still far from 0,8 melting point as the ideal temperature to create plastic state material. Because of faster speed, the welding process only required 8 minutes to complete, making it as a cause of inadequate heat that leads to its inability to form plastic state material. The pin probe then could not stir this semi-solid state effectively so that the joint and its visual quality was very poor. Porosity occurred almost on the entire welding track.

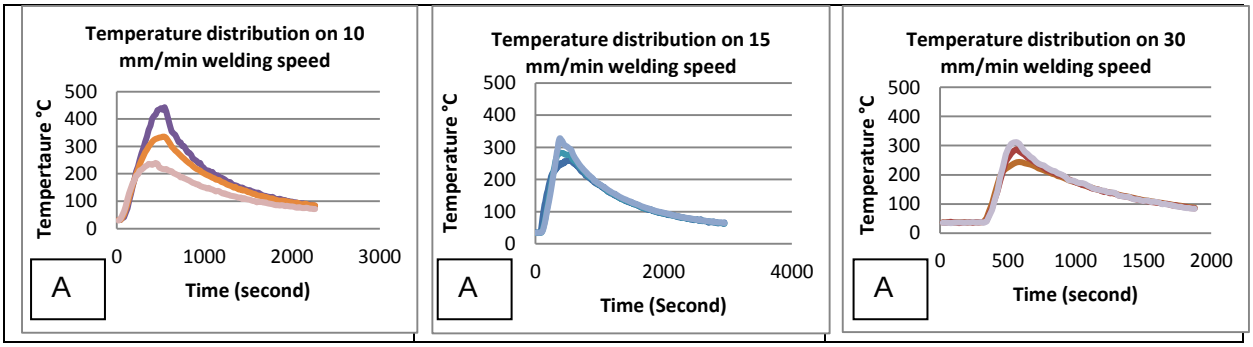


Figure 10. Temperature distribution of FSW on A1) 10 mm/min, A2) 15 mm/min, A3) 30 mm/min feedrate speed.

3.3. Scanning Electro Microscopy (SEM)
10 mm/min feedrate speed
The welding result with this feedrate speed shows well-joined joint without blowhole present along the welding track. This result could be obtained because of high temperature distribution with 434 0C as its peak temperature so that homogenous plastic state material could be formed. In addition to it, 15 minutes welding duration provided good joint quality. (fig. 11 A123).

15 mm/min feedrate speed
From the SEM display on the welding result with this feedrate speed, there are many blow holes formed because of low temperature distribution with peak temperature only 311 0C. The plastic state temperature could not be reached, causing the pin probe to stir the material in effectively. The pin probe could not stir the plastic state material completely. Because of its 450 edge design, only half of

the pin's depth of the plastic state area could be stirred. As a result, the joint quality is poor and weak with rough surface texture (fig. 11 B123).

30 mm/min feedrate speed

From the SEM observation displayed in fig. 11 C123, it is evident that plastic state material is not formed using this speed. Such condition is caused by low temperature distribution, which was only 3120C, far from 0,8 melting point (528 0C). The joining then failed because the pin could not stir semi-solid material. The welding only formed a line mark along the joint as the final result.

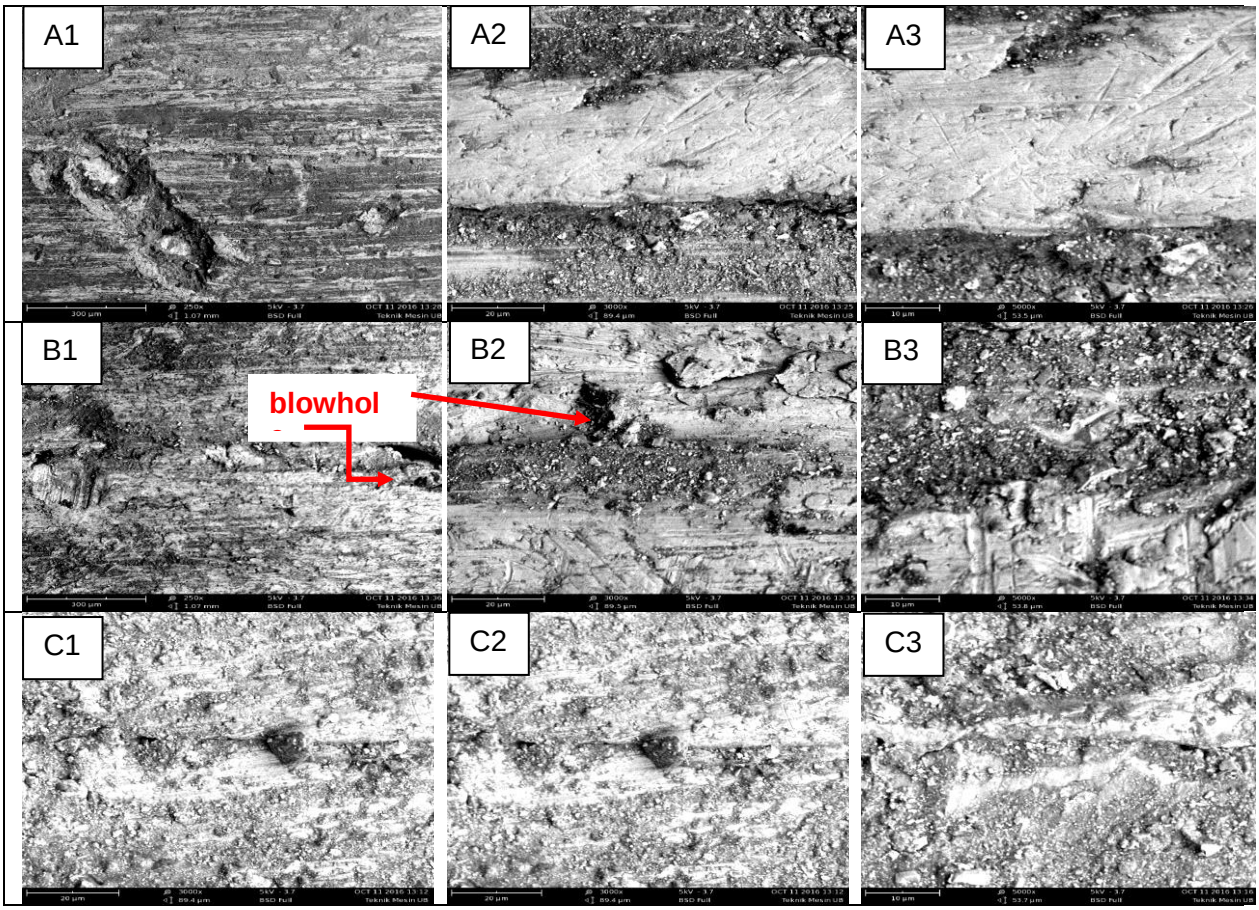


Figure 11. SEM texture with 250X, 3000X, and 5000X magnification A123) on 10 mm/min, B123) on 15 mm/min, C123) on 30 mm/min

3.4. Micro Structure

In fig.12, the result from welding on 10 mm/min feedrate speed shows a solid joint line that represents a good joint quality (as in fig. 12). From its micro structure, the plastic state is clearly more homogenous compared to the results from the other feedrate speeds because the heat generated on 10 mm/min feedrate speed is considered high at 434 0C. On such condition, the
pin probe can stir the plastic material better so that the mixture has the best quality and highest tensile test score.

The micro structure view shows that β-Mg2Si phase dominates the alloy and Magnesium Oxide (MgO) compound is formed on the temperature as low as 1500C [14,15]. With the Magnesium substance decreasing, the mechanic state of the aluminum 6061 diminishes. The white color in the micro structure is Silica (α-Al phase) in the aluminum alloy as an evidence that a fine mixture is present during stirring on the plastic material. Silica it self gives good flowability for aluminum.

Since the plastic material had direct contact with the probe/tool, the micro structure formed is more delicate, more homogenous, and darker. The thermo mechanically affected zone (TMAZ) structure

looks rougher with more white color. The black substance on the micro structure is β-Mg2Si phase mixed with Fe (iron) from probe/tool, and the white one is α-Al phase.
Higher feedrate speeds as 15 mm/min and 30 mm/min ended up in micro structure with lighter color. Higher speed means shorter welding time, and that also means less MgO compound formed as seen in fig.12, so as table 3.

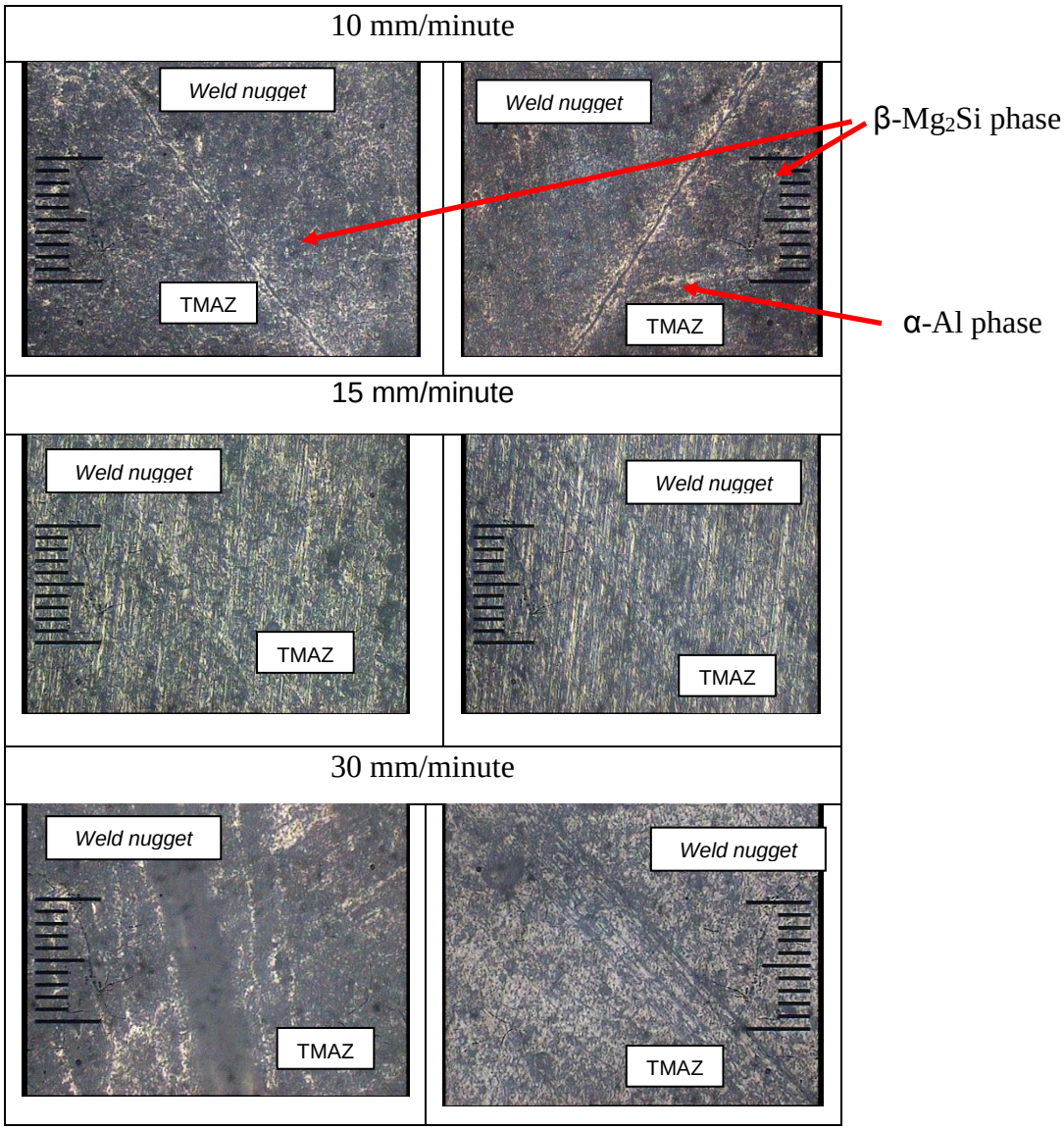


Figure 12. Micro structures from the welding result

Table 4. Chemical analized laboratories

No.	Sample Code	Para meter	Metrology result (ppm)			Method
			I	II	III	
1.	CL-45 (1)	Mg	1868.412	1868.412	1868.825	Atomic Absorption Spect.
2.	30mm/min	MgO	3097,828	3097,828	3128,355	
3.	CL-45 (2)	Mg	1997,299	1978,886	3097,828	Atomic Absorption Spect.
4.	15mm/min	MgO	3311,521	3280,993	3280,993	
5.	CL-45 (3)	Mg	1960,474	1960,474	1997,299	Atomic Absorption Spect.
6.	10mm/min	MgO	3250,466	3250,466	3311,521	

Table 4 shows that the lower the feedrate performed on FSW will be more and more formed magnesium oxide compounds. So that will cause a reduction in the content of magnesium in aluminum 6061. This will result in reduced mechanical properties of aluminum 6061.

3.5. Micro Hardness Vickers

The microhardness tests was conducted to identify the hardness value on the welding area. The test was conducted with micro Vickers method with 100 gf or 0.1 kgf indenter load.

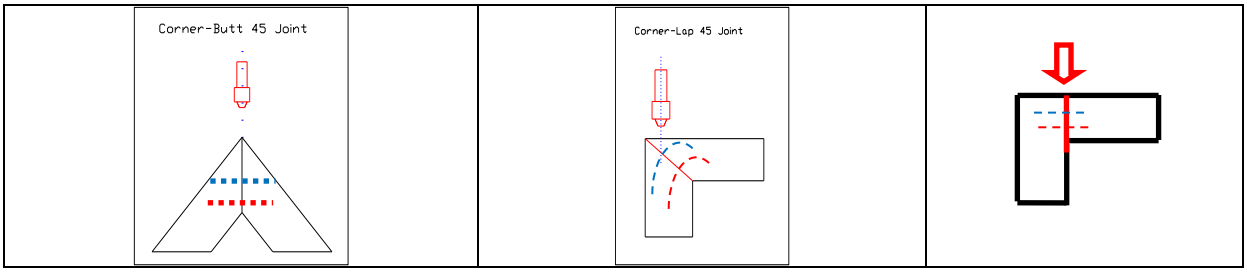


Figure 13. The point of Microhardness tests

The hardness test was done around the welding zone with 12 indentation points to the right and left from the joint area.

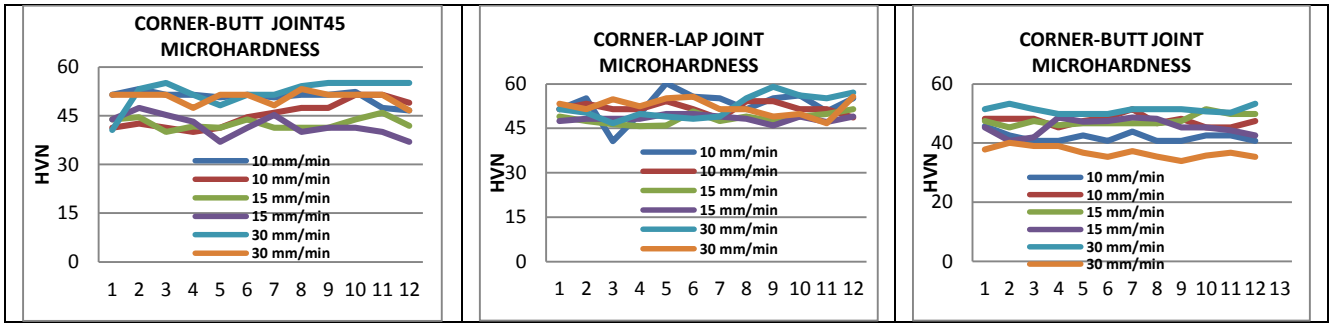


Figure 14. Hardness score graph using micro Vickers method

Corner Butt 45

Confirm Figure 14, the microhardness value of 10 mm/min and 15 mm/min feed rate speed are lower than of 30 mm/min. With higher temperatures generated from lower feed rate speeds, the Mg (magnesium) in the aluminum, with its lower melting point than the aluminum, was able to oxidize and form MgO compound.From the x-ray, there was no peak as observed. In fact, the higher the feedrate speed was, the less heat and temperature were generated. As the result, the MgO compound was then not very well formed and the microhardness value was higher than the one with lower feedrate speed [16] as viewed in fig. 14. So based on the theory and the acquired data, FWS on Al 6061 with temperature as high as 0.8 TM[17]would affect its hardness value to decrease.

Corner Lap 45

From Figure 14, welding on 10 mm/min and 15 mm/min feedrate speed results in lower average hardness score compared to 30 mm/min feedrate speed because lower speed contributes in higher temperature, in this experiment were 3060C and 2430C. With magnesium's lower melting point than aluminum, higher temperature causes the formation of MgO compound. From X-Ray test, the peak occurred, meaning that there was ample amount of magnesium that oxidized. With less magnesium in Al 6061, the hardness score is lower. In conclusion, FSW with high temperature on Al 6061 will cause lower hardness level [14].

Corner Butt

Figure 14, is showing a micro hardness testing, tested perpendicular to the FSW connection. There are 12 test points on the left side and right side of the 6 point connection. Each point is 500 µm. The micro hardness Vicker tests show that at low feedrate 10 mm / min hardness is lower than the feedrate 15 mm / min or feedrate 30 mm / min. This is because magnesium aluminum alloys to form magnesium oxide (MgO) compounds. Then it will result in reduced magnesium alloy, and the mechanical properties of aluminum is also reduced. This is consistent with the statement [Dawood 2015; Muhammad 2012].

3.6. Tensile

To conduct the tensile test, a jig fixture was used as displayed on Figure 15.

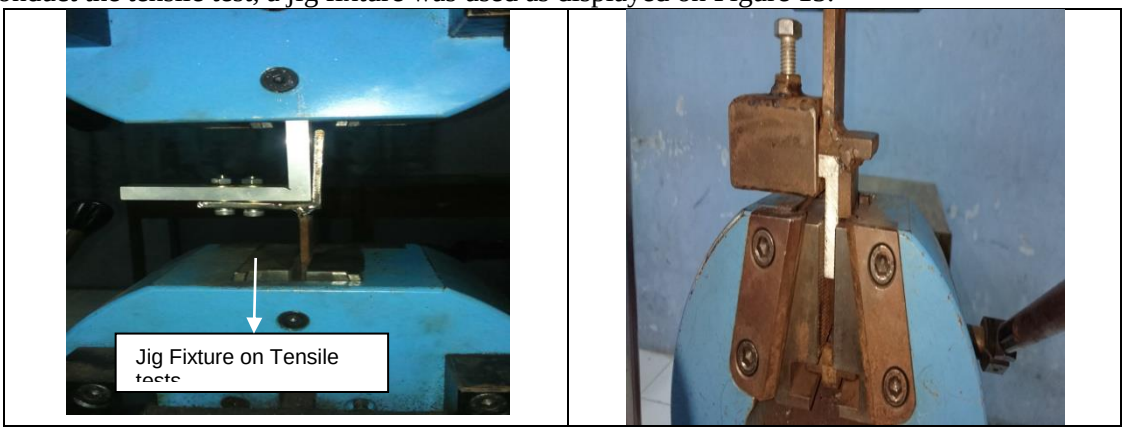


Figure 15. Tensile test with jig fixture

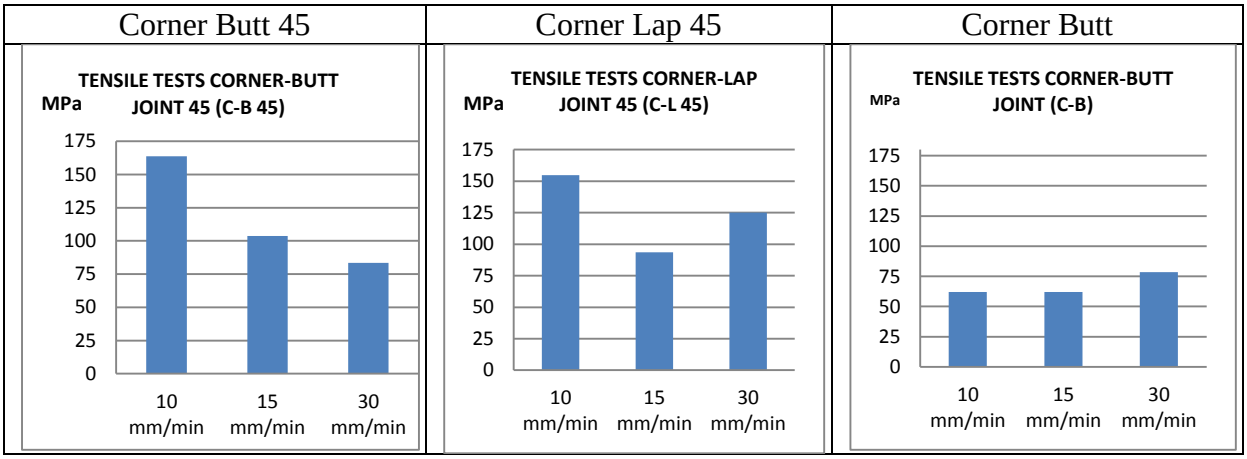


Figure 16. Tensile tests average stress value FSW

Fig 16. In connection C-B 45 feedrate10 mm/min showed the greatest tensile strength. This is caused by oxides which occur many binds with Magnesium, which will improve the mechanical properties. Also are plastic materials that are formed more and more, and will be perfectly stirred by the pin probe.In connection strength of its C-B and C-L 45 is lower than 45. This is due to the probe pin is not capable of stirring the plastic material is perfect, because the plastic material that goes directly into the cold. Oxides which occur also unable to bind Magnesium, thereby decreasing the mechanical properties. Temperature distribution in Figure 11, supporting a decrease in mechanical properties. Because MgSi will be stable at 2000C, at temperatures above 2000C MgSi will settle and dissolve spread by mixing the probe pin. It also will reduce the mechanical properties [Dawood 2015].

The highest tensile test score is 154,67 MPa at Corner Lap 45, acquired from 10 mm/min feedrate speed. This score can be achieved because on low feedrate speed, the temperature distribution is high so that the plastics state area formed is wider. The size of plastic state area determines the quality of the joint and the tensile test score. Furthermore, the spinning pin probe did not have direct contact entirely with between the edges of the work-piece so that it only stir the material partially. Yet, the corner design provides more homogenous plastic material for the welding process so that the stirring is more effective with better tensile strength compared with15 mm/min or 30 mm/min feedrate speed.

In the tensile test the second experiment was carried out without temperature measurement, but more emphasis on variations such as: feedrate (6 mm/min, 8 mm/min, 10 mm/min, 15 mm/min, dan 30 mm/min), Engine speed (1000 Rpm, 1500 Rpm, dan 2000 Rpm), and probe pressure (584 Kg, 607 Kg, 630 Kg, dan 653 Kg) on Aluminum 6061 material that will be connected. Obtained data as in the table below,

Table 5. The result of the KNewton tensile force is the Corner Butt 45 joint

FORCE Kg	**584**			**607**			**630**			**653**		
Spindle speed (Rpm) / **Feedrate (mm/mnt)**	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**
6	**0.27**	**0.43**	**2.84**	**3.12**	**11.1**	**5.80**	**5.31**	**7.29**	**6.42**	**2.74**	**4.48**	**4.24**
8	**6.92**	**8.59**	**7.20**	**7.63**	**8.93**	**8.31**	**9.11**	**9.36**	**10.1**	**2.72**	**4.34**	**7.88**
10	**0.57/1.1**	**9.12**	**0.28/1.44**	**4.17**	**10.38**	**0.17**	**8.53**	**6.9**	**0.18**	**4.83**	**2.86**	**0.99**
15	**3.82**	**0.11**	**0.88**	**1.22**	**1.65**	**0.6**	**2.15**	**1.79**	**0.4**	**1**	**1.95**	**0.62**
30	**2.15**	**0.31**	**0.53**	**2.15**	**1.51**	**-**	**1.35**	**2.3**	**-**	**1.19**	**0.76**	**-**

Table 5 shows the tensile strength decreases at 2000 Rpm engine speed, for variations in the probe force and feedrate. This happens because at the end of the 45 corner butt connection plastic material will form. The plastic material that is formed moves from retreating side (RS) to advancing side (AS), then the connection will shorten due to the high heat energy that is formed at a rotation of 2000 Rpm. By shortening the connection will cause the material strength to decrease (Figure 17).

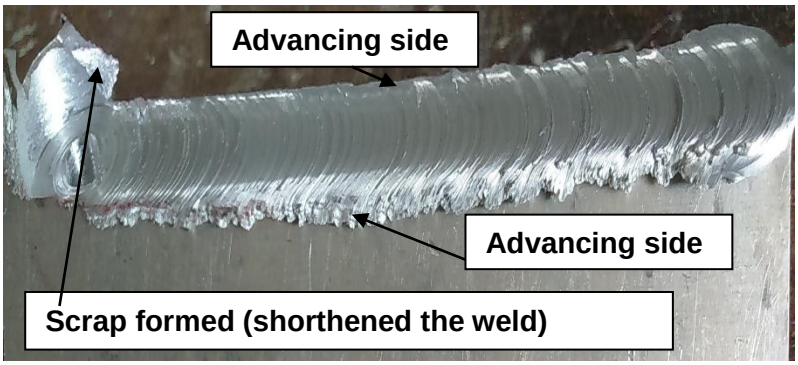


Figure 17. Macrophoto at Corner Butt 45 design

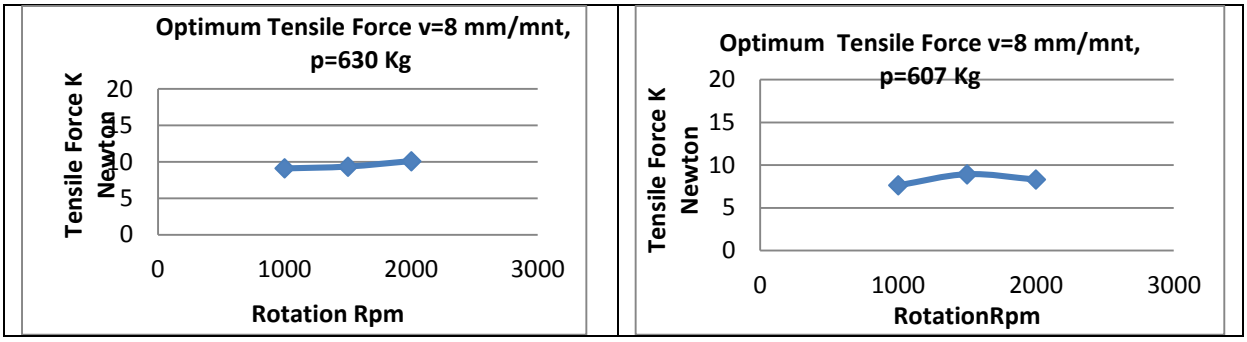


Fig.18 Optimum tensile force design Corner Butt 45

Figure. 18, shows the optimum tensile force produced for all rotation variations in the constant feedrate of the 45 joint corner butt joint, this is because the end of the connection design is shortened as a result of the pressure of the probe which suppresses the plastic material. The plastic material formed was pressed by the probe so that the corner butt joint design was 45 shortened, and the connection area of the small FSW process resulted in the pull force produced by the low connection.

Table. 6 The result of the KNewton tensile force is the Corner lap 45 joint

FORCE Kg	**584**			**607**			**630**			**653**		
Spindle Speed (Rpm)	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**	**1000**	**1500**	**2000**
Feedrate (mm/mnt)												
6	**5.3**	**6.67**	**5.54**	**13.7**	**15.31**	**17.01**	**6.45**	**13.43**	**14.05**	**8.1**	**11.9**	**9.96**
8	**7.71**	**8.13**	**6.63**	**10.99**	**14.56**	**14.56**	**9.68**	**14.96**	**13.62**	**5.65**	**14.7**	**13.61**
10	**8.11**	**13.4**	**12.0**	**13.97**	**13.58**	**5.31**	**9.58**	**7.95**	**5.85**	**7.24**	**6.36**	**5.91**
15	**14.8**	**8.20**	**4.95**	**15.44**	**13.33**	**4.78**	**12.61**	**11.62**	**6.6**	**9.69**	**9.38**	**6.28**
30	**7.75**	**-**	**-**	**14.31**	**-**	**-**	**11.25**	**-**	**-**	**8.71**	**-**	**-**

Table 6 shows the tensile strength decreases at 2000 Rpm engine speed, this happens because the heat energy achieved is high, so it forms a lot of plastic material, then it will move from Retreating Side (RS) to the Advancing Side (AS). To the US there was a portion stirred by the Probe Pin, but many were dumped up to form scrap. Then scrap causes line defects along the connection, and this causes the tensile strength to decrease (Figure 19).



Figure 19. Scrap formed and defects that occur

The optimum tensile strength occurs in the probe compressive force 607 Kg, feedrate 6 mm / min, and 1000 Rpm round obtained a pull force of 13.7 KN, then the rotation is increased to 1500 Rpm obtained

a pull force of 15.31 KN. The round is raised again to 2000 IDR resulting in a tensile force of 17.01 KN (Fig. 20), this is due to the higher engine speed, and a low feedrate of 6 mm / min will increase the heat input. With increasing Heat Input, will increase the tensile force.

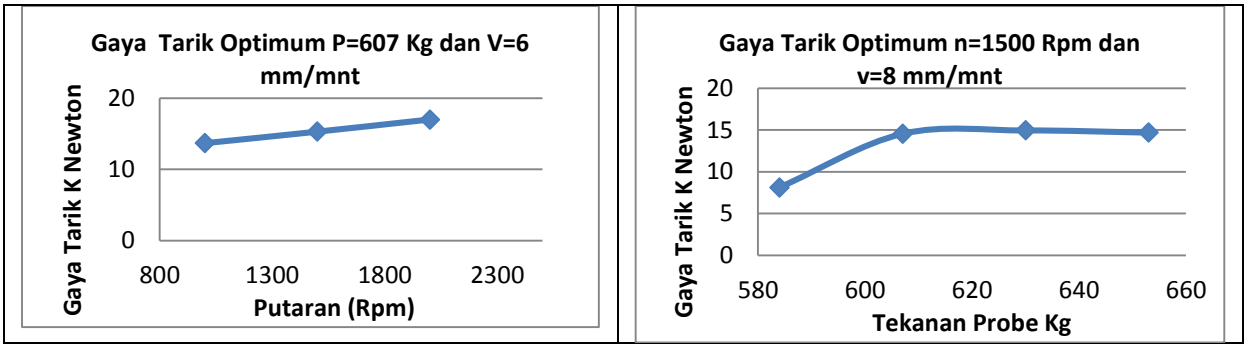


Figure 20. Optimum tensile force joint Corner Lap 45

Table 7. The result of the KNewton tensile force is the Corner Butt joint

FORCE Kg	584			607			630			653		
Spindle Speed (Rpm) / Feedrate (mm/mnt)	1000	1500	2000	1000	1500	2000	1000	1500	2000	1000	1500	2000
6	11.29	13.84	11.62	15.32	10.27	9.04	19.17	15.93	11.33	9.55	17.17	14.66
8	15.39	13.1	5.68	9.68	13.28	7.8	10.36	12.99	9.10	9.28	12.55	17.90
10	11.57	10.86	10.77	18.15	17.55	11.27	11.42	7.20	8.21	15.57	15.55	14.88
15	16.31	11.15	4.56	15.81	11.53	5.62	10.03	9.61	11.77	13.38	15.14	7.75
30					3.31			4.72			5.31	

Table 7 shows the high tensile strength of the corner butt joint compared to other connection designs. This happened because of the corner butt connection, having high heat energy produced would cause the material to become perfectly plastic, then stirred entirely by the probe pin on the shoulder, because the connection design had a symmetrical shape. At a 2000 Rpm round the heat energy generated is high, this will cause a tensile strength for all variations of the connection, because the amount of plastic material moved from the hospital to the US to form scrap. This will reduce the strength of the material (Fig. 21). Figure 22. The second experimental optimum strength is 19.17 KNewton, on graph A, this happens because there is no plastic material scrap. In figure B the optimum force occurs at 1000 Rpm is 19.17 KNewton. The engine speed was increased to 1500 Rpm. The pull force would drop to 15.93 KNewton, then the engine rotation would be increased again the pull force would decrease to 11.33 KNewton. This is in the form of scrap in the AS.

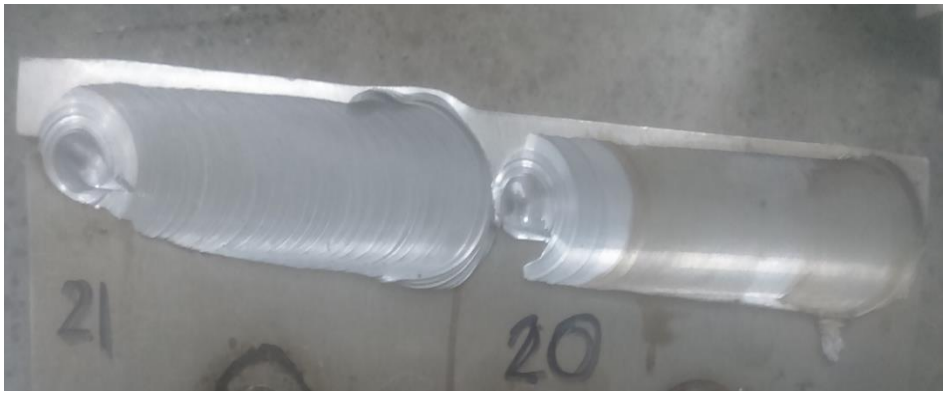


Figure 21. Scrap yang terbentuk sedikit pada sambungan Corner Butt

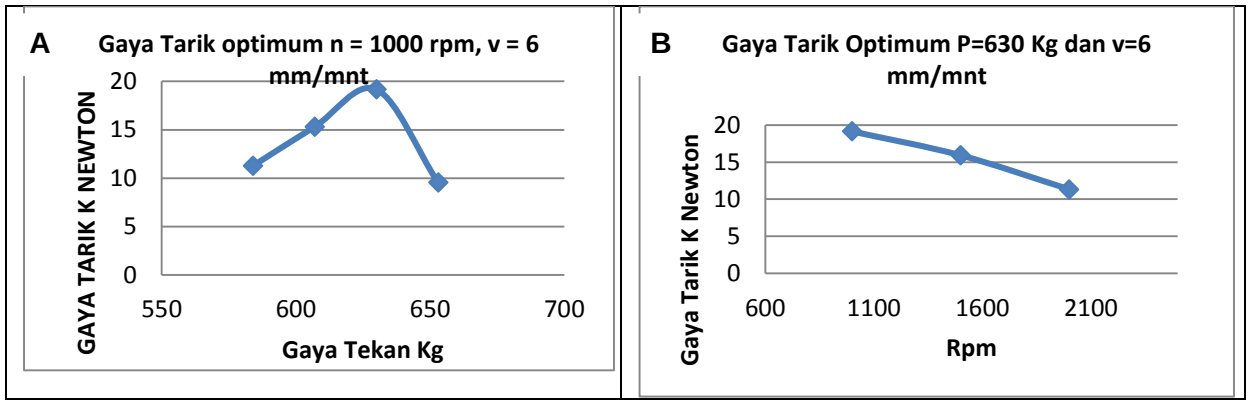


Figure 22. Optimum Tensile Force Joint Corner Butt A) n,v constan, B) P,v constan

4. Conclusion

From the friction stir welding method on aluminum 6061with 45˚ corner-butt joint, several conclusions below were drawn.

The effect of feed rate variation on several joints of this first trial joint is as follows:

1. Corner lap 45 joint, corner butt joint and corner butt joint can be connected properly.
2. Temperature distribution affects the microstructure formed, micro hardness and tensile stress and tensile force. At the lowest temperature measurement of 3060C occurs at the connection angle corner lap 45 joint feed rate 30 mm / min, with the highest hardness 51.53 HVn for the surface and middle, and the tensile stress is 125.1 Mpa. The highest temperature measurement of 4150C occurred at the corner butt 45 joint with a feedrate of 10 mm / min, while micro hardness was 53.27 HVn on the outer surface, and micro hardness was 42 HVn for the position below it. The tensile stress is 163.7 MPa higher than other variations.
3. Optimal tensile strength was achieved for corner butt joints with a variation of 1000 Rpm engine speed, 6 mm / min feedrate, and 630 Kg probe pressure, while the lowest tensile force was also at the corner butt joint with 1500 Rpm engine speed variation, feedrate 30 mm / min, and compressive force 607 Kg.
4. Friction Stir Welding is a non-knowledge skill seen from the tensile force produced

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