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Research Article

Experimental Study on Effect of Welding Parameters of Friction Stir Welding (FSW) on Aluminium AA5083 T-joint

[1]M.T.S.M. Said, [1]D.A. Hamid, [2]A. Ismail, [2]S.N.N. Zainal, [3]M. Awang, [4]M.A. Rojan, [1]I.M. Ikram and [1]M.F. Makhtar

[1]Institute of Product Design and Manufacturing, Universiti Kuala Lumpur, Cheras, Kuala Lumpur, Malaysia
[2]Institute of Marine Engineering Technology, Universiti Kuala Lumpur, Malaysian Lumut, Perak, Malaysia
[3]Department of Mechanical Engineering, Universiti Teknologi Petronas, Seri Iskandar, Tronoh, Perak, Malaysia
[4]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra, Perlis, Malaysia

Abstract

Friction Stir Welding (FSW) is a high reliability solid state joining process that promote energy efficient, versatile and environmental friendly. In this study, experiments were conducted to investigate the effects of FSW welding parameter for different transverse speeds (i.e., 67, 82 and 92 mm min^{-1}) and rotational speeds (i.e., 490, 653 and 910 rpm) on the weld quality of Aluminium Alloy (AA) 5083 T-joint. A customized fixture had been made to clamp 2 pieces of AA5083 and AISI H13 cone with thread tool shape is used as tool pin profiles in this present study. Five samples were successfully prepared and three mechanical tests were carried to validate the specimens such as visual inspection on the surface weld, macro inspection and tensile test. It was found that the suitable welding parameter obtained is rotational speed 910 rpm and transverse speed 92 mm min^{-1}. The specimen produces no defect on the weld surface and cross section as well as obtained highest ultimate tensile strength of 90.33 Mpa.

Key words: Friction stir welding, welding parameters, T-joint, customized fixture

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Corresponding Author: M.A. Rojan, School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra, Perlis, Malaysia

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Friction Stir Welding (FSW) is new joining method derived from conventional welding which enables the advantages of solid state welding. This joining technique has been shown to be effective for joining aluminium alloys, magnesium, copper and other low-melting point metal[1]. It is technically a simple process where a non-consumable rotating tool with a specially designed pin profile and shoulder is inserted into the abutting edges of metal sheets or plates to be joined and traversed along the line of joint[1,2] as shown in Fig. 1. As the process goes, the non-consumable rotating tool generate frictional heat to the material causing intense plastic deformation at elevated temperatures, resulting a good quality of welding as well as fine microstructure properties thus produces good mechanical properties[1].

Most commercial FSW applications use simple butt joint configurations hence alternative designs such as T-sections and corner welds are very rarely considered, thus previous experiment regarding FSW T-joint is literary limited. Zhao *et al.*[3] investigated the different welding parameters applied in the FSW T-joint process using AA6013 aluminum. The experiments setup is shown in Fig. 2. For welding parameters, constant rotational speed of 1000 rpm was used and variable transverse speeds of 100-400 mm min^{-1}.

It is found that transverse and rotational speed of the tool is greatly affecting the formation of microstructure and strength properties of specimen. Zhao *et al.*[3] also discussed about kissing bond defect that occur on their specimen. Kissing bond is pre-crack defect near nugget zone area, as it can be the starting point for specimen to fracture and failed. It is suggested that kissing bond defects occur at T-joints specimen is much related to the welding parameters; significantly influence the features and sizes of kissing bond defects.

Hao *et al.*[4] investigated the effect of welding parameters on mechanical properties and micro structures using Al-Mg-Er alloy. Rotational speeds of 400-1200 and 100-400 rpm of transverse speeds was used in the experiment. They revealed that a fine grain structure in nugget zone can be obtained with the increasing rotation speed of the tool but decreasing welding speeds will resulting increasing in grain structure. As the rotation speed increased, the hardness of the nugget zone decreased and when welding speed increase the hardness of the nugget zone also increased. Higher yield strength and ultimate tensile strength can be obtained when applied lower rotational speed. The yield strength and ultimate tensile strength values decreased as the rotation rate increased but increasing the welding speed led to an increase the yield strength and ultimate tensile strength of the joints.

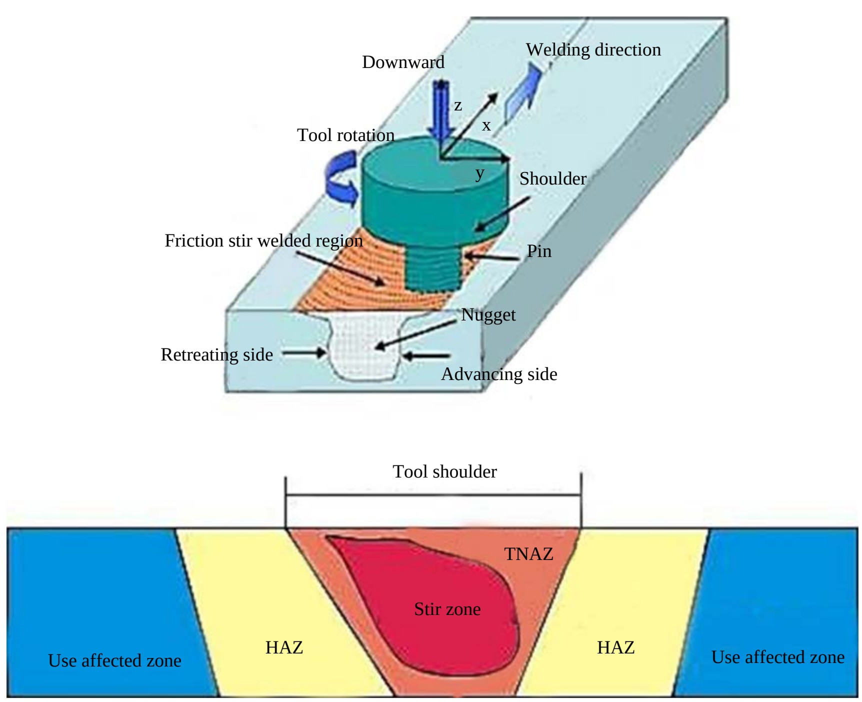


Fig. 1: Principle process of friction stir welding and weld region

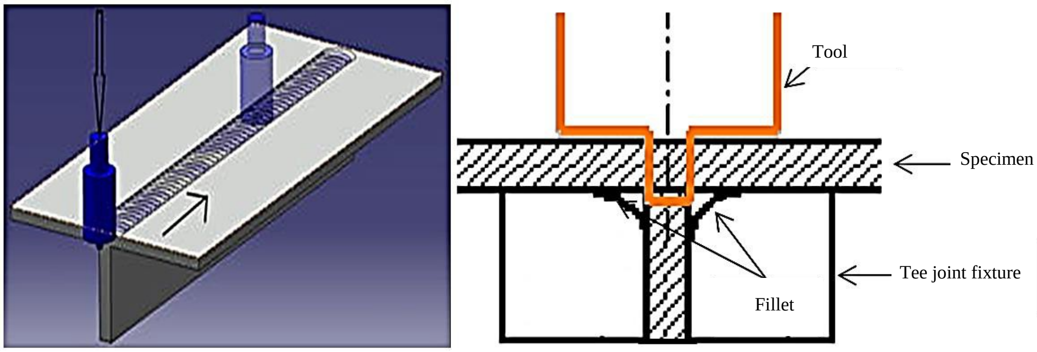


Fig. 2: FSW T-joint (lap position) schematic view

Kumar *et al.*[5] investigated the heat input related to welding parameter of FSW aluminium AA5083. It is found that at higher rotational speeds, it produce high heat input but the study also show that excessive heat could weaken the microstructure and strength of the material. While this effect of rotational speed on the heat input is more at significant lower welding speed. It is also reported that tool rotational speed, welding speed and tool shoulder diameter are most significant parameters affecting heat generation input and axial force, while longitudinal force is significantly affected by welding speed and probe diameter.

Hou *et al.*[6] and Cui *et al.*[7] conducted a studies about influences of three different T-joint geometry (T-lap, T-butt-lap and T-butt) and variable transverse speeds of FSW using AA6061-T4 aluminum. Constant rotational speed of1008 rpm was used with different transverse speeds (75, 142 and 218 mm min^{-1}). From the experimental results, it is revealed that tunnel defects and kissing bond are easily formed and vary significantly in T-joints of the three joint geometries. The defects are significantly related with decreasing the traverse speed. From their result, T-lap joints present the superior tensile properties from other geometries. Costa *et al.*[8] conducted an experiment that applied FSW process into MIG (Metal Inert Gas) T-joint weld AA6082-T651 and AA5083-H111 aluminium. It is found that the improvement in fatigue strength due to grain refinement of the microstructure, defects removal, such as porosity and lack of wetting and stress concentration reduction due to the increased toe radius of the weld.

Cui *et al.*[9] revealed a study of combination of T-lap and T-butt with different processing parameters using AA6061-T4 aluminium. Welding parameter were variable in rotational speeds (700-1100 rpm) and transverse speeds (50-125 mm min^{-1}). It is revealed that in the Nugget Zone (NZ), the microstructure was characterized by fine grains structure. Grains in nugget zone could become larger due to increase in tool rotational or decrease in traverse speed. This is because high heat input was applied to the specimen. From their experiment also, the deformation of grains in TMAZ was found to be more severe with the same situation as nugget zone. The lowest hardness value in HAZ and TMAZ could be decreased by increasing the tool rotational speed. Shahri and Sandstrom[10] investigated of notch stress and fatigue of FSW T-joint and lap joint.

Table 1: AISI H13 steel chemical composition

Composition	Content (%)
Chromium (Cr)	4.75-5.50
Molybdenum (Mo)	1.10-1.75
Silicon (Si)	0.8-1.2
Vanadium (V)	0.8-1.2
Carbon (C)	0.32-0.45
Nickel (Ni)	0.3
Copper (Cu)	0.25
Manganese (Mn)	0.2-0.5
Phosphorus (P)	0.03
Sulfur (S)	0.03

Table 2: AISI H13 steel mechanical properties

Properties	Content (%)
Ultimate tensile strength (20°C)	1200-1590 MPa
Yield strength (20°C)	1000-1380 MPa
Reduction of area (20°C)	50%
Modulus of elasticity (20°C)	31200 ksi
Poisson's ratio	0.27-0.3

MATERIALS AND METHODS

The AISI H13 steel is used because its machinability and good elevated temperature strength and widely used for FSW in joining aluminum within thickness range of 0.5-50 mm[11]. AISI H13 steel is used to make cone shaped FSW tool with 8 mm pin length with 20 mm diameter shoulder as shown in Fig. 3, designed with cone shape[12]. The chemical composition and mechanical properties of AISI H13 are given in Table 1 and 2, respectively. About 4 mm thickness aluminum AA5083

Fig. 3: FSW cone shaped tool

plate is used as specimen with the measurements of the horizontal member had a width 9.75 mm and length 158 mm while the vertical member's width was 140 mm and length 158 mm. The experiment is carried out using universal milling machine Milko 37 and specimen were clamped using special made fixture for FSW tee joint as shown in Fig. 4. The experimental setup is shown in Fig. 5. A cylindrical shouldered tool rotated at constant speed and plunge to the specimen for 30 sec. Then, it's moved at a constant transverse speed along joint line between two aluminum plates which are lapped together; horizontal and vertical. The frictional heat is generated between wear resistant tool shoulder, pin and surface of the specimen. The heat then softens the material using the concept of mechanical mixing process and heat within the material without reaching to the material melting point. Based on the tool design, experimental test were carried out according to the parameter that had been decided as shown in Fig. 6 and a tilt angle of 30 was applied during experiment in order to produce downward force[13]. After 5 experiments were carried out, 3 tests were conducted to validate the results obtained. Visual inspection on surface samples to find any crack or surface imperfection and cross section was conducted to detect for possible voids or imperfections such as crack, excessive flash, surface tunnel, wormhole and lack of penetration according to American Welding Society standard[14]. Tensile tests were performed according to DIN50125 and three tensile samples were prepared for each weld setting. A customized jig was made to hold specimen during tensile strength test as shown in Fig. 7.

RESULTS AND DISCUSSION

Visual inspection: The surface finishing for each FSW sample of FSW3 and FSW4 gave smooth weld surface with some lateral flash; meanwhile FSW1, FSW2 and FSW5 show smooth weld surface condition as shown in Fig. 8. From observation, it shows that is relation between rotation speed, travel speed and flash occurrence. The lower values of rotation and travel speed resulting no lateral flash. In lieu, the greater of both speeds may direct to the presence of lateral flash. Hence, it explains that the welding particulars may influence the characteristic of external surface.

Cross section inspection: The visual inspection conducted on cross sections of FSW1, FSW2, FSW3, FSW4 and FSW5 samples shows no defects in the weld region as shown in Fig. 9. Although, there are no defects on weld samples, further analysis such as micro structure analysis is needed to confirm the results. Kissing bond is a common defect that happens on FSW T-joint. It can only be trace by conducting micro

Fig. 4: Specialize fixture for T-joint

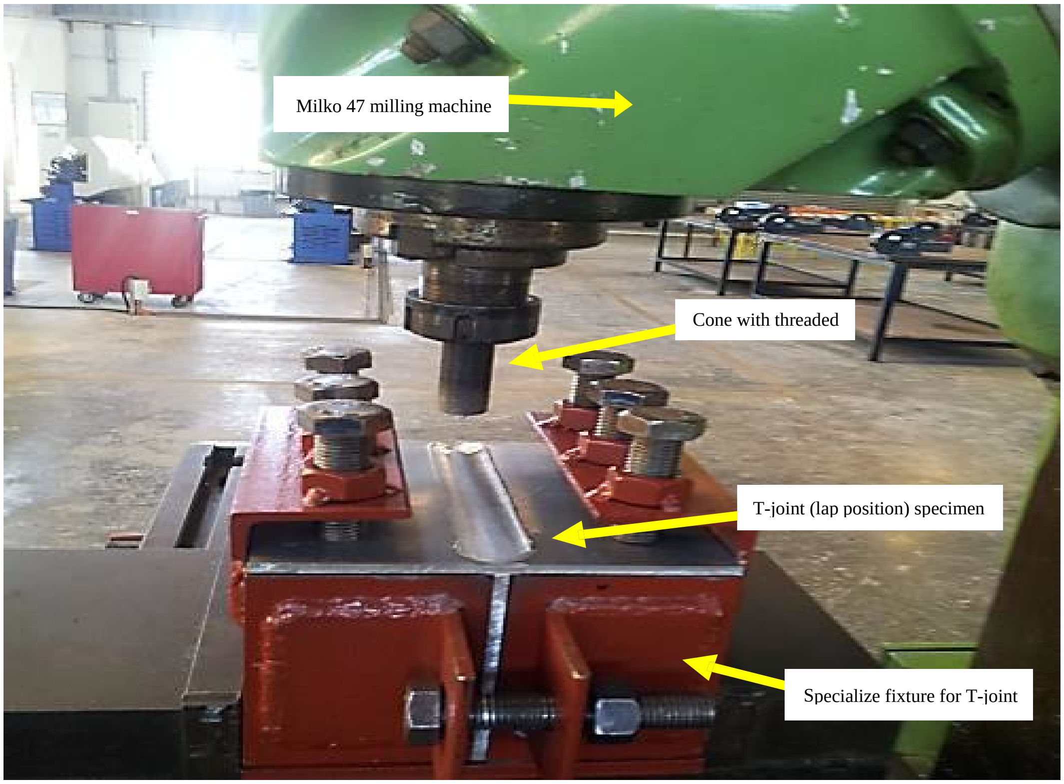


Fig. 5: Experimental setup for FSW T-joint

FSW sample	Welding paremeters		Remarks
	Rotation speed (rpm)	Travel speed (mm sec^{-1})	
FSW 1	490	67	Difference in rotation speed but constant in travel speed
FSW 2	653	67	
FSW 3*	910	67	
FSW 3*	910	67	Difference in travel speed but constant in rotation speed
FSW 4	910	86	
FSW 5	910	92	

Fig. 6: Welding paramter for this experiment

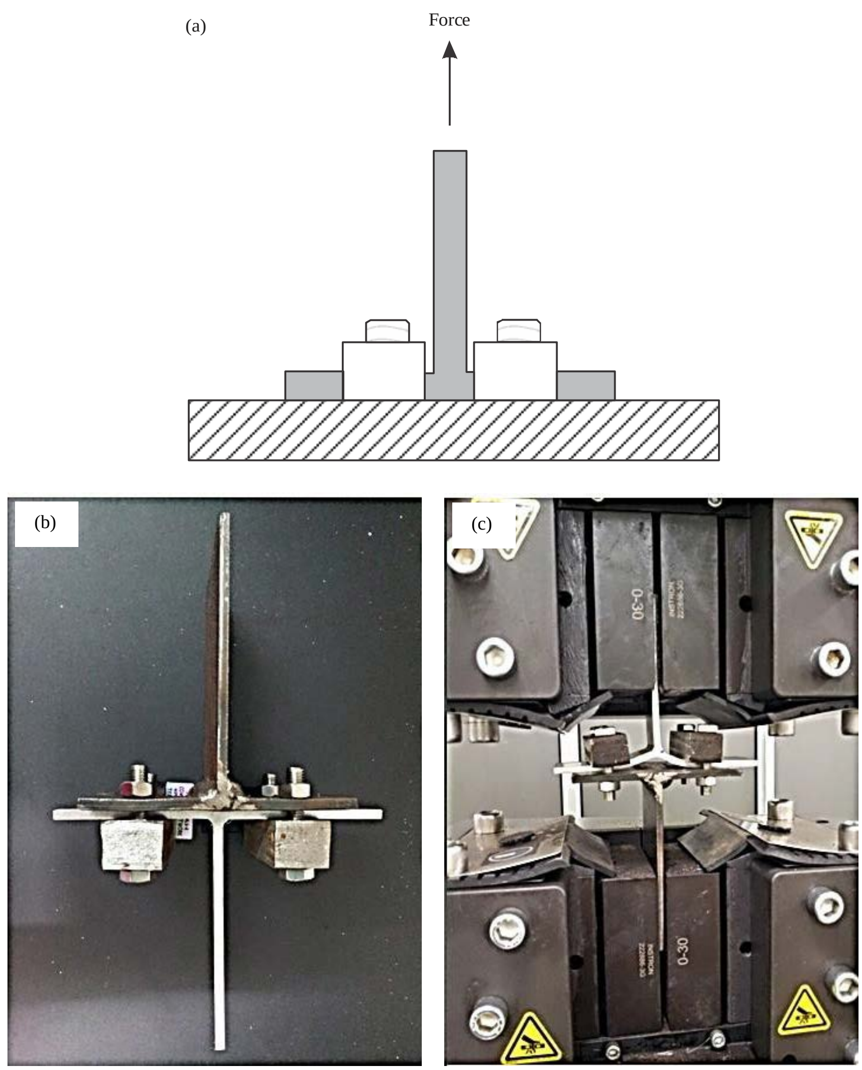


Fig. 7(a-b): Specialized jig for tensile test

structure analysis. It is a pre-crack that usually happen at merger between two welded plates[6].

Tensile strength test: The fracture result as shown in Fig. 10, obtained is very much influenced by the welding parameter. From the result shows that FSW1 and FSW3 fractured on retreating side. This could lead due to incompatibility of combination on transverse and rotational speed for these particular samples thus fractured on retreating side. High temperature tend to weaken the mechanical strength thus

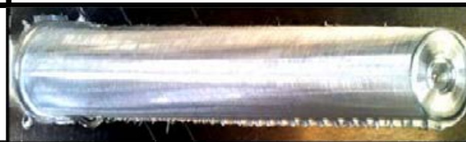
FSW sample	Weld surface finishing	Remarks
FSW 1		Smooth weld
FSW 2		Smooth weld surface
FSW 3		Smooth weld surface with lateral flash
FSW 4		Smooth weld surface with lateral flash
FSW 5		Smooth weld surface

Fig. 8: Visual inspection on weld surface

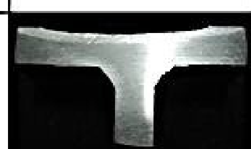
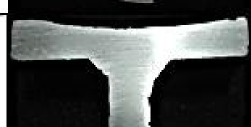
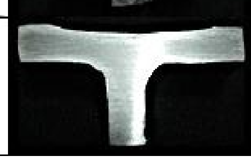
Weld sample	Cross selection of weld	Remarks
FSW 1		There is no defect in the weld region
FSW 2		There is no defect in the weld region
FSW 3		There is no defect in the weld region
FSW 4		There is no defect in the weld region
FSW 5		There is no defect in the weld region

Fig. 9: Cross section inspection on weld samples

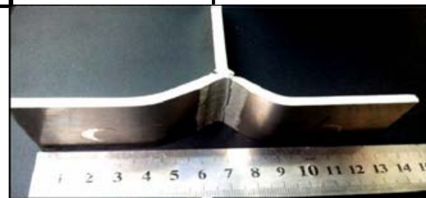
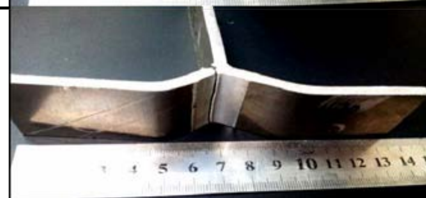
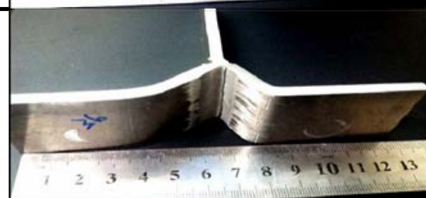
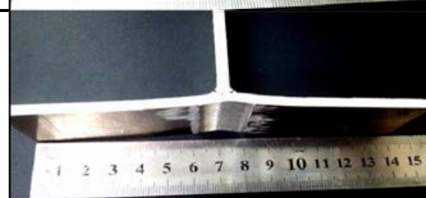
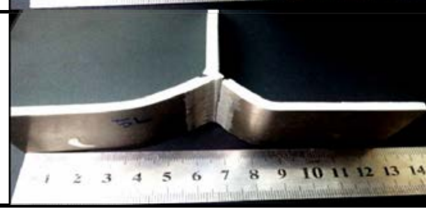
FSW sample	Advancing side	Retreating side	Remarks
FSW 1			Fracture on retreating side
FSW 2			Fracture on advancing side
FSW 3			Fracture on retreating side
FSW 4			Fracture on both side
FSW 5			Fracture on advancing side

Fig. 10: Fracture result form tensile test

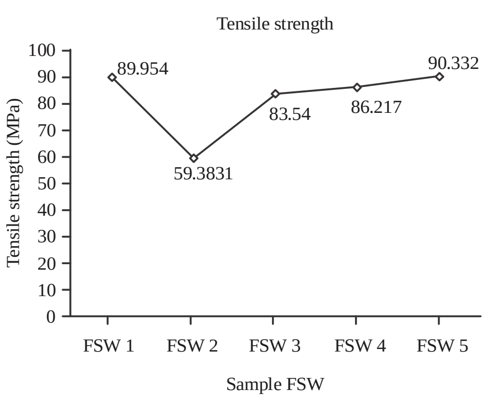


Fig. 11: Tensile strength results, the rotation speed does not match with the reavel speed. That is the reason of decreasind value

lead to fracture but mostly high heat generation occur at advancing side[15]. The FSW2 and FSW5 fractured on advancing side, which could related to that statement and only FSW4 fractured on both side which may due to the same as previous reason.

The tensile strength values are plotted based on results achieved, Fig. 11 shows the tensile strength for each FSW samples. The highest value of ultimate tensile strength (90.33 MPa) result in this experiment is FSW5; 910 rpm and 92 mm min^{-1} and the lowest value obtained in tensile strength test (59.38 MPa) is FSW2; 653 rpm and 67 mm min^{-1}. The FSW5 achieved highest result because of the compatible welding parameter (910 rpm, 92 mm min^{-1}) inserted. The heat generation that occur is suitable to produce good mechanical properties. In search of suitable welding parameter, FSW3 and FSW4 tensile value is increasing (83.54 and 86.217 MPa). This value can prove that suitable rotational speed is 910 rpm. The FSW1 and FSW5 shows a bit different on tensile strength value but welding parameter for FSW5 was taken due to highest tensile strength value obtained.

Cui *et al.*[9] and Hao *et al.*[4] reported that with the increasing of rotational speed or decreasing of transverse speed will increase the grain size in Nugget Zone (NZ) and extent the deformation grain size in thermo-mechanically zone (TMAZ). That statement could support founding in this experiment, but the rotational speed and transverse speed are direct proportional to each other and must be compatible. Heat generation is also play a major role in process parameter. Durdanovic *et al.*[16] stated that when the rotational speed is high, heat produce is also high and the transverse speed affect is little during heat generation. If the rotational speed is too high while transverse speed is low, it will 'Burn' and weaken the structure and strength properties of the material.

CONCLUSION

From the results of the research experiment, several conclusions can be drawn:

- Five experiments of FSW T-joint (lap position) with different welding parameter were successfully performed
- Visual inspection on weld surface and cross section showed no defect. There is lateral flash occurred on weld surface for all samples
- Increment in rotational speed will increase ultimate tensile strength and yield strength of the weld, while increment in transverse speed doesn't give major change in material strength properties
- The selection of rotational and transverse affects the ultimate tensile strength and yield strength
- The suitable welding parameter is 910 rpm and 92 mm min^{-1} obtained the highest strength at 90.33 Mpa

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