THE POSITION OF THE JOINTS WITH ANGLE OF 90^0 AT FRICTION STIR WELDING (FSW)

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This research was use aluminum 6061 with 150 mm length, 50 mm wide, and 10 mm thick. The probe was made from EMS 45 simple design. Three variations used of feedrate speed is 10 mm/min, 15 mm/min, and 30 mm/min. Spindle rotation constantly set 2000 rpm, the heat generated was recorded. Corner-Butt (C-B)joint determined, the lowest heat generated from 220^{0}C-320^{0}C and the tensile test was60 MPa. The highest tensile testwas 163 MPa, achieved by Corner-butt 45 (C-B 45) joint on 10 mm/min feedrate speed. It was verified by the heat temperature from 300^{0}C-420^{0}C and clarified by its micro and macrostructure.

KEYWORDS
Friction Stir Welding, Corner-Butt Joint 45^0, Corner – Butt, Feedrate, Aluminum 6061

1. INTRODUCTION

Discovered and patented a solid state welding technique called friction stir welding (FSW). Solid welding is an easy welding method to combine metals without requiring any particular skill [Thomas 1991].This kindof welding does not require high heat nor feeder electrode. Thistechnique would eliminate the porosity andpresent homogenous microstructure and phase. Moreover, residual stresses are also low. Heat is generated from friction between the cut surface and the probe[Thomas 1991].

[Mortensen 2011] States that in FSW, the heat is generated from the spindle rotation and the joiningoccurs because of the radial force toward the axial direction. The higher the pressure, the more heat is generated. Such condition will greatly influence the result of the welding and affect the material's mechanic state.[Ozekcin 2004] says that FSW is a welding method for two Ferro or non-Ferro metals without liquefication and can be done with or without pressure. FSW does not alter the basic characteristics of the metals and is often performed to aluminum that does not endure *post weld heat treatment* (PWHT)

In performing FSW, according to [Cao 2005], the spinning probe is pressed and penetrated onto the work-piece's surface. The friction then generates heat, therefore connecting the welded materials. [Malarvizhi 2013] has proved that the heat in FSW technique is influenced by the probe's diameter. Its size will affect the formation of micro structure, macro structure, and the tensile strength on the dissimilar metals welding between Al 6061 dan AZ 31 Magnesium.

The successfulness of the welding is determined by the heat generated from the friction between the probe and the work-piece. The shoulder's and pin's diameter of the probe hold a significant role in generating heat. The amount of heat generated also depends on the spindle rotation speed of theuniversal milling machine. The material correspondingly contributes in generating heat. According to [Xiong 2013], the steady state heatgeneratin the plastic state is formulated below.

$$k\frac{d2T}{dx2}+\frac{q}{cp}+\frac{vdt}{dx}0 \quad\text{...1}$$

k = material's thermal conductivity,
d_2T/dx^2 = temperature gradient,
q = generated heat, Cp = heat coefficient,
and vdt/dx = speed gradient

According to [Manvatkar 2014], the heat in the peak temperature and average cooling values are formulated as follow

$$Q = \frac{2}{3}\pi[\delta\tau + (1-\delta)\mu P] \times \omega[(R_s^3 - R_p^3)(1+\tan\alpha) + R_p^3 + 3R_p^2 H_p] \quad\text{...2}$$

δ = probe's and material's relative coefficient
τ = shear stress (Kg/mm^2), μ= friction coefficient,
P = axial force (Kg), ω= *rotational speed* $(\frac{rad}{dtk})$,R_s= Shoulder radius (mm), R_p= pin radius (mm) *, and* H_p= pin length (mm).

During the welding process, the heat is generated from the friction by the probe that spins on the work-piece which eventually creates plastic state compound. This state can be observed in the thermomechanically affected zone (TMAZ) [Nandan 2008].

FSW is a current technique in joining aluminum without feeder electrode required. The heat is generated from the rotation of welding tool which results in deformation in the welding area. This joining process is called solid welding. [Padgett 2003]. FSW can be applied in similar or dissimilar metals with more efficient result, whereas liquid welding may cause hot cracking, blow holes, and distortion [Kazi 2001, McNelley 2008].

[Silva 2014] concludes that key featureson T- Joint FSW optimization are 1000 rpm rotation speed, 15 mm shoulder diameter, 3.9 mm aluminum thickness, and 2.5

as the ratio value between the pin and shoulder diameter. The welding speed apparently gives no significant effect to the mechanic state of FSW joint. The joining of aluminum with combination of T-Lap Joint and T-Butt Joint models can be performed with the use of specific clamping design [Zhao 2013].

Similar experiment by joining aluminum with 3 kinds of joint model, which are T-lap, T-Butt-Lap, and T-Double-Butt Joint with specific clamping design.FSW with T joint is basically performed by pressing the probe onto the work-piece then moving it toward the welding zone with particular speed. T-joints can be applied in many structures as in high pressure container support, bridges sustainer, and many more. If the T-joints are welded with liquid welding technique, the residual stress will be massive and the distortion will occur. Although such distortion can be minimized with particular heat treatments, the time and cost required will increase. The micro structure formed in the nugget zone is soft. That soft tone area can be expanded if the probe rotation speed is increased and the travelling speed is decreased [Cui 2012]. T-joints aluminum welding is essential for means of transportation such as planes, ships, and car seats and body structure as well as bridges structure and high pressure container. T-joint possesses well physical formwith firm and strong structureas its advantage [Hou 2013].

This research observed Friction Stir welding (FSW) on aluminum 6061 with the dimension of 150 mm length, 50 mm wide, and 10 mm thick with 45^0 cut on the edge. The joints variation applied areCorner-Butt 45^0 Joint, andCorner-Butt Joint. The traveling speed varied from 10 mm/min, 15 mm/min, and 30 mm/min with 2000 rpm probe rotation speed. From the result of experiments with those variations, the correlation between micro structure, hardness level, and generated heat were then analyzed to measure the highest tensile stress score.

2. EXPERIMENTAL PROCEDURES

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

Table 1. Chemical composition of 6061 aluminum alloy (wt.%)

The aluminum 6061 as the object of this research contain chemical substance as described in Tab. 1. The aluminum's edgewas milled to form 45^0corner. The probe was made from hardened EMS 45 with simple design.

In Fig. 1 is explained, Before welded, the aluminum was perforated. There were 16 holes, each was at the distance of 20 mm with another. These holes were used to place the thermocouple to measure the temperature using acquisition data.

The temperature distribution measuring at some point will get a picture of aluminum plastics which will affect the quality of the connection, this is as will be done in Fig. 1.

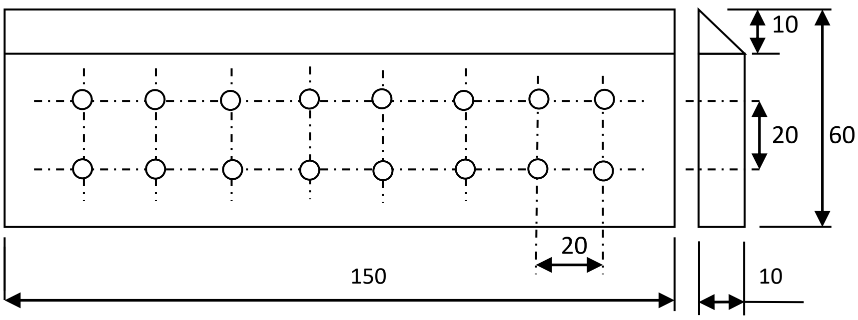


Figure 1. Before welded, the aluminum 6061wasPerforated

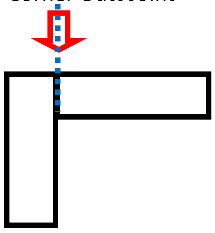
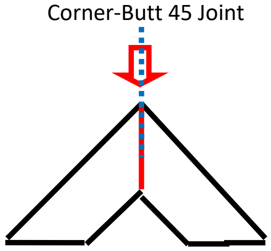
Corner-Butt Joint		Corner-Butt 45 Joint	
	10 mm/min 15 mm/min 30 mm/min		10 mm/min 15 mm/min 30 mm/min

Table 2. Joint and traveling speed varied

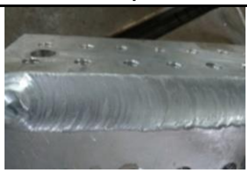
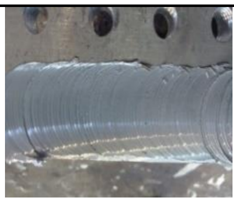
Parameter	10 mm/min	15 mm/min	30 mm/min	Material study
C-B 45				
C-B				

Table 3. Welding macrostruckture result

3. RESULT AND DISCUSSION

3.1. Micro structure

Corner-Butt 45 Joint (C-B 45**)**, the micro structure displays ideal, homogenous blend because the pin probe could generate sufficient heat in all feedrate speeds to form plastic state compound around the welding area. Therefore, the joint could be welded with satisfying result with 400^0 C temperature around the welding zone(Fig.6). Black spots contained in Fig. 6, is a mix of ferro the pin probe and material aluminum 6061. This can be evidenced by increased wear of the probe pin, pin length and diameter of the pin, and will cause the connection to be strong.

The feedrate 10 mm/min slurry more perfect, visible from the slurry flow is shown on the microstructure, and the black spots more. While at feedrate 15 mm/min spots that occur more and more visible in the image of the microstructure occurring point 3.Corner-Butt Joint (C-B) provides homogenous micro structure and ubiquitous compound around the welding zone. The pin probe could properly merge the materials in this type of joint. The shoulder could generate enough heat to form plastic state on the welding zone and heat loss could be reduced. Fig. 2. describes such condition visually. Feed rate of 15 mm/min mixing that occurs is clearly visible (Fig. 2). plastically perfect condition it will cause the connection will be better.

To be concluded, the micro structure on C-B 45and C-B joints are more satisfactory compared to the other joints. In these joints, the heat generated could create wider plastic state compound. The pin probe could also worked at its finestin those joints and the pressure from the shoulder could provide constructive support in stirring the materials. Those factors backed up the satisfying results of the FSW in these joints.

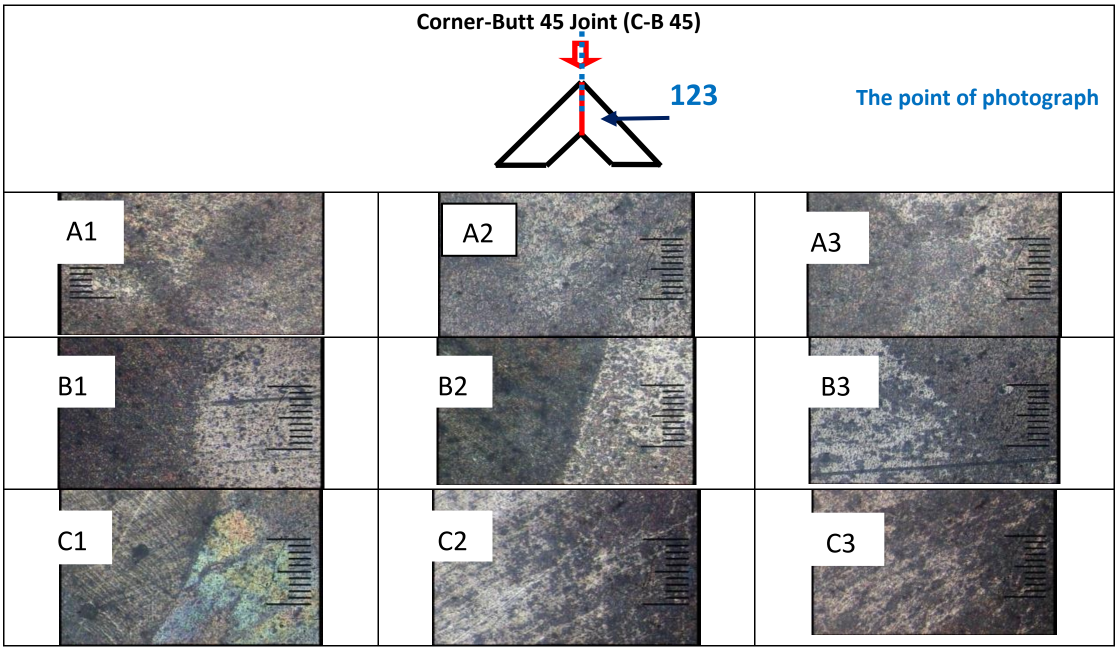


Figure 2. Micro structure on Corner-Butt 45 Joint (C-B 45) with 10 mm/min feedrate speed (A),15 mm/min feedrate speed (B), and 30 mm/min feedrate speed (C) shows well-mixed joints.

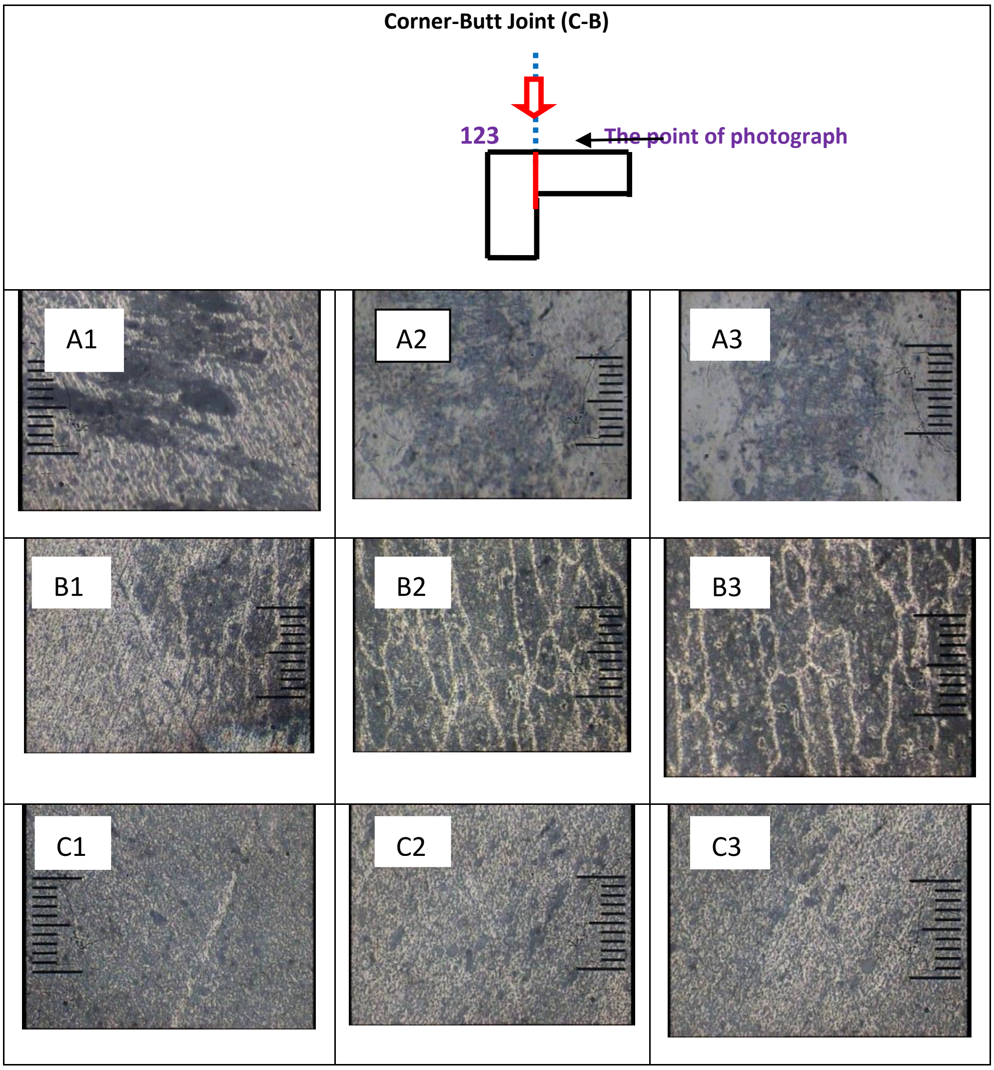
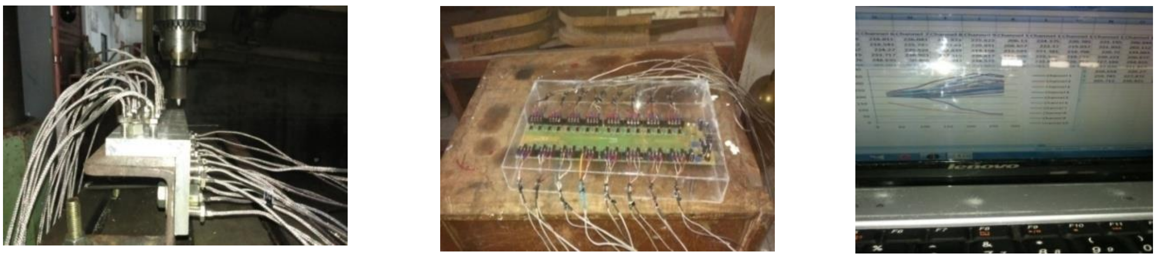


Figure 3. Micro structure on Corner-Butt 45 Joint (C-B 45) with 10 mm/min feedrate speed (A), 15 mm/min feedrate speed (B), and 30 mm/min feedrate speed (C) shows well-mixed joints.

3.2 Temperature distribution

In measuring the temperature, acquisition data, data logger, and thermocouple in the fig. 4 were utilized.



A B C

Figure 4. (A) Thermocouple (B) data logger (C) acquisition data

In Corner-Butt 45 (C-B 45) joint with 10 mm/min feedrate speed, the highest temperature distribution was 420^0 C, nearly 0.8 Melting Point [Tang 1998]. Such number of temperature was possible to reach because the pin probe could perfectly fit in between the edges on the welding track and the shoulder probe was such a suitable heat generator. The slow process that required longer time could eventually aid to accomplish the welding with enough temperature.

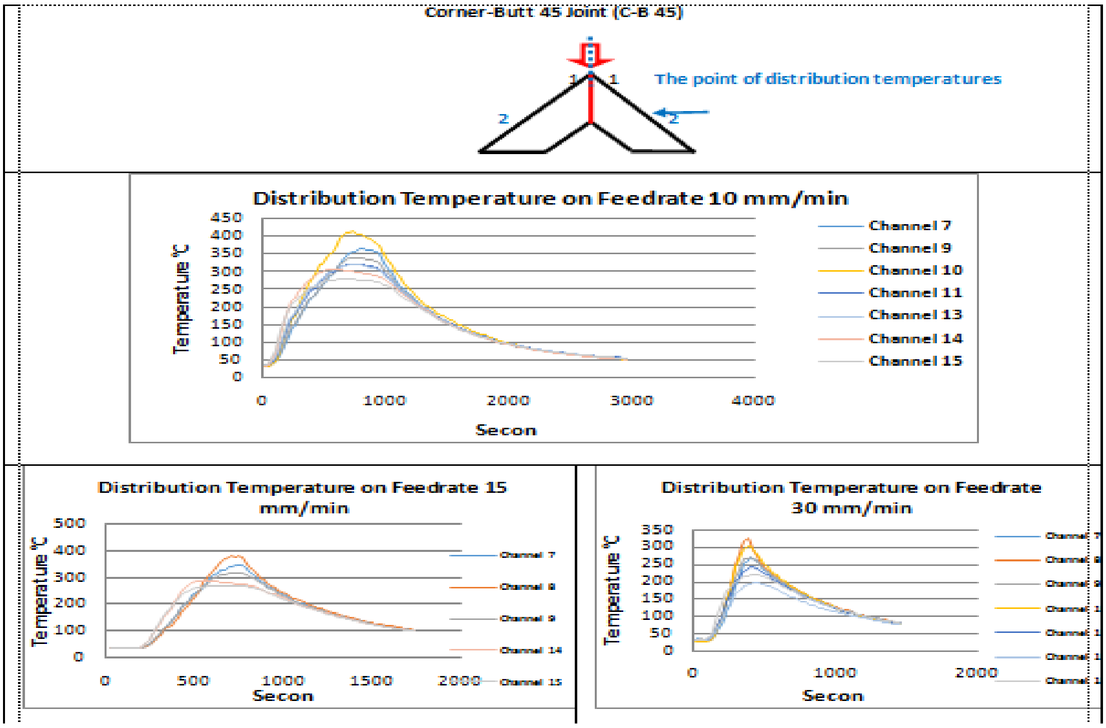


Figure 5. Temperature distribution on C-B 45 with 10mm/min,15mm/min, and 30 mm/min feedrate speed

An ample plastic state area was then formed, leading to a well-mixed joint with a convincing micro structure (fig. 3). With 30 mm/min feedrate speed, the highest temperature distribution was only 300^0 C. The plastic state then was not formed to the ful lest. Even so, the pin probe could still penetrate in between the welding track's edges so that it could still stir properly and create decent compound without any porosity (fig. 5).

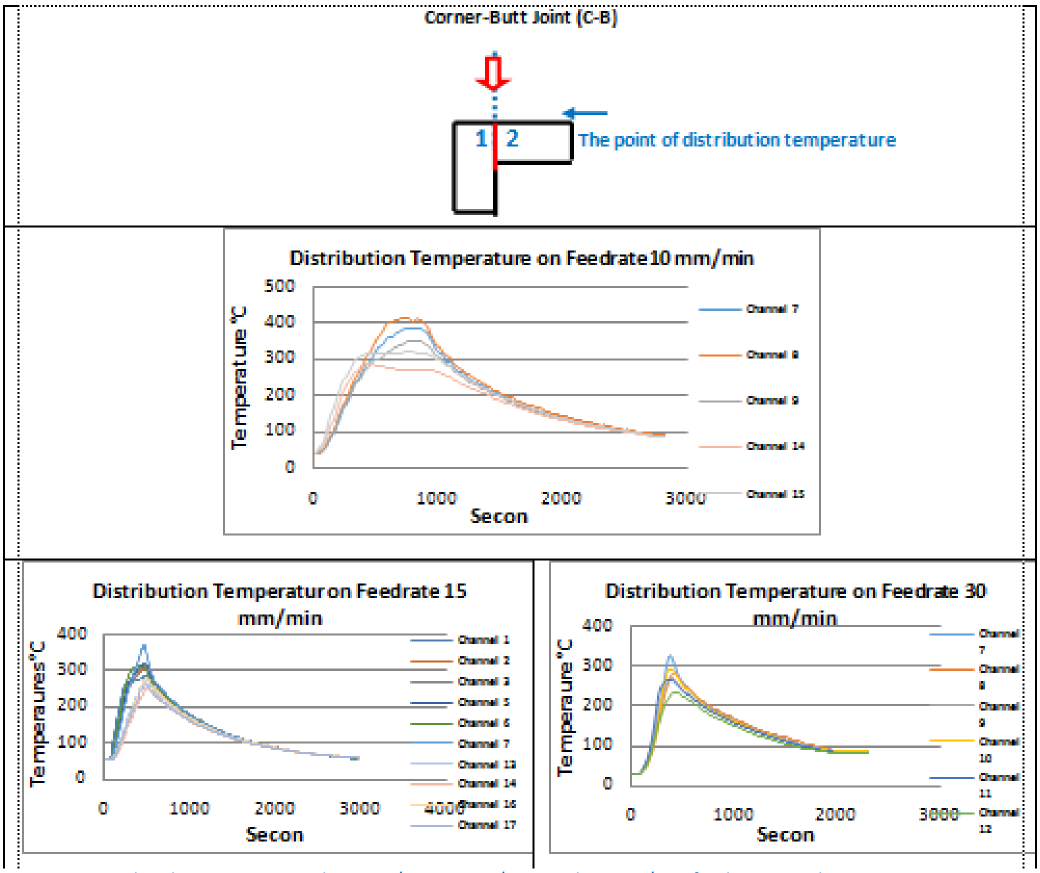


Figure 6. Temperature distribution on C-B with 10mm/min,15mm/min, and 30 mm/min feedrate speed

Corner-Butt Joint (C-B) Fig.6 , the highest temperature distribution was 400 ^{0}C, achieved on 10 mm/min feedrate speed. This could happen because the slow welding process took longer time to complete. Spending 15 minutes in the practice, the heat generated could form wider plastic state area on the work-piece. The sides of the joints that were in direct contact with the entire surface of the pin probe could absorb heat straightly, giving a well-merged joint as displayed in its micro structure. (fig. 3 on A1,A2, and A3). On 15 mm/minfeedrate speed, the highest temperature distribution was lower in 364 ^{0}C (fig. 6), 15 mm/min feedrate. However, the micro structure (fig. 3 on B1, B2, and B3) shows a well-merged compound. Direct contact between the work-piece and the rotating pin probe could form expected plastic state of the material. On 30 mm/min feedratespeed, the highest temperature distribution was 309,7^{0}C. Similarly, the joint was still well-connected since there wasn't much heat loss and the plastic state was met.

From the narrative Fig.6, it is figured out that the joint quality is not determined by the generated heat but by the ability of the pin probe to stir between the edges on the welding track. Aside of that, the diameter and length of the pin probe provide significant impact on the joint quality.

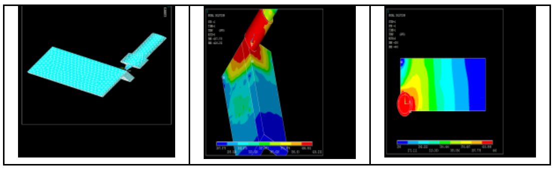


Figure 7. Temperature distribution that occurs from the thermocouple

Fig. 7 shows the distribution of heat occurs in the solid welding process, the round start the first 5 minutes of high heat that occurs above 300 ^{0}C, but the heat was still centered on the probe pin, pin probe further and further away from the lower heat distribution. Also on arms probe pin is still below 300 ^{0}C. The longer the heat will flow in all directions.

3.3. Micro hardness

Fig. 8, 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 [Dawood2015; Muhammad 2012].

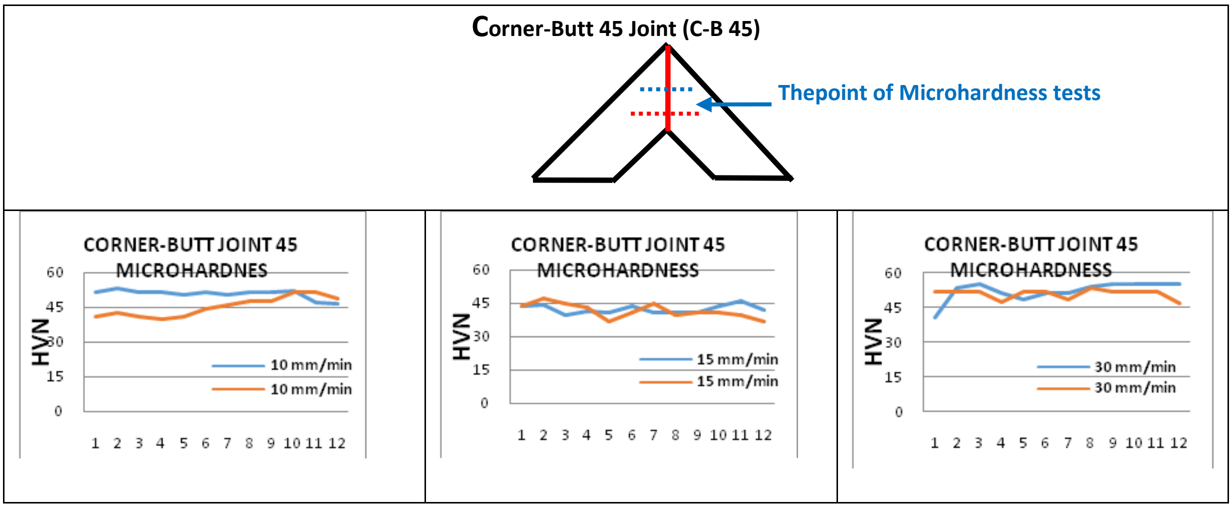


Figure 8. The micro hardness on C-B 45with 10mm/min,15 mm/min, and 30mm/min federate speed

Fig.9 is showing, the connection Corner-Butt also show the same thing with the connection Corner-Butt 45. the micro-hardness vickers test shows that, feedrate 10 mm/min will be generated hardness values lower than a feedrate 15 mm/min or 30 mm/min.

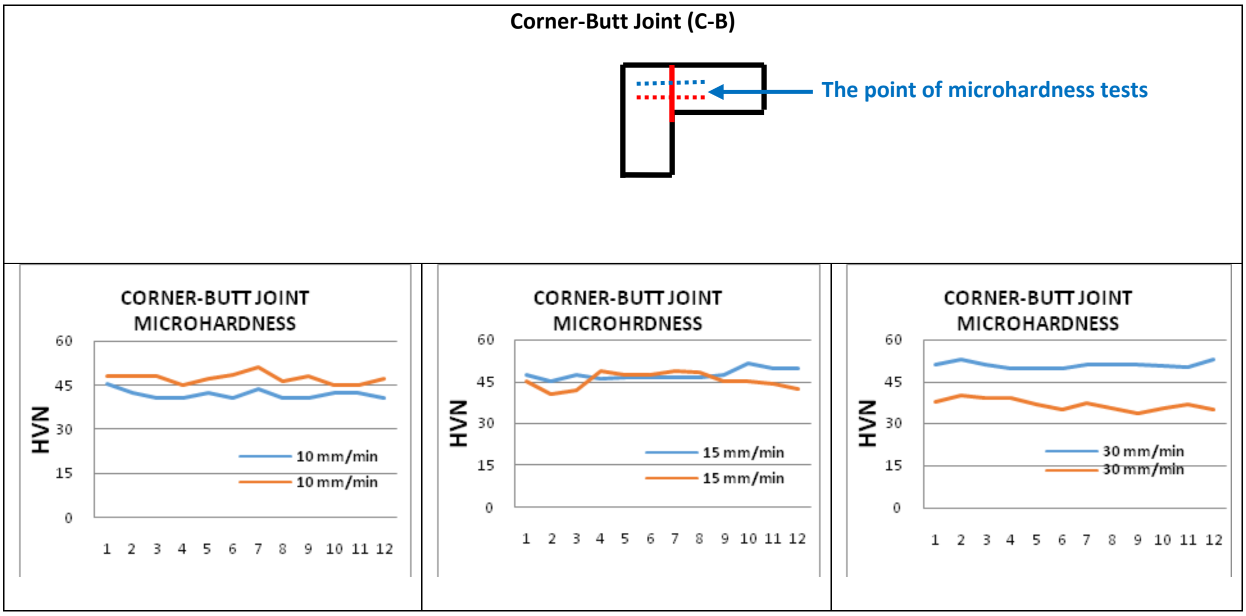


Figure 9. The micro hardness on C-Bwith 10mm/min,15 mm/min, and 30mm/min federate speed

3.4. Tensile tests

Fig 10. 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 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 6, 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].

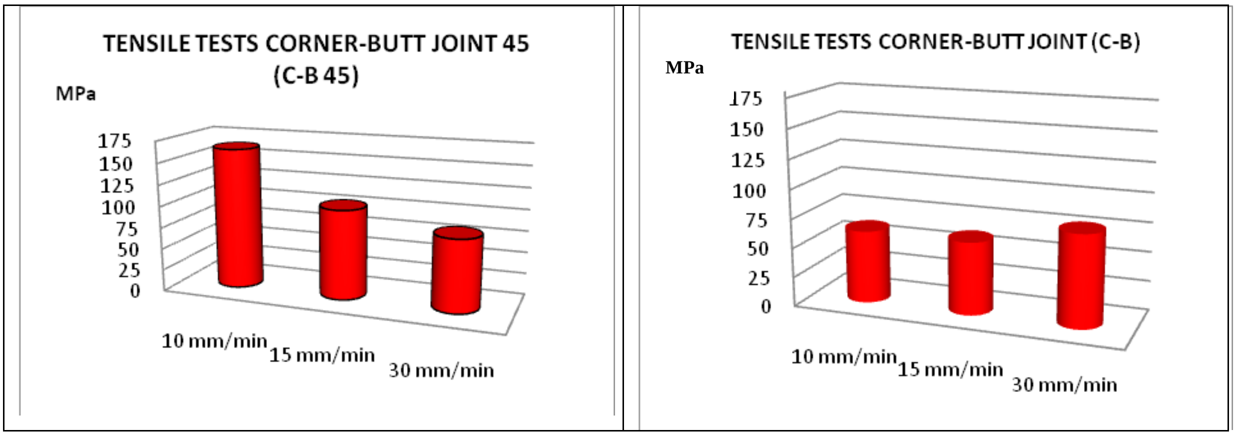


Figure 10. Tensile test result on all joints with 10mm/min,15 mm/min, and 30mm/min feedrate speed.

4. CONCLUSIONS

The finest mixture was achieved by C-B 45and C-Bjoints on all feedratespeeds because the pin probe could penetrate between the edges of the joint and stir them well.High temperature distribution above 400⁰C could be achieved by all joint variations on 10 mm/minfeedrate speed because the duration taken to complete the welding was longer up to 15 minutes.The micro hardness value above 52 HVN was formed by all joint variations on 30 mm/minfeedrate speed because the temperature distribution with such speed was low,therefore the Magnesium loss was just minimum. The highest tensile test score was 163.7 MPaby C-B 45jointon 10 mm/min feedrate speed. The temperature distribution reached 420⁰C, consequently forming plastic state on the work-piece.For this joint, the temperature distribution reached 420⁰C.

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