EFFECT OF ROTATIONAL SPEED AND DWELL TIME ON PHYSICAL AND MECHANICAL PROPERTIES OF FRICTION STIR SPOT WELDING ALUMINIUM 1100 WITH ZN POWDER INTERLAYER ADDITION

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FSSW, AA1100, rotational speed, dwell time, Zn interlayer, Tensile Shear Load

Abstract :

Friction stir spot welding (FSSW) is one of the development of solid state welding to joint lightweight materials such as aluminium. In the automotive industry, lightweight materials are needed in the structure of vehicle construction to improve efficiency in vehicles. This research aims to find out how the effect of rotational speed and dwell time on physical and mechanical properties on the weld joint of aluminium 1100 with Zn interlayer addition. Variations used in rotational speed 1000, 1250, 1600 rpm and dwell time 6, 7, 8 s. Pullout fracture occur in tensile tests that are getting bigger with increasing rotational speed and dwell time. The results of SEM and EDS observations showed that the metallurgical bonded zone increased and kept the hook defect away. The spread of Zn in the stir zone area causes the formation of solid Al-Zn phase in a solid solution. The hook defect filled with Zn can minimize cracks that occur, so increased the tensile shear load. The highest tensile shear load value of FSSW AA1100 without Zn interlayer is 3.61 kN, while the FSSW AA1100 with Zn interlayer addition is 4.34 kN..

INTRODUCTION

The use of lightweight and strong materials is one of the important things, especially in the automotive sector to improve fuel efficiency in vehicles. The construction structure of the vehicle also requires a good welding procedure to improve the mechanical properties of the material [1-2].

Friction stir welding is one of the new welding techniques in the automotive sector. Friction stir welding (FSW) is a solid state joint found and developed at The Welding Institute (TWI), UK. The first time friction stir welding (FSW) was used for welding Aluminium alloys [3].

Friction Stir Spot Welding (FSSW) is a variant of FSW where the tool is not moved in the direction of the joint. In other words, the tool only enters the material then is drawn to produce a point or called spot weld. FSSW is specifically only used in welding applications with small strength, thin material, and highly contoured parts [4-5].

Fereiduni, et al. [6] stated that the variables that are very important in the FSSW process are rotational speed and dwell time. Rotational speed is the speed of the tool rotation, while the dwell time is the time needed for the stirring process. This parameter determines the mechanical properties of the joint through heat generated, material flow around the pin, and joint geometry.

The effect of rotation speed on the mechanical properties of the joint is very large, so that it can improve the mechanical properties of the weld joint, especially tensile strength. With increased rotation speed, resulting a wider stirring area and higher heat addition, thus increasing the size of the stirring zone and the bonding area of the two specimens. [7]. This hotter welding environment softens the workpiece so as to facilitate welding tools to stir the material [8].

Problems began to emerge when in FSSW welding there was a decrease in joint strength which occurred because some surfaces experienced arches called hooking defects [9]. To overcome this, it can be done with the addition of Zn powder interlayer on the FSSW joint.

Interlayer Zn and Substrate Mg can diffuse between the two, forming an Mg-Zn intermetallic

[10]. Balamsundaram et. al [11] stated that the ultrasonic spot welded Al and Cu joints with Zn interlayer formed the formation of eutectic structures such as spiral flowers which showed the solid phase of Al-Zn, causing the tensile shear strength increase doubled.

The addition of Zn interlayer is useful for increasing the joint strength because it can reduce the hook defects that occur, thus causing the joint zone area enlarge [10]. Therefore, this study will examine the welding of AA 1100 FSSW with the addition of Zn interlayer with parameters of rotation speed and dwell time.

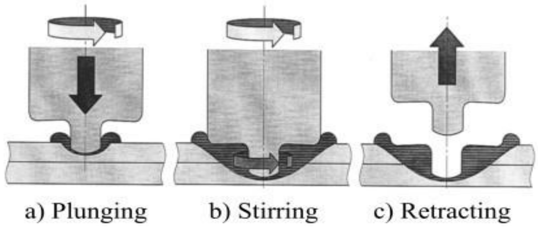


Figure 1. Illustration of the FSSW Process: (a) penetration; (b) stirring; (c) recall [19].

EXPERIMENTAL

AA 1100 aluminium plate material is used in this FSSW research. The cut plate with a size of 125 mm X 40 mm X 2 mm refers to the JIS G 3136 standard as in Figure 2. The middle surface between the plates is given Zn interlayer is in powder form as shown in Figure 3. Zn interlayer has a thickness of 0.2 mm and weighs 0.3 grams.

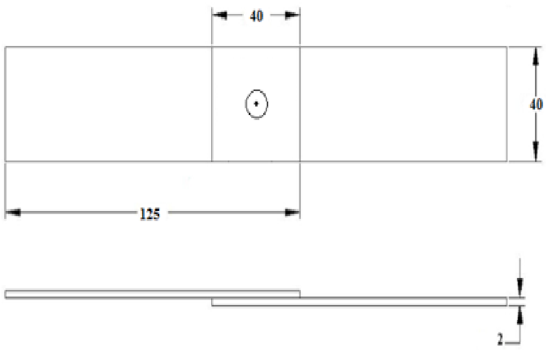


Figure 2. FSSW specimen size scheme

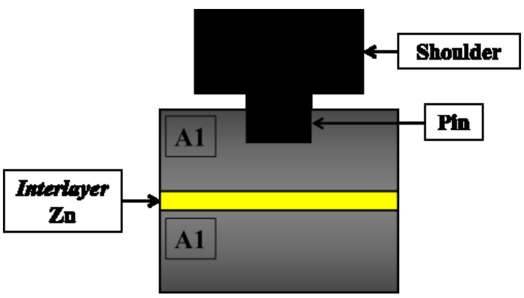


Figure 3. Zn interlayer placement scheme

Each specimen with and without Zn interlayer is welded in the middle of the plate as shown in Figure 2. The parameters used are rotational speed of 1000, 1250, 1600 rpm and dwell time of 6, 7, 8 s. Tensile testing is carried out as in Figure 4. The tensile speed used is in accordance with the JIS Z 3136 standard [26] which is a constant of 1 mm / min.

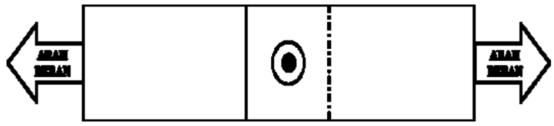


Figure 4. Schematic of tensile shear load test

Macro structure testing is conducted to observe FSSW joint zones and hook defects at each variation of rotational speed and dwell time. Allegations of Zn flow that spread on FSSW joints will be proven with SEM and EDS testing.

RESULT AND DISCUSSCION

a) Macro Photo Result Data

The macroscopic observation showed that there was a dark color in the metallurgical bonded zone (MBD) area which was suspected to be the Zn interlayer which was mixed by the pin and spread to the edge of the keyhole. The round of the pin makes the two materials mix, so that the material flow around the pin is formed [27]. Figure 5 (a) shows the detailed image of the keyhole, while Figure 5 (b) shows the MBD area around the keyhole and the hook defect in the partially metallurgical bonded zone (PMBD) area.

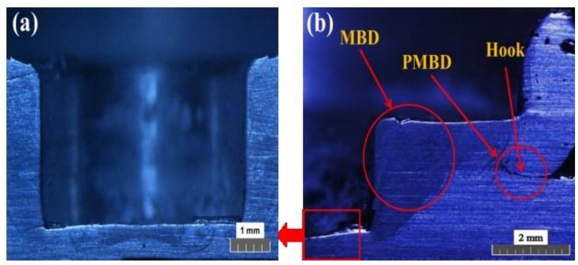


Figure 5. Material Flow in Regions (a). Under Keyhole; (b). MBD and Hook Defect

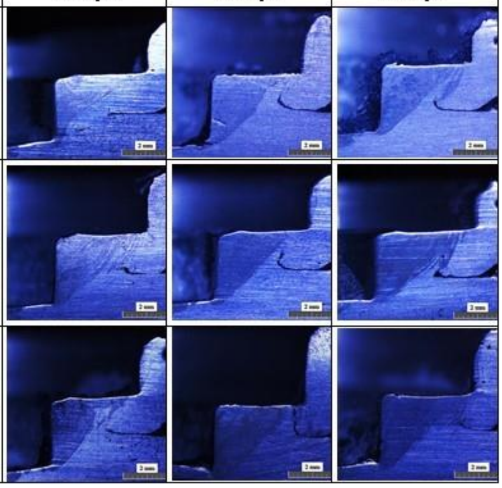
Pinning and tool presses during the welding process cause the heat input to become large and the MBD area is expanding, thus increasing the size of the stirring zone and the bonding area of the two specimens as rotation speed increases [7]. As a result of the expanding MBD area, it will keep the PMBD area away where a hook defect is formed. The hook defect is formed due to the movement of material upwards when the tool performs the penetration process on the workpiece and becomes one of the factors that causes the joint strength to decrease significantly [22,27]. This can be avoided by using rotational speed parameters and dwell time, because the increasing rotational speed and dwell time the stir zone will be wider causing the hook defect to stay away from the keyhole [15].

Table 1 shows the effect of rotational speed and dwell time on the area of metallurgical bonded zone (MBD). The MBD area looks bigger and bigger with increasing rotational speed and dwell time. At dwell time 8 s, the MBD area increases as the rotational speed increases.

The wider MBD area causes the PMBD area to further away from the keyhole. This proves that increasing rotational speed and dwell time is effective to keep the hook defect from the keyhole. Variations in dwell time 8 s show the largest MBD area and the PMBD area is the furthest from the keyhole as in Table 1.

Table 1. Zn flow in weld area with Zn interlayer

Variasi		Kecepatan Putar		
		1000 rpm	1250 rpm	1600 rpm
Dwell time	6 s			
	7 s			
	8 s			



b) SEM and EDS Test Results Data

Figure 6 (a) shows the results of the sem test on variations without Zn interlayer, while Figure 6 (b) shows the results of the sem test on variations with the Zn interlayer.

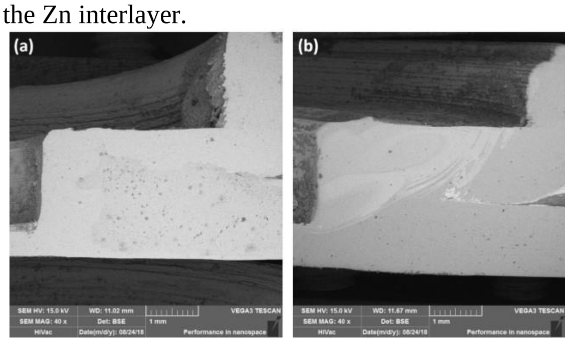


Figure 6. SEM test results: (a) Variations without Zn interlayer; (b) Variations with the Zn interlayer

In Figure 6 (a), the aluminium FSSW joint interface without Zn interlayer shows no color difference. This is because the absence of Zn element in the FSSW joint is in accordance with the EDS results in Figure 7. (b).

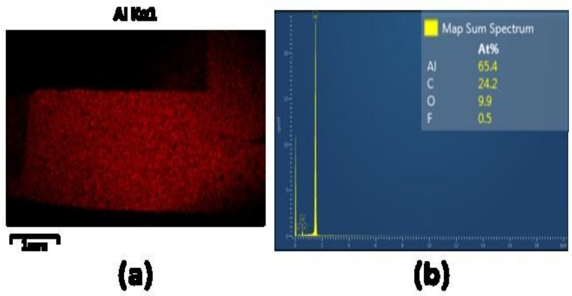


Figure 7. (a). Mapping test results on specimens without Zn interlayer; (b). EDS test results on specimens without Zn interlayer.

The Mapping test results in Figure 7 (a) also show the same thing, where the Al element almost dominates in interface area of welding joint.

A very clear difference is seen in the SEM test results with variations in Zn interlayer addition according to Figure 6 (b), namely the discovery of a white layer on the FSSW welding interface.

In EDS testing, the white layer was proven to be the Zn interlayer which was mixed during the stirring process according to Figure 8. Point number 1 had the highest Zn element as much as 18% and at point number 2 it contained 8.2% of Zn. The Zn element is still found in the gray layer shown by point number 3 with a content of 0.4%.

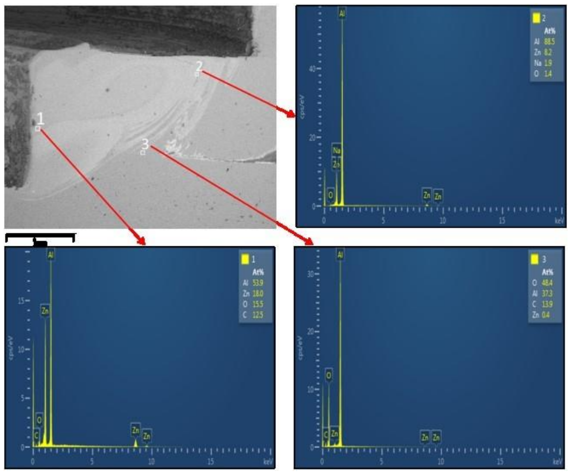
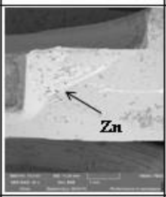
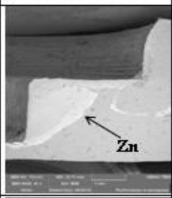
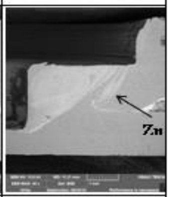
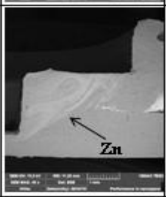
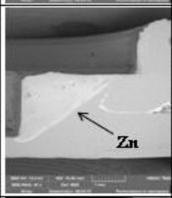
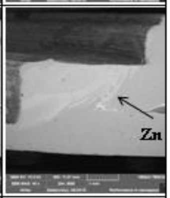
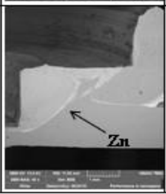
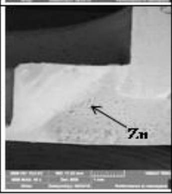
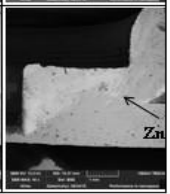


Figure 8. EDS test results on specimens with Zn interlayer

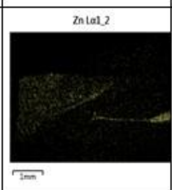
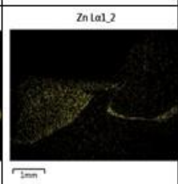
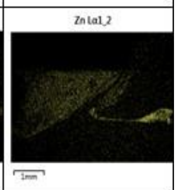
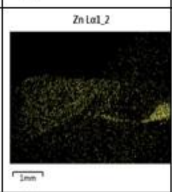
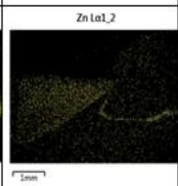
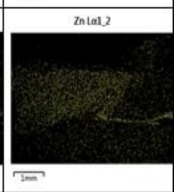
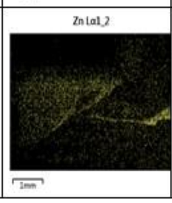
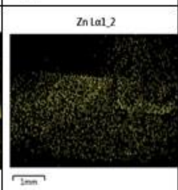
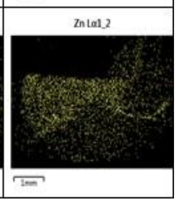
Dong, et al. [28] stated that the increasing parameters of rotational speed and dweel time cause the Zn element to be more scattered on the weld joint interface according to Table 2.

Table 2. Distribution of Zn in SEM observations

Variasi		Kecepatan Putar		
		1000 rpm	1250 rpm	1600 rpm
Dwell time	6 s			
	7 s			
	8 s			

The results of SEM observations on specimens with a speed parameter of 1000 rpm showed that there were only a few elements of Zn carried by the flow during the stirring process. The most abundant distribution of Zn elements is found in variations with a rotating speed of 1600 rpm and dwell time 8 s. This is in accordance with the observations of the mapping test results in Table 3.

Table 3. Distribution of Zn in Mapping test observations

Variasi		Kecepatan Putar		
		1000 rpm	1250 rpm	1600 rpm
Dwell time	6 s			
	7 s			
	8 s			

Mapping test is done to show that the distribution of Zn elements that occur in the welding process is in accordance with the results of SEM and EDS observations. In Table 3, the distribution of Zn elements is evenly distributed in the interface of the aluminium FSSW welding results as the parameters of rotational speed and dwell time increase.

The distribution of the Zn element causes a diffusion process between elements of Al and Zn in a solid solution which is better as plastic deformation increases [29]. When plastic deformation increases, more and more Zn flow is spread to Al to form a solid phase of Al-Zn. This is indicated by the formation of the lamellar shaped grain structure in accordance with Figure 9 (a). Grain shape such as lamellar shows Al and Zn diffuse well, so that it can increase the strength of the welding joint marked by a significant increase in shear tensile strength [11,16,17]. Figure 9 (a) shows the results of SEM tests on the stir zone area with the addition of Zn interlayer. Figure 9 (b) shows the results of SEM tests on the stir zone area without the addition of Zn interlayer. Variations without Zn interlayer have darker grains compared to variations with the Zn interlayer due to the absence of Zn elements in the welding interface area.

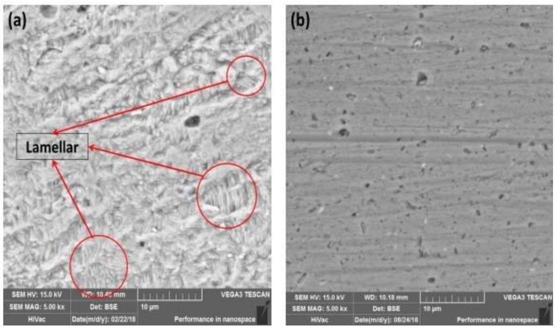


Figure 9. SEM Test on the Zone Stir Area (a) Variation with the Zn interlayer, (b) Variation without Zn interlayer.

Hook defects also appear in the PMBD joint area because of the flow of material moving upward when the tool penetrates the material. Figure 10 shows the hook defects in variations without Zn interlayer addition. Long hook defects will increase the PMBD area. When the PMBD area increases, the stress concentration will also increase causing crack to appear along the PMBD area [30]

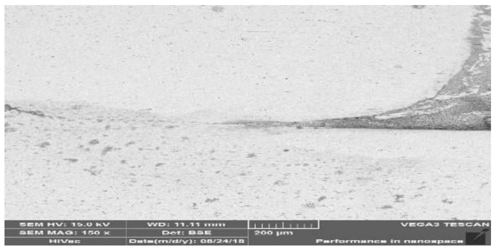


Figure 10. Hook defects in Zn interlayer joints.Zn

The results of the EDS test in Figure 11 also show that in the weld joint of FSSW aluminium without the addition of Zn interlayer is not found a Zn element in the hook defect area, so that the hook defect is still in the sharp form resulting in a large stress concentration. Large stress concentrations in the hook defect area cause cracks to spread to the upper and lower material. This is one of the problems that can cause the connection strength to decrease [31].

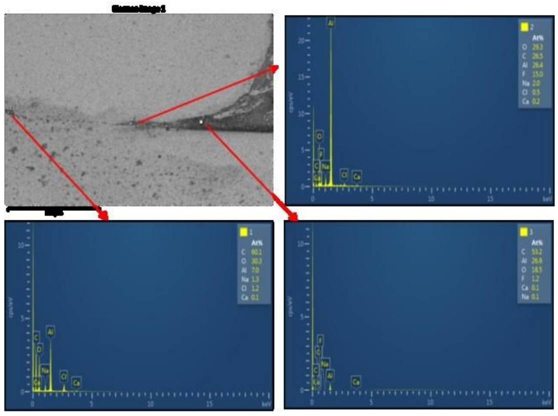


Figure 11 EDS test results on Zn interlayer without joint in the hook defect area

These problems can be overcome by the addition of Zn interlayer in each rotational speed variation and dwell time, so as to minimize cracks that occur in weld areas. The defective shape of the hook filled with the Zn interlayer will be blunt and shorter, so the stress concentration on the hook defect is smaller. When the hook defect is shorter it will increase the shear tensile load on the weld area [32]. So that the strength of the joint is influenced by stress concentration, mechanical properties of the material, and load.

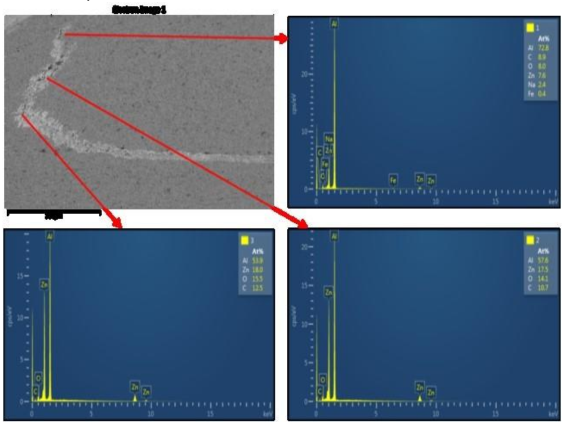


Figure 12. EDS test results on the joint with Zn interlayer in the hook defect area

EDS test results on variations with the addition of Zn interlayer are shown in Figure 12. At point 3, the highest Zn element content is 18%. At point number 2 has 17.5% of Zn elements. The least Zn element content at point 1 is 7.6% because this point is the farthest point from the MBD area. Table 4 shows that the hook defects are increasingly filled with Zn interlayer with increasing rotational speed and dwell time. With increasing rotational speed and dwell time making the stir zone area wider and the Zn flow more evenly distributed on the interface area to the hook defect area, so that the hook defect is filled with Zn and further away from the keyhole. The hook defect filled by the Zn interlayer causes the stress concentration to be small so that the crack can be avoided.

Table 4. SEM Test Results on Hook Defects

Variasi		Kecepatan Putar		
		1000 rpm	1250 rpm	1600 rpm
Dwell time	6 s	Zn	Zn	Zn
	7 s	Zn	Zn	Zn
	8 s	Zn	Zn	Zn

c) Tensile Shear Load Test Results Data

Tensile test results show that the increase in rotational speed and dwell time, the greater the drag pull. Figure 13 shows the effect of rotational speed and dwell time on the drag shear load of the joint without Zn interlayer and with the addition of Zn interlayer. The highest shear tensile load was obtained when the rotational speed was 1600 rpm and rotated and dwell time 8 s on the Zn interlayer without variation was 3.61 kN and the variation with the Zn interlayer was 4.34 kN.

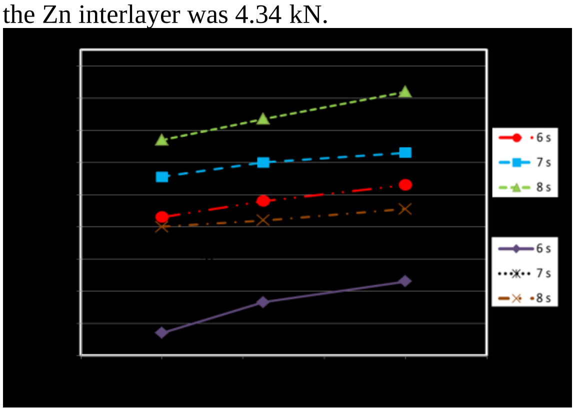


Figure 13. Graph value on tensile shear load of AA 1100 welding joint without Zn interlayer and with Zn interlayer

Increasing rotational speed and dwell time cause greater stirring, so the lower material and Zn interlayer also lift up so that the area of the stir zone increases. The stir zone area increases, the MBD area also increases. The small MBD area causes the joint to break and the tensile strength becomes small [33,34].

Hook defects are one of the factors that causes the strength of the joint to be low. This is supported by the results of the EDS test in Figure 11, where the hook defect seen in the specimen without the addition of Zn interlayer is still pointy because there is no Zn element that fills the cavity in the hook defect which causes the stress concentration to occur. Shear pull load increases with the addition of Zn interlayer.

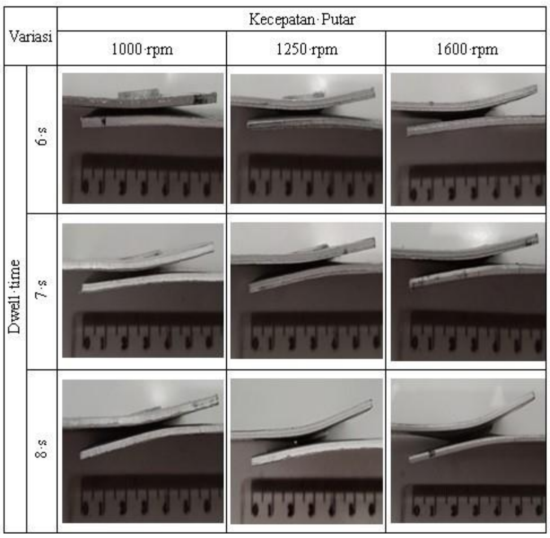
Table 4 shows that the hook defects filled with Zn are better with increasing rotational speed and dwell time. The hook defect filled by the Zn interlayer produces a small stress concentration. Small concentration of concentration causes strength to increase. The hook defect also keeps away from the keyhole due to the expanding MBD area so the shear pull load on the joint also increases. The MBD area increases means that the nugget also enlarges so that the fracture can be minimized [31].

With the increase in the MBD area, the spread of the Zn element will also be wider causing more and more solid solutions to be formed between Al and Zn. In accordance with the results of the Mapping test in Table 3, the Zn element is evenly spread over the weld interface area. Figure 9 (a) shows the shape of the lamellar structure which shows that Al and Zn diffuse well. Xu, et al. [1] stated that the addition of Zn interlayer functions to increase joint bond, so that the joint strength increases.

The greater rotational speed helps the diffusion reaction between Al and Zn thereby increasing the strength of the joint. The more solid solution that occurs causes the solid phase of Al-Zn, so that the grain formed will become more fine. Fine grains will further inhibit the movement of dislocations when subjected to mechanical loads [24]. So that the joint strength will increase. Table 5 shows the results of tensile tests on specimens without the addition of Zn interlayer.

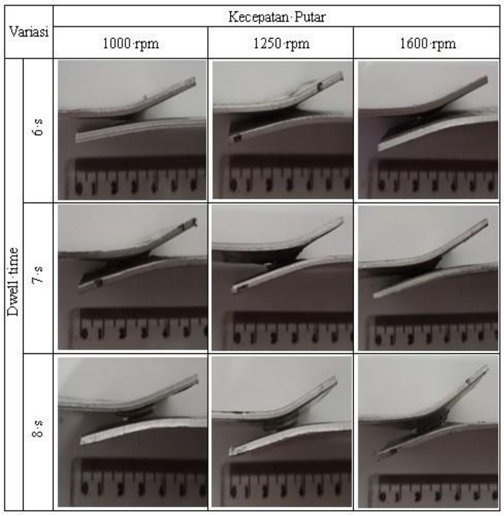
Fracture that occurs are pullout fracture which are getting bigger along with increasing rotational speed and dwell time parameters. This is because the greater the rotation speed and dwell time will produce a maximum shear tensile load [33].

Table 5. Pullout fracture on welding joint without Zn interlayer



The biggest pullout fault occurs in specimens with rotational speed variations of 1600 rpm and dwell time of 8s. Tensile test results on the specimen with the addition of the Zn interlayer are shown in Table 6. The type of fault that occurs at the FSSW joint with the Zn interlayer is the same as the type of fault that occurs in the joint without the addition of the Zn interlayer, the pullout fault. FSSW joint with Zn interlayer addition has a pullout fracture type that is greater than the variation without Zn interlayer, due to the addition of Zn interlayer. This is supported by Liu et al. [21] who stated that shear strength increased well in the diffusion-bonding case of Mg and Al with the addition of Zn interlayer.

Table 6. Pullout fracture on welding joint with the Zn interlayer



Variations in Table 6 have a pullout fracture that is greater than the variation in Table 5. For example, the rotational speed of 1600 rpm and dwell time 8 s have significant differences. This shows the influence of Zn interlayer in increasing joint strength.

CONCLUSION

The conclusions obtained from this study are as follows:

1. *Metallurgical bonded zone* area increases with increasing rotational speed and dwell time so that the hook defects move away from the weld point. Al and Zn can diffuse in a solid solution and form finer grains with increasing rotational speed and dwell time. AA1100 joint with Zn interlayer addition has finer grain than AA1100 joint without Zn interlayer addition. Interlayer Zn also managed to fill the hook gap so that the hook defect decreased.
2. Tensile shear load of welding joint increases with increasing rotational speed and dwell time. There was an increase in tensile shear load on AA1100 weld joint with Zn interlayer addition compared to AA1100 weld joint without Zn

interlayer addition. Interlayer Zn is effective in increasing the tensile shear load so that the joint strength also increases.

Daftar Pustaka

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