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The Effect Of Friction Spot Stir Welding In Installing Rivet Double Cover Lap Joints On 7075–T6 Aluminum Plate On Shear Strength

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Abstract

Friction Spot Stir Welding (FSSW) is a variation of Friction Stir Welding(FSW) developed in metal processes. The principle of FSSW is rotating an object that is wear-resistant and then rubbed with a plate joint. The use of FSSW can be utilized in the installation of rivets such as in the drilling process, so this process needs to be investigated. This is because the heat caused by rotation will change the mechanical properties of the material so further research is needed. In this study, a connection performance comparison was made between the FSSW method and the drill. The plate used is aluminum 7075-T6 with a lap joint connection type. To find out each performance, a shear test, hardness test, and metallographic test were carried out. From the results of the shear strength test, it can be concluded that the FSSW variation is the best with an average shear strength value of 755.190 MPa, while the drill variation has an average shear strength value of 470.227 MPa. The average value for drill variations in the Heat Affected Zone (HAZ) area was 185.06 while for the FSSW variation, it only reached 147.75. The macro test results proved that the cause of the shear strength in the FSSW was greater than that of the drill, this was caused by the difference in the size of the rivet diameter due to the use of a bad rivet gun. Meanwhile, based on the results of micro photos, the size of the structure in the HAZ area will be relatively longer than the RAW section, this is caused by friction between the tool and the workpiece.

Keywords:
FSSW, rivet, aluminum, shear, metallographic.

1 Introduction

The use of metal materials is currently increasing rapidly. This is because metal materials have good mechanical properties and resistance to certain loads. Metal as a structural material has been widely used in the industrial sector[1].The selected material usually has the provisions of being easy to manufacture, good mechanical properties, and corrosion resistance. One metal with these characteristics is aluminum. Aluminum is widely used in preparing aircraft structures, one of which is aircraft skin [2].

Airplane skins are made from metal that is rust-resistant and has good environmental resistance so that it can provide good performance. The metal that is widely used in aircraft is aluminum. Aluminum is used because it has the advantages of being easy to manufacture, corrosion resistance, and relatively good mechanical properties [3]. Apart from that, aluminum has a relatively light mass so the load lifted by the aircraft is lighter.

The process of connecting aircraft skins using rivets [4]. Installing rivets on aircraft usually uses a rivet gun which has been set to a certain pressure. The use of rivets has the advantage of being easy to install and having sufficient strength to accept external loads from the aircraft. However, the use of rivets will give the surface of the skin a protrusion from the rivet head which will increase the drag force. Based on this, it is necessary to have a connection between aircraft skins that is smoother but still has good strength. One method that can be used is using Friction Stir Spot Welding (FSSW) [5].

The connection technique using rivets places a rivet nail which will be tightened against the joint so that it can bind the joint firmly. Mechanically, ordinary rivet joining does not change the material properties of the material being joined, unlike welding which can change the properties of the material being welded [6]FSSW is a development of Friction Stir Welding (FSW). The difference lies in the rotational movement of the welding tip. FSSW will rotate and move downwards until it reaches a certain limit and then rises. Meanwhile, in FSW the rotation of the welder will go down, and then move to the side according to the part to be joined. In principle, it is almost the same, namely heating the two metals to be connected so that they reach the melting point and fuse. This research requires a connecting process[7] using double rivets to combine 7075-T6 aluminum plates with a lap joint configuration, then the plates will be drilled and FSSW processed.

2 Research Methods

2.1 Aluminum and Alloy

Aluminum is a type of metal that has good corrosion resistance and mechanical properties. Apart from that, aluminum is also easy to manufacture so it is widely used in transportation and industry.Aluminum is widely used because it has the advantage of being light, aluminum weighs 1/3 of iron [2]. So it is suitable for needs in the transportation sector. When interacting with air, aluminum will produce a layer of self-protection against corrosion. Corrosion resistance can be increased by anodizing. Easy to manufacture because it has high malleability, aluminum can be made in various shapes. Thus it will be suitable for complex construction. Aluminum is non-toxic and has virtually no odor.

The aluminum surface is easy to clean so it can be used as a cooking tool. It does not react with magnets, because of this property aluminum can be applied in making compasses, antennas, and computer components. Conductive to electricity, aluminum is usually used in making the inside of cables. Suitable in low temperatures, in low-temperature conditions aluminum will increase tensile strength and is not brittle. So aluminum can be used in extreme conditions. Easy to recycle, because it has a low melting point. These advantages make aluminum develop rapidly for use in making certain structures. Because the material has relatively low properties, aluminum is often combined with other materials.

2.2 SeriesAluminum Composition7075-T6

According to research conducted by [8]7075-T6 series aluminum is wrought type aluminum.The chemical composition content of aluminum is around 91.18%, with this content the mechanical properties of 7075 series aluminum as the main material. The use of 7075 series aluminum material according to [9]found in aircraft structures that have high strength.

2.3 Friction Spot Stir Welding

FSSW is a variation of FSW which was developed to replace the role of rivets. The principle of FSSW is to rotate an object that is resistant to wear and then rub it against the plate joint. The result of this friction will cause the material to become plastic and will interact with other plates to continue to be rotated until they blend perfectly.

The FSSW process consists of 3 stages, namely plunging, stirring, and retracting. The main component in the FSSW process is the shoulder tool which will rotate because it is connected using a milling or drilling machine. An illustration of the FSSW process is in Fig.1[6].

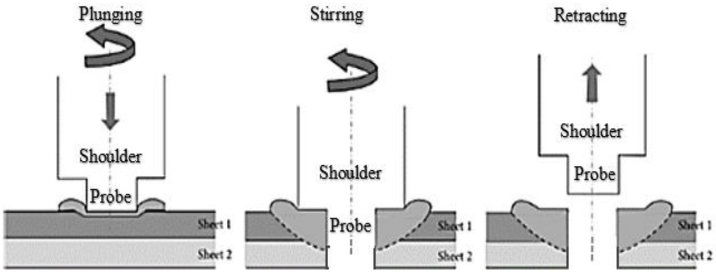


Fig. 1. FSSW Process.

Plunging in this process is carried out by dripping on the surface of the material which has been clamped at the ends so that it does not move when interacting with the rotating shoulder tool. This process aims to facilitate the process of inserting the probe. Stirring is the main process in FSSW, the probe will be fully inserted and will be held for some time (dwell time) to ensure the two plates can be connected. Retracting is the final process in FSSW, namely retracting, the shoulder tool which has interacted sufficiently with the plate will be pulled upwards.

On the shoulder tool, there is a probe as in Fig. 2. which functions to make holes in the plate and which will carry out the stirring process.

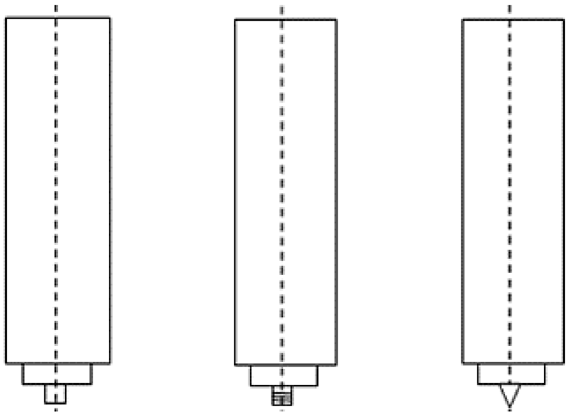


Fig. 2. Probe shapes[10].

After the FSSW process is carried out, there will be several zones if observed at the micro level. The zones are as shown in Fig 3.

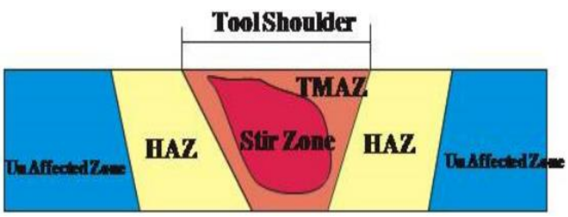


Fig. 3. FSSW result zone [10].

The results of the FSSW microphotographs are in Fig. 3and an explanation from Fig. 4 namely:

a. Unaffected zone/based metal/parent metal

This zone is not affected by heat due to the stirring process on the plate. So the properties of the material are still the same as before the stirring process occurred.

b. Heat Affected Zone (HAZ)

This zone is the closest to the stirring location, so in this area, the material has undergone a thermal cycle and caused changes in the mechanical properties of the original material.

c. Thermo Mechanically Affected Zone (TMAZ)

In the TMAZ zone, which is the location where the stirring process occurs, the material will experience plastic deformation due to the heat generated by the rotating probe. The stirring process allows plastic stretching to occur but without recrystallization or weld nuggets.

d. Stir zone

This is the location where the probe will rotate and interact with the material. At this location, there is also a flow arm zone which is the impact of soft material being dragged by the probe.

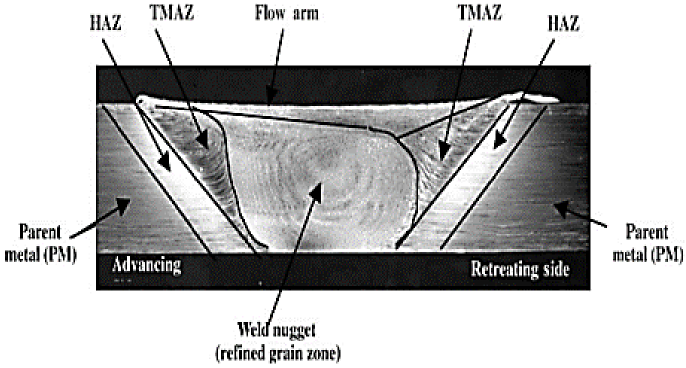


Fig. 4. Macro photo results of the FSW zone [10].

2.4 Connection Method

Splicing of materials aims to connect the materials to form a structure so that the separate materials can be united as strongly as if they were one unit. The types of connections in materials according to [6] include riveting, Tungsten Internal Gas (TIG), Friction Stir Welding (FSW), Metal Internal Gas Welding (MIG), and bolts.

In the welding process, there are several types of connections, each connection has its characteristics. According to [11]the types of welded joints are butt joints, T-joints, lap joints, corner joints,s, and edge joints. The pictures of the types of welded joints are in Fig.5.

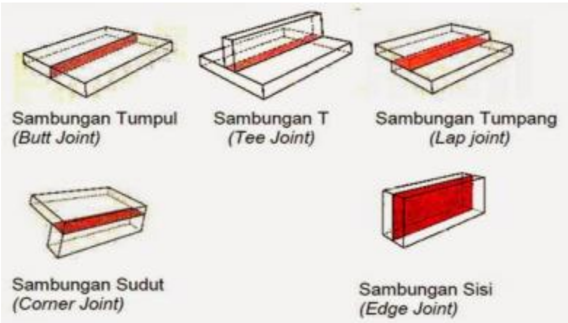


Fig. 5. Types of welded joints.

2.5 Rivets

Riveting is a method used to connect plates of material using a rod that has a head. Connections using rivets are used once, and cannot be reused. If you want to remove a rivet, you have to damage the rivet.Rivets can be made of aluminum, bronze, copper, nickel, and steel [6]. In this study, universal head-type rivets with the MS20470 series were used, an explanation of the rivets is in Table 1.

Table 1. Description of series rivets MS20470

Item	Description
Stem length	10.87 mm (min) and 11.37 mm (max)
Head type	Universal
Head height	2.36 mm (min) and 2.61 (max)
Stem diameter	5.53 mm (min) and 5.66 (max)
Shear strength	26000 Psi
Heat treatment	T-4
Material	Aluminum alloy 2117

There are several configurations for installing rivets with the aim ofa certain strength. The types of rivet configurations are in Fig. 6. In this study, a double riveted lap joint configuration was used. The more rows of rivets will of course increase the structural strength of the connection.

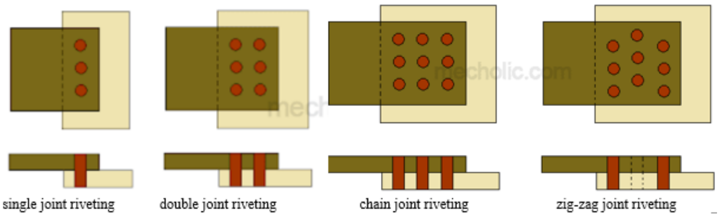


Fig. 6. Rivet configuration [12].

2.6 Shear Test

The shear test is a test on a particular specimen by applying an axial force perpendicular to the specimen. The principle of the shear test is almost the same as the tensile test, one end of the specimen will be clamped and then the other end will be pulled until the specimen fails.The shear test aims to obtain values of shear strength, yield strength, and characteristics of the fracture that occurs [6]. These values are obtained from the shear test equipment which already has its calculation system. However, basically to find out the shear strength value can use Eq. 1.

$$\sigma = \frac{P}{A_0} \quad (1)$$

where:
σ :shear strength (MPa)
P : shear load (N)
A_0 : cross-sectional area (mm^2)

The graph of shear test results produced after testing has the basic principle of a stress-strain curve graph. The graph can represent the mechanical properties of the material being tested (Fig. 7).

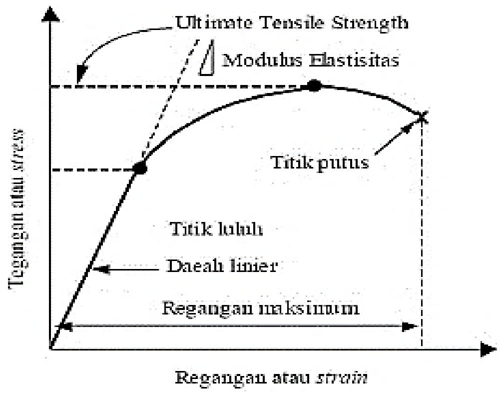


Fig. 7. Stress-strain curve.

The linear region is the region where the relationship between strain and stress is still linear. So the higher the strain, the higher the stress will be. The yield point is the transition point for changes in material properties, namely elastic to plastic. Ultimate tensile strength is the maximum stress that can be achieved by a test specimen. The modulus of elasticity is the ratio between maximum stress and maximum strain. So it can be interpreted as the maximum stress at each strain that occurs in the specimen. The breaking point is the condition where the specimen fails or breaks so that the graph reading will be completed.

2.7 Hardness Test

Hardness testing is a method of testing materials by pressing an indenter until the specimen experiences point damage. Three types of identifiers can be used as shown in Fig. 8, Fig. 9 and Fig. 10[13].

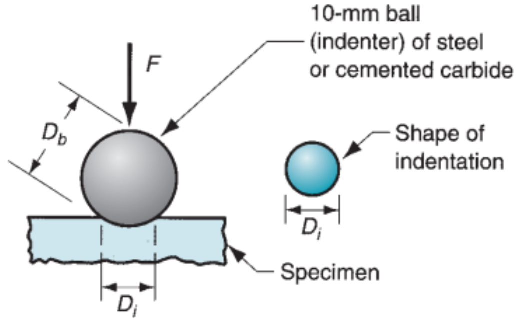


Fig. 8. Indenter hardness Brinell test[13].

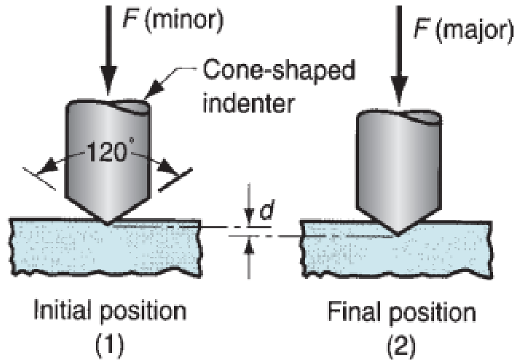


Fig. 9. Indenter hardness Rockwell test [13].

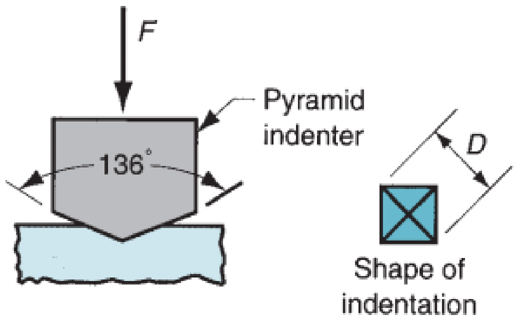


Fig. 10. Indenter hardness Vickers test[14].

This research carried out hardness testing using a pyramid indenter. To determine the hardness of a material using the Vickers method is in Eq. 2[15].

$$VHN = \frac{1{,}8544P}{d^2} \quad (2)$$

where:
VHN :vickers hardness number (HV)
P :load (kgf)
d :diagonal width (mm)

2.8 Metallurgy

Metallography is generally used to visualize certain areas, to determine the condition of the metal. In general, metallographic testing is divided into two, namely macro and micro tests. Macrostructural testing can use a camera with high magnification so that the area to be visualized can be seen clearly.

2.9 Design

The research was carried out using experimental methods, researchers made specimens from 7075-T6 aluminum plates which would be connected using rivets in a double configuration. The method that will be used is drill and FSSW, the type of connection used is lap joint. The finished specimen is subjected to shear testing until the specimen fails or the joint breaks. In this way, the mechanical strength of the connection that has been made will be known. The broken joints are then subjected to hardness testing to determine the differences in hardness in each area affected by the FSSW effect. Metallographic tests in the form of macro and micro tests are carried out to see the joints in detail.

2.10 Specimen Preparation

Prepare the necessary tools and materials, cut 7075 T6 aluminum plate according to the dimensions in Fig. 11.

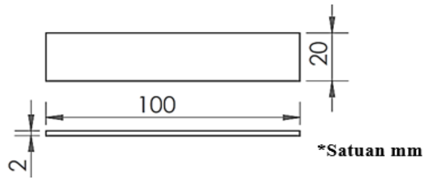


Fig. 11. Plate dimensions.

Drilling into the plate according to Fig. 12.

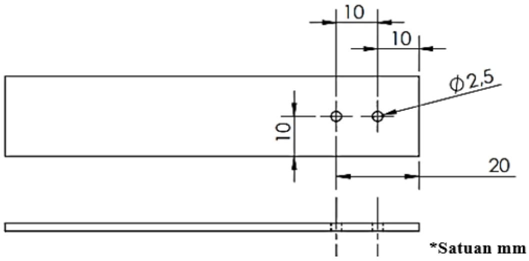


Fig. 12. Hole position.

Connecting two plates using a double rivet with the help of a rivet gun and a lap joint connection type. The rivet configuration is in Fig. 13.

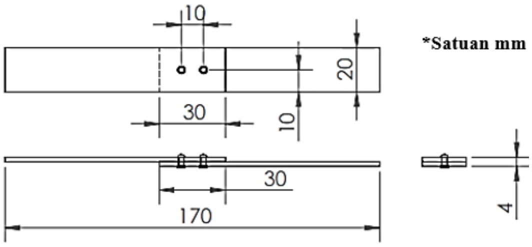


Fig. 13. Rivet installation position.

Install the shoulder tool with a probe size of 2.5 mm on the milling or drilling tool according to Fig. 14.

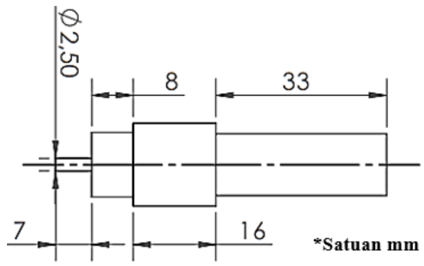


Fig 14. Tool shoulder dimensions.

Clamps the side of the plate and provides support on the bottom surface of the plate. The position of the FSSW process is as in Fig. 15. The FSSW process is carried out on each rivet.

After completing the stirring process, the probe is removed. The next process is installing the rivets using a rivet gun. The steps used in the drilling method are the same as the FSSW process, only the workpiece is replaced using a drill bit.

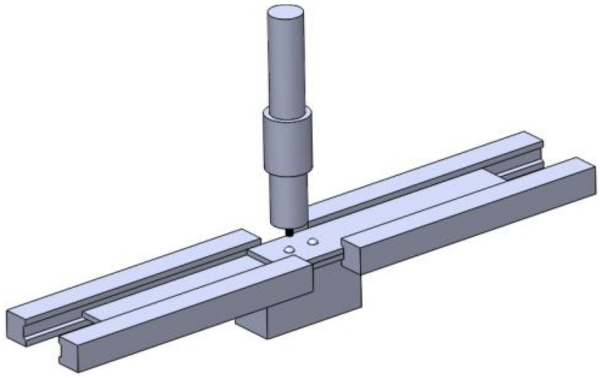


Fig. 15. FSSW process position.

2.11 Testing Phase

The testing stages in this research are the process of installing rivets which have been confirmed to be perfectly connected, followed by shear testing. One end of the specimen is clamped in the vise of the tensile testing tool and the other end is clamped in the puller. Position during the tensile test, namely as in Fig. 16.

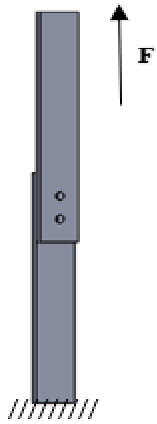


Fig. 16. Position of the shear test specimen.

The specimen will be pulled continuously until the rivet connection fails. A computer connected to the tensile tester will record data during the test. After the tensile test is complete, the next step is to cut half of the plate being tested for hardness and metallographic testing. Minimize the cuts around the rivet joints, then insert them into the resin. The purpose of giving resin is to make it easier for micro-test equipment to capture images of joints.

3 Results and Discussion

3.1 Shear Test

The results of shear tests on drill variations are in Table 2. From the Table 2, it can be seen that the best specimen with the highest shear stress value is drill specimen 2 with a value of 491.223 MPa. Overall, the average result of the drill variations has a maximum shear stress of 470.227 MPa.

A summary of the shear test results of the FSSW variations is in Table 3. The best specimen is found in FSSW 3 with a shear stress value of 872.507 MPa. Overall, the FSSW variation produces an average maximum shear stress of 775.190 MPa.

Table 2. Shear testing of drill variations

Specimen	Test No	Diameter (mm)	Sectional area (mm^2)	Maximum point load (N)	Shear stress maximum point stress (MPa)
	1	2.5	4.91	2369.346	482.924
Drill	2	2.5	4.91	2410.114	491.233
	3	2.5	4.91	2141.692	436.523
			Average		470.227

Table 3. Shear testing of drill variations

Specimen	Test No	Diameter (mm)	Sectional area (mm^2)	Maximum point load (N)	Shear stress maximum point stress (MPa)
	1	2.5	4.91	3184.020	648.972
FSSW	2	2.5	4.91	3650.696	744.091
	3	2.5	4.91	4280.738	872.507
			Average		470.227

A summary of the results of the FSSW variation shear test is in Table 17. The best specimen is found in FSSW 3 with a shear stress value of 872.507 MPa. Overall, the FSSW variation produces an average maximum shear stress of 775.190 MPa.

Fig. 17 shows the results of shear tests for the FSSW and drill variations. It appears that there is a comparison between the FSSW and drill specimens. The maximum stress value for the FSSW variation has a stress value of 872.507 MPa, while the drill variation has a maximum stress value of 491.223 MPa. The difference in results is due to other factors that cannot be known in the manufacturing process.

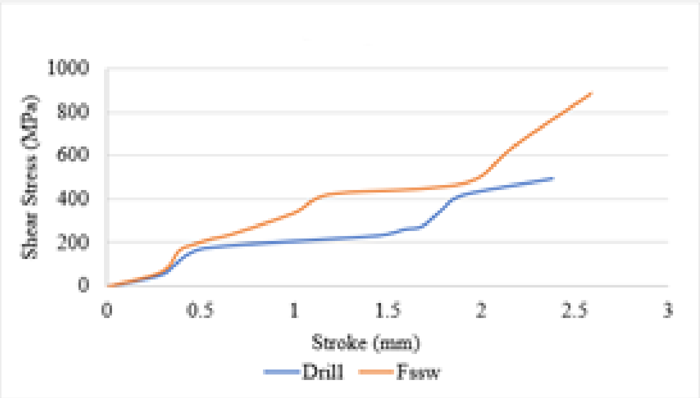


Fig. 17. Shear test results of FSSW and drill variations.

From the shear test results, it can be compared between variations. The comparison of shear stress is in Fig. 18. In this figure, the FSSW variation has a higher shear stress than the drill variation. This is also the same as the results of research conducted by [12]which proves that the FSSW variation is better than drill. Meanwhile, the strain ratio that occurs is not too different, so the FSSW variation in terms of shear testing is better than drill. These results prove that the result of friction between the tool and the workpiece can influence the shear strength value, due to the heat that occurs, which will change the structure of the workpiece.

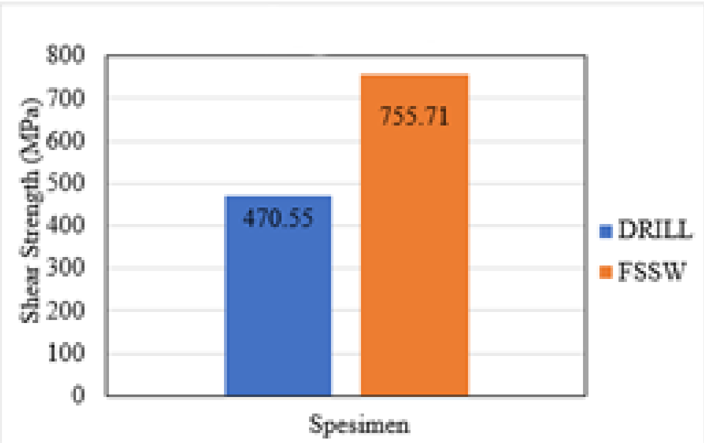


Fig. 18. Shear test results of FSSW and drill variations.

3.2 Hardness Tests

The hardness test results are in Table 4. From the hardness test results in the VHN area, the drill variation has a higher average value than the FSSW variation. Then, in the HAZ area or areas that experience heat due to the tool and workpiece rubbing together, the VHN value is also higher in the drill variation. The effect of the process of installing rivets on plates using a rivet gun. Overall, the average hardness of the drill variation has a VHN value of 185.06, while the FSSW variation is 147.75. So the drill variation in terms of hardness is better than the FSSW variation. In Fig. 19 there is a bar graph to make it easier to differentiate the hardness results between variations.

Table 4. Hardness testing results

Varieties	Spec	d1(μm)	d2 (μm)	d (μm)	d (mm)	VHN	Average
HAZ FSSW	1	33.5	34	33.75	0.0338	162.77	147.75
	2	37.5	36.5	37	0.0370	135.43	
	3	35.5	36	35.75	0.0358	145.06	
HAZ DRILL	1	30.5	30.5	30.5	0.0305	199.30	185.06
	2	29	29	29	0.0290	220.45	
	3	37	37	37	0.0370	135.43	

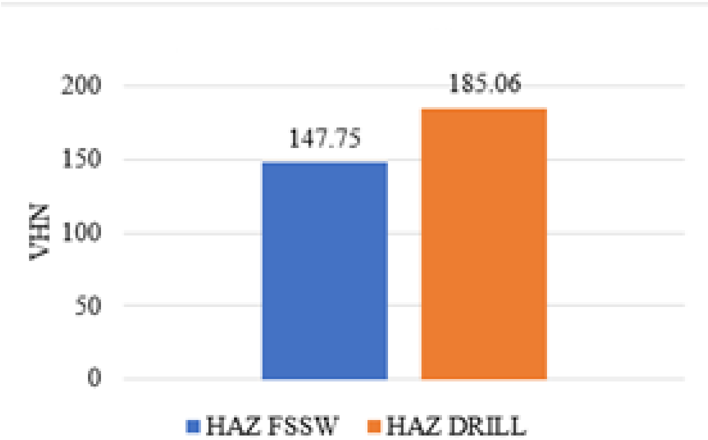


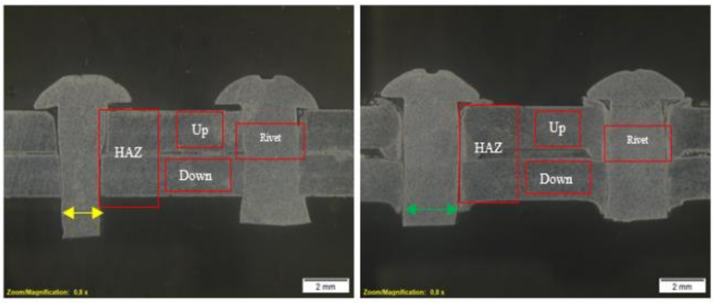
Fig. 19. Comparison of VHN values.

3.3 Macro and Microstructure

Fig. 20. is the result of installing the drill and FSWW methods. From the macro test results it can be seen that there is a difference in rivet size(Fig. 21). Drill variation, one of the yellow arrow rivets has a relatively smaller size compared to the other green arrow rivets. This is one of the factors that causes the shear strength in the drill variation to be smaller than the FSSW variation.

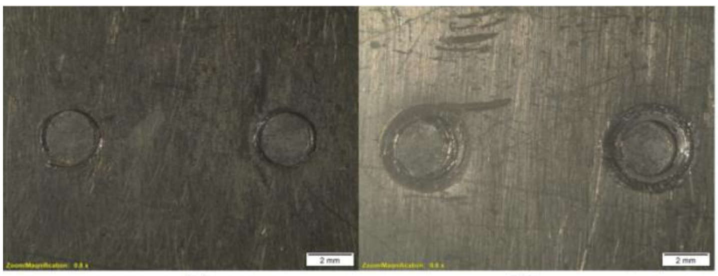
Fig. 20. Results of installing the drill and FSWW methods.

Fig. 22 is the result of a top-view macro photo, it can be seen that the FSSW variation has greater deformation in the rivet hole due to the reaction of the rivet when a load is applied. The deformation in the drill variation is smaller, this is following the shear strength results that the drill variation is smaller than FSSW. The relatively smaller size of the rivet means that before the rivet hole experiences deformation, the rivet will break first. This is different from the FSSW variation where the rivet causes deformation in the rivet hole.



(a) (b)

Fig. 21. Side view of macro test results (a) drill (b) FSSW.



(a) (b)

Fig. 22. Top view of macro test results (a) drill (b) FSSW.

Fig. 23 shows the results of micro photos in the RAW and HAZ areas for various drills. In the RAW area, the structural size is relatively shorter than in the HAZ section. This is because in the HAZ area, the workpiece experiences friction with the tool, which will change the size of the microstructure. It can be seen that in the HAZ area, the size of the microstructure is obtained using the formula, namely long 20 minus short 15 equals 5, this result divided by short 15 equals 0.3. This result multiplied by 100% equals 33%, where the HAZ area extends 33% from the BM structure than the RAW area. This is also due to direct friction between the tool and the workpiece.

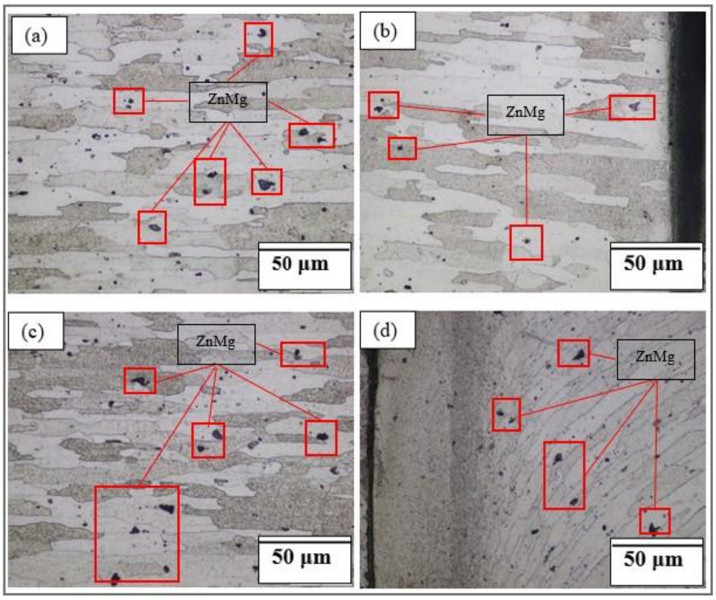


Fig. 23. Micro photo results of drill and FSSW variations.(a) Raw drill, (b) HAZ drill, (c) Raw FSSW (d) HAZ FSSW.

4 Conclusion

The shear strength test results, it can be concluded that the FSSW variation is the best with an average shear strength value of 755.190 MPa. Meanwhile, for the drill variations, the average value of shear strength reached 470.227 MPa. Thus, in connections, it is better to use FSSW rather than drill to maintain the shear strength value. The hardness test results show that the drill variation has a higher VHN value than FSSW. The average value for the drill variation in the HAZ area is 185.06, while for the FSSW variation it only reaches 147.75. This occurs because there is heat due to friction between the tool and the workpiece, which can change the structure of the material. In this case, the FSSW variation will reduce the hardness value more than the drill variation. The macro test results prove that the shear strength of the FSSW is greater than that of the drill, this is caused by the difference in rivet diameter size as a result of poor use of the rivet gun. Meanwhile, based on the results of micro photos, the size of the structure in the HAZ area will be relatively longer than the RAW section, this is caused by friction between the tool and the workpiece.

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