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# The Effect Of Friction Spot Stir Welding In Double Rivet Lap Joint Installation Of Aluminum 2024-T3 On The Strength Of Shear Tests

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**Abstract**

The process of joining materials is very necessary to facilitate the manufacture of industrial products. Among these connections are rivets, bolts, nails, glue, and welding which is mostly done on metal materials. The aircraft skin is usually connected with rivets through a drilling process. Joining metal materials, especially aluminum, uses many welding techniques.The welding method currently being developed is Friction Stir Welding (FSW). FSW developed the Friction Stir Spot Welding (FSSW) process in joining metals, especially in this study using 2024-T3 aluminum. The purpose of combining the rivet method with FSSW is to see the material's mechanical characteristics when applied to aluminum material. The FSSW method uses a 2500 RPM engine speed milling machine using a blunt tool holder with a pin dimension of 2.5 mm. It is carried out using a pneumatic drill using a drill bit with a dimension of 2.5 mm. Aluminum 2024-T3 has of 200×20×2 mmdimensions, a hole spacing of 15 mm with double rivet lap joint installation. The results showed that the FSSW variation had a higher tensile shear strength of 2.8% than the drilling variation. However, the hardness value in the drilling variation is 56.3% higher than the FSSW variation in the Heat Affected Zone (HAZ). Microstructural observations also indicate differences in the HAZ region, where the FSSW is reduced in size and longer. This is due to the heat treatment process due to friction between the pin tool and the aluminum, thus changing the structure.

**Keywords:**
FSW, rivet, FSSW, double rivet lap joint, AA 2024-T3.

## 1 Introduction

Safety factors in the aviation industry are the responsibility of manufacturers. So airplanes must withstand tensile, compressive, and fatigue forces. The aircraft structure must be light, strong, and sturdy. Aluminum is used because it is lightweight and has relatively low strength and corrosion resistance. Aluminum alloy 2024 is a material that is often used because of its high strength and low corrosion resistance. Aluminum is widely used in making aircraft structures, especially in the skin section [1]. Airplane skin is the outermost layer, which forms aerodynamic forces and protects the aircraft. The aircraft's surface is made of rust-resistant metal with good environmental resistance.

The rivet joining method joins materials to the aircraft skin and makes them stick together [2]. Rivets are pins used to join plates and other components. Good rivet joints can join materials together without cracking. Cracks in rivets can cause loose connections. Therefore, it is necessary to develop better connection methods. One method used is Friction Stir Spot Welding (FSSW) [3]. FSSW is a development of Friction Stir Welding (FSW). The difference lies in the rotational movement of the welding tip. FSSW is a welding method that uses a rotating tool (shoulder and pin) inserted into the joint of two workpieces. The tool moves in line with the joint slowly to produce a weld. The heat produced comes from friction between the rotating tool and the workpiece, so the material softens and is connected by a pin [4].

This research was carried out by connecting 2024-T3 aluminum plates using a double rivet configuration with the FSSW method. This research aims to determine the rivet strength and quality of FSSW connections. The research results are expected to provide an understanding of welding technology, increase insight into metal welding, especially aluminum, and determine the durability of the joining process using shear tests on 2024-T3 aluminum plates.

## 2 Research Methods

### 2.1 Aluminum and Alloys

Some of the characteristics of aluminum as a material are relatively lightweight, corrosion resistant, easy to manufacture, non-toxic, non-magnetic, conductive to electricity, resistant to heat, strengthened at low temperatures, can reflect light, heat and electrical waves, easy to recycle because it has a low melting point. Wrought aluminum is aluminum that is made by forging. Wrought aluminum alloys have a 4-digit number; the first number indicates the series of aluminum alloys used in its manufacture. If the number in the 1xxx series is zero (10xx), it indicates pure aluminum, whereas the numbers 1-8 indicate special regulations. An alloy different numbers for alloy groups 2xxx - 8xxx indicate blend changes. The last two digits mark the differences within each group, and the numbering is insignificant.

The information above is that there are two types of treatment on wrought aluminum; non-heat treatable and heat treatable. Non-heat-treatable means the material cannot be hardened by heating, while heat-treatable means it can be hardened by heat treatment. The treatment of aluminum is explained in Table 1.

Table 1. Aluminum treatment [1]

| Letter | Description | Information |
|---|---|---|
| F | As fabricated | Printing process without any hardening or heat treatment |
| O | Annealed | Heat treatment provides minimal strength, increasing relativity toughness |
| H | Strain hardened | Strengthening using cold work |
| W | Heat treated | Heat treatment but produces an unstable character |
| T | Heat treated | Heat treatment without any further strain hardening heat treatment |

### 2.2 Aluminum 2024-T3

Aluminum 2024-T3 is a type that is widely applied in the automotive sector. This type of aluminum is usually used in aircraft and used in skins. This type of aluminum is widely used in aircraft skins because it is easy to rivet [5]. The aluminum content 2024-T3 has the essential constituent ingredients(Table 2).

Table 2. Aluminum composition 2024-T3[6]

| Alloy type | Composition (%) |
|---|---|
| Silicon (Si) | 0.50 |
| Iron (Fe) | 0.50 |
| Copper (Cu) | 3.8 – 4.9 |
| Manganese (Mn) | 0.3 – 0.9 |
| Magnesium (Mg) | 1.2 – 1.8 |
| Chromium (Cr) | 0.10 |
| Zink (Zn) | 0.25 |
| Titanium (Ti) | 0.15 |
| Aluminum | Balance |

T3 series aluminum is heat-treatable aluminum and naturally cooled. Then, 2xxx aluminum combined with copper will have good properties, and good tensile strength.

### 2.3 Friction Spot Stir Welding (FSSW)

The principle of FSSW is that two objects rub together continuously to produce heat. This friction will cause an object to become plastic and interact with other plates to continue to rotate so that the plates unite perfectly. The work stages of FSSW are as in Fig. 1. The first is toll rotating; this process is the initial stage carried out on the FSSW work machine, namely the tool or bit will rotate first before touching the specimen[7]. The second is plungers, where in this condition the FSSW tool starts to touch the outside of the specimen and form a hole. The third, stirring works begin to go deeper through the first specimen and will combine the two aluminum pieces with melting, which is influenced by heat from the movement of the tool with the aluminum. The fourth drawing out is the final step, removing aluminum using the FSSW tool.

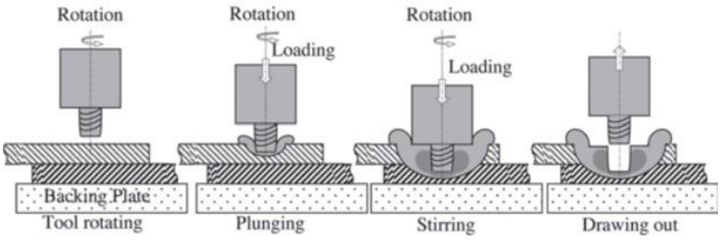


Fig. 1. Process friction spot stir welding[8].

### 2.4 Geometry ofFriction Stir Welding

The friction stir welding tool has two parts: the shoulder and the pin. The shoulder is a cylindrical part with a larger diameter than the pin. Meanwhile, the pin is a small cylinder located under the shoulder. Three tool surfaces can produce heat during the friction stir welding process, allowingthe metal joining process to occur. The shoulder tool consists of a triangular-shaped triangle with a diameter of 6 (mm) as seen in Fig.2[9].

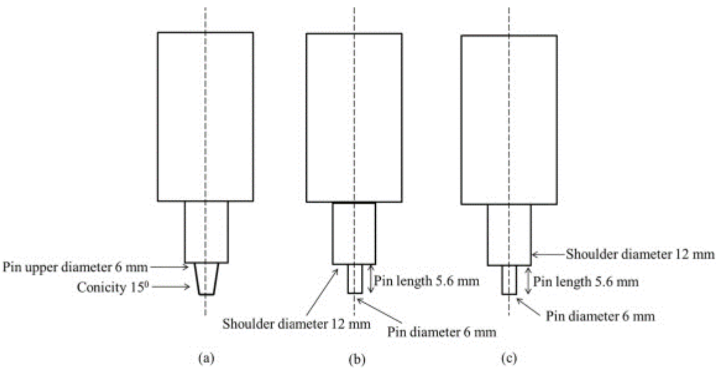


Fig. 2. Form of tool probeFSW[10].

Form of tool probe FSW as shown in Fig. 2 consists of: (a) straight cylindrical is a shoulder or pin that is circular and has a diameter of 12 mm, (b) square is a shoulder or pin from friction stir welding, which is rectangular and has a diameter of 12 mm, and (c) this shoulder is used to make holes in the aluminum plate which will carry out the stirring process.

### 2.5 Rivet

Rivets are pins that connect plates permanently so that if you want to open the pin installed, it must be damaged. Then, for its application, it is widely used in making iron connections on bridges and in aircraft skins. One type of rivet is a rivet. Rivets have a mushroom-like shape, where the shape of the nail head is semi-circular.

The advantages of this connection are that it is simpler, easy to inspect, and easy to open the nail by cutting the head of the rivet [11]. Rivets can also be treated with heating to bond firmly to the joint. The shape of the rivet head can distinguish rivets. This difference can differentiate the type of rivet and the rivet material used. There are two types of rivets generally used, namely universal heads and countersunk heads, as in Fig. 3. There are types of rivets. To understand the types of rivets, you must first know the forms of rivet head manufacturing, which are as shown in Fig. 3.

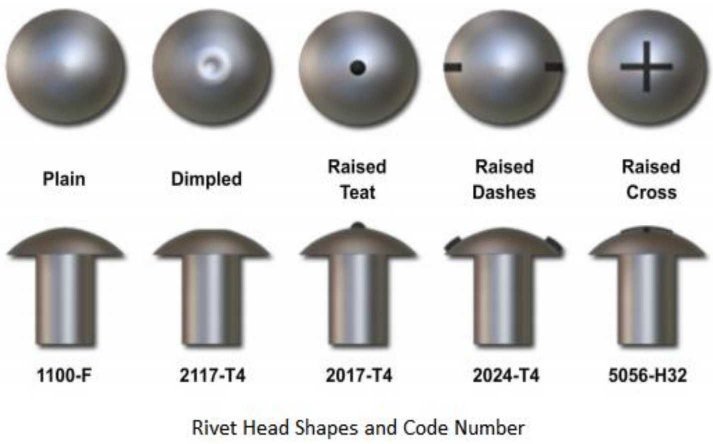


Fig. 3. Head universal rivet[12].

#### 2.5.1 Rivet Size and Drill Bit Size

The diameters of rivets and drill bits often used according to SRM are shown in Table 3.

Table 3. Rivet size and drill bit size

| Rivet dia (in) | Drill size | |
|---|---|---|
| | Pitot | Final |
| 3/32 | 3/32 (0.0937) | #40 (0.098) |
| 1/8 | 1/8 (0.125) | #30 (0.1285) |
| 5/32 | 5/32 (0.1562) | #21 (0.191) |
| 3/16 | 3/16 (0.1875) | #11 (0.191) |
| 1/4 | 1/4 (0.250) | F (0.257) |

#### 2.5.2 Description of Series Rivets MS20470

Description of series rivets MS20470are shown in Table 4.

Table 4. Description of series rivets MS20470

| Item | Information |
|---|---|
| Shear strength | 26000 single pounds per square inch |
| Heat treatment | T-4 solution heat treated overall |
| Material | Aluminum alloy 2117 overall |
| Material document and classification | Qq-a-430 fed spec single material response overall |
| Surface treatment | Anodize overall or oxide film overall |

#### 2.5.3 Rivet InstallationConfiguration

There are various types of riveting installation, including the double riveting lap joint configuration, as in Fig. 4. The more rows of rivets, the greater the strength of the connection structure.

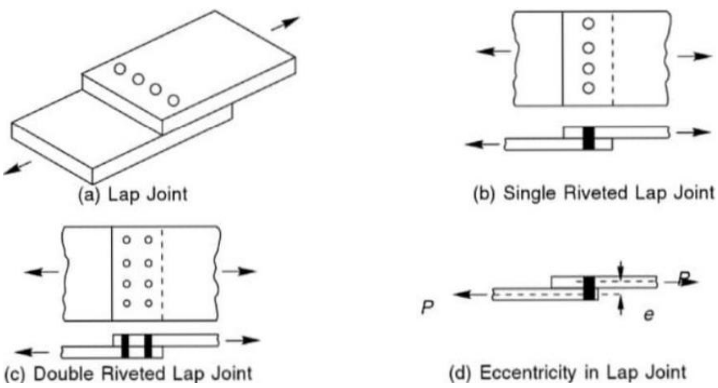


Fig. 4. Lap joint configuration [8].

## 2.6 Lap Joint Connection

A lap joint (overlapping joint) is a joint that consists of two objects or objects that are on top of each other as in Fig. 5.

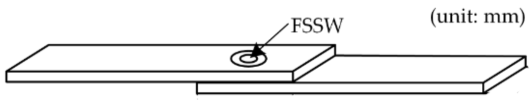


Fig. 5. Lap joint connection type [13].

## 2.7 Shear Test

The shear test is a test that is similar to the tensile test.The aim is to determine the tensile strength of the specimen to be tested. This test is carried out by holding one end and the other and pulling until the specimen fails. The shear test output is to determine the shear stress of the specimen being tested [14]. This test is carried out by applying a continuous load to the specimen.

This research uses a tensile test for shear testing on aluminum. The Eq.1 used in the shear test.

$$\tau = \frac{F}{A} \quad (1)$$

Where:

$\tau$ = Shear stress (MPa)

$F$ = Force (N)

$A$ = Surface area (mm$^2$)

## 2.8 Microstructural Observations

Microstructuralobservations are used to determine microphotographs of fractures in a specimen, as in Fig. 6. So, can be determined the interaction of the two plates connected using the FSSW method. The tool used to determine micro results is to use an optical microscope to view the section Thermo Mechanically Affected Zone (TMAZ), Heat Affected Zone (HAZ), Base Metal (BM), and Weld Nugget (WN).

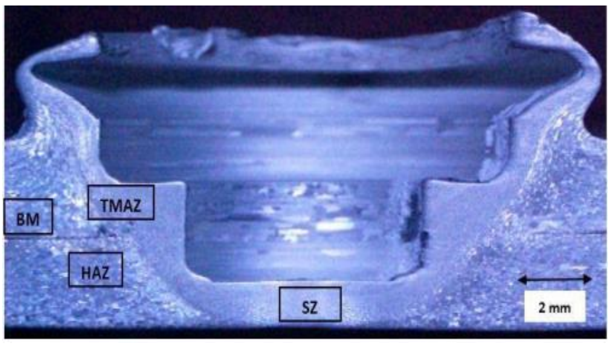


Fig. 6. Microphotographs of FSSW [15].

The explanation microphotographs of FSSW:

1. Base Metal/Parent Metal (PM) is a part of the work material that is not affected or deformed by the heat generated during the FSW process.
2. Heat-Affected Zone (HAZ) is the area closest to the center of the welding location and has experienced a thermal cycle during the welding process. The material in this area has undergone a thermal cycle which causes changes in the microstructure and mechanical properties of the base material.
3. The Thermo Mechanically Affected Zone (TMAZ) in this area of the welding tool deforms the material plastically of course, the heat produced during the welding process also influences the material. In hot aluminum materials, it is possible to produce plastic strains without a recrystallization process.Usually, a clear boundary differentiates between the recrystallization area (weld nugget) and the deformed TMAZ area.
4. The Steering Zone (SZ) is the fully recrystallized region around the tool pin. The grains in the mixing zone are approximately the same and often smaller than those in the parent material.

## 2.9 Hardness Test

A hardness test aims to determine a metal's hardness level. This test can determine the hardness value of a material or specimen.According to[16] there are three ways to test hardness:

a. Brinell

The Brinell test method is carried out by compressing a steel ball of hardened chrome steel to a diameter determined by the action of a static compressive force on the surface of the metal being tested without vibration.

b. Rockwell

Rockwell hardness tends to determine hardness in the form of a material's resistance to indentation in the shape of a steel ball or diamond cone.

c. Vickers

Vickers hardness is a hardness testing method to determine the hardness of a material or specimen. This test has the smallest indenter compared to other hardness tests as in Fig. 7.

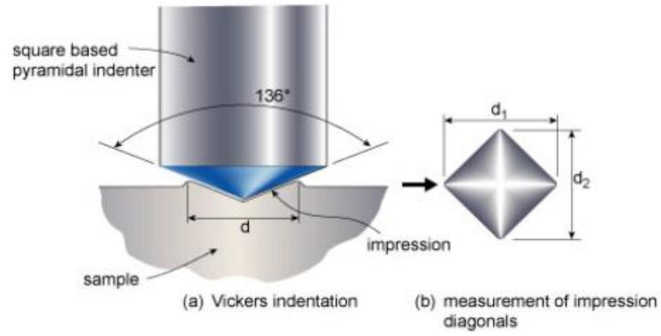


Fig. 7. Vickers indenter [17].

This research uses the Micro Vickers hardness method because it provides results in the form of a continuous hardness scale, and this test uses relatively small specimens, so a small size indenter is needed. The equation used in calculating the Vickers hardness value in Eq. 2.

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

Where:

$VHN$= Vickers hardness number (HV)

$P$ = load (kgf)

$d$ = diagonal the indenter (mm)

The information in Fig. 8. on the dimensions of the 2024-T3 series aluminum plate: (a) the width of a 2024 aluminum plate is 20 mm, (b) the length of a 2024 aluminum plate is 100 mm, and (c) the thickness of the 2024 aluminum plate is 2 mm.

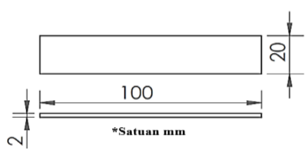


Fig. 8. Dimensions of 2024-T3 series aluminum plate.

Table 5. Chemical composition of Al 2024-T3 and Al 2117 (ASMT)

| AA2024 | | AA2117 | |
|---|---|---|---|
| Composition | Percent (%) | Composition | Percent (%) |
| Si | 0.5 | Si | ≤0.8 |
| Fe | 0.5 | Al | ≤90 |
| Cu | 3.9 | Mn | ≤0.2 |
| Mn | 0.6 | Kr | ≤0.1 |
| Mg | 1.5 | Fe | ≤0.7 |
| Zn | 0.25 | Zn | ≤0.25 |
| Cr | 0.1 | Cu | 2.2-3.0 |
| Ti | 0.15 | Mg | 0.2-0.5 |
| Al | 95.2 | | |

Carry out the drilling process to the size of the aluminum plate according to Fig. 9.

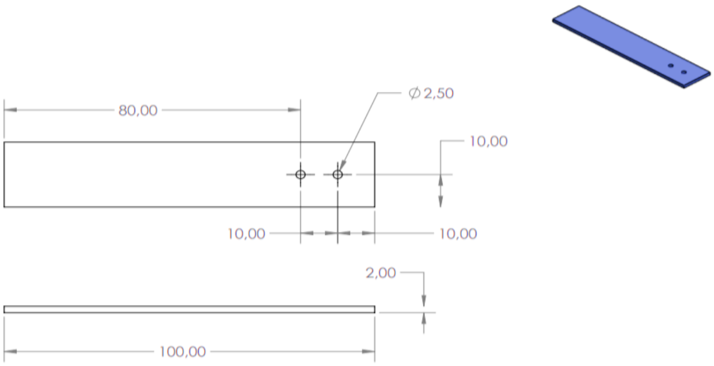


Fig. 9. Aluminum plate drilling position.

Connect the two aluminum plates according to Fig. 10using a double rivet with the help of a rivet gun and using a lap joint connection type.

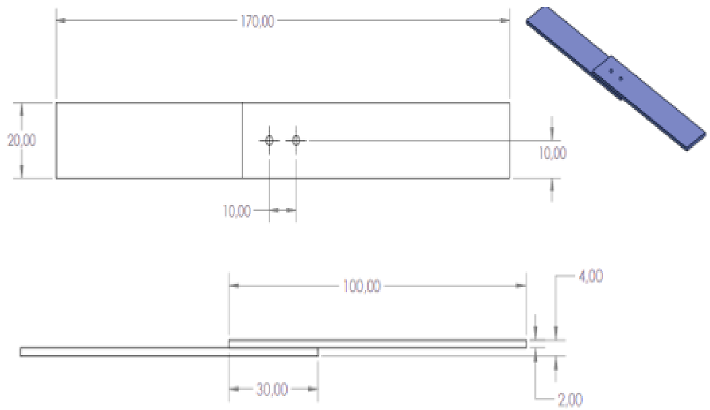


Fig. 10. Rivet installation dimensions.

The writers are installing shoulder tools on milling or drilling tools. Dimensions of tool sizes are made from AISI steel, according to Fig. 11.

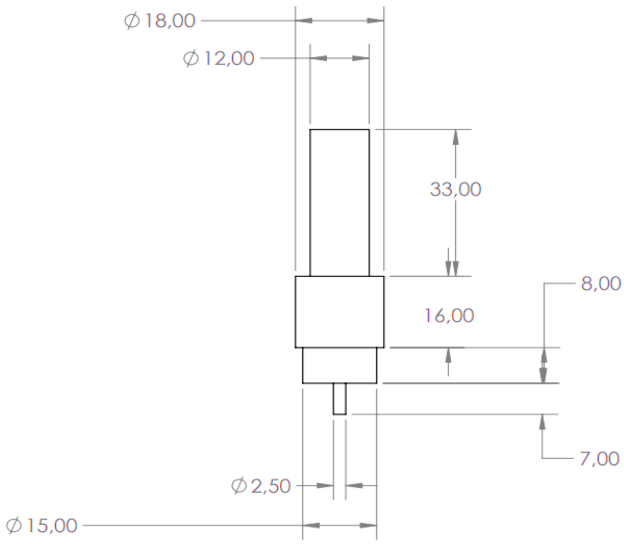


Fig. 11. Shoulder tool dimensions.

The FSSW process is carried out using a cylindrical probe with a size of 2.5 mm and a spindle rotation speed of 2500 RPM. Clamps the two aluminum plates and provides support on the bottom surface of the plate. When tested, it did not shift for the position of the FSSW, as in Fig. 12:

a. Set the rotation speed to 2500 RPM.
b. Lower the shoulder tool using a stirring process according to Fig. 13. with a penetration depth of 1.5 mm.

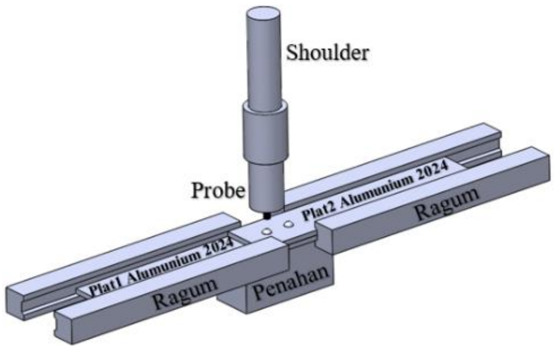


Fig. 12. FSSW process.

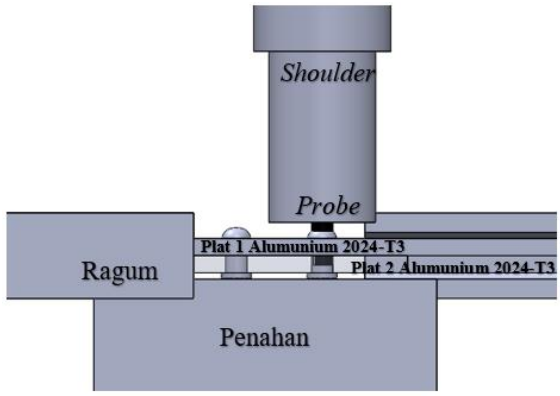


Fig. 13. Stirring process.

## 3 Results and Discussion

### 3.1 Hardness Test

The parameters used are 100 gf load and penetration time 10 seconds. Hardness testing is carried out to determine changes in hardness in the Heat Affective Zone (HAZ) area. Due to the friction between the tool and the workpiece during the FSSW or drilling process, it can produce heat, which can change the mechanical properties of the workpiece.

In Table 6, the hardness test results for the drill and FSSW variations can be seen. In the FSSW variation, it can be seen that specimen 1 has a higher VHN value than specimen 2 and specimen 3, with a value of 145.06 VHN. Meanwhile, for the drill variation, the highest value for VHN is found in specimen 2, with a value of 160.38 VHN.

Table 6. HAZ position hardness test results

| Variation | Spec | d1 | d2 | d | D | VHN | Avg |
|---|---|---|---|---|---|---|---|
| | 1 | 35.5 | 36 | 35.75 | 0.0358 | 145.06 | |
| FSSW | 2 | 41 | 44 | 42.5 | 0.0425 | 102.64 | 122.18 |
| | 3 | 39.5 | 39.5 | 39.5 | 0.0395 | 118.83 | |
| | 1 | 34 | 35 | 34.5 | 0.0345 | 155.77 | |
| DRILL | 2 | 34.5 | 33.5 | 34 | 0.034 | 160.38 | 148.18 |
| | 3 | 39 | 37 | 38 | 0.038 | 128.39 | |

From the research results, the FSSW variation in the HAZ area has a lower hardness value than the drill variation; due to the heat treatment between the tool and the specimen. Due to the heat, the material changes its hardness value due to changes in its microstructure. The drill variation shows another phenomenon: the HAZ area has a higher hardness value. This can happen because changes in heat due to friction change the microstructure to make it harder. Thus, the results of the drill variations are the opposite of the FSSW results, the tool difference factor being one of the causes of this difference. Overall, the hardness value in the drill variation is higher than in the FSSW variation.

Fig. 14.shows the average hardness using the Vickers method. The difference in height between the drill and FSSW methods can be seen, which is caused by the heat generated from the friction of the tool and the aluminum material. This can affect hardness and structural differences due to thermal effects in the HAZ area.

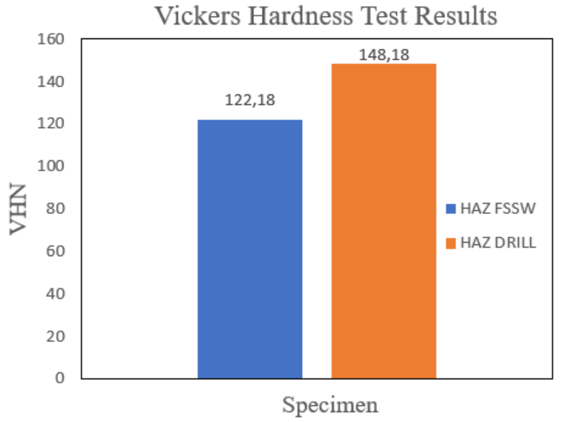


Fig. 14. Comparison of hardness values of HAZ sections.

### 3.2 Shear Strength

Shear strength testing is carried out to determine the reaction of joints in plates to shear loads. In Table 7 can be seen the data from the shear stress calculation results, which are calculated based on the maximum load given by the tensile testing equipment to the plate connection and then divided using the cross-sectional area of the rivet used.

Table 7. Shear strength results

| Spec | Dia | Area ($mm^2$) | Max force kgf | Max force N | Shear strength (MPa) | Avg (MPa) |
|---|---|---|---|---|---|---|
| Drill 1 | 2.5 | 4.91 | 300.16 | 2943.56 | 599.50 | |
| Drill 2 | 2.5 | 4.91 | 314.99 | 3089.00 | 629.12 | 598.82 |
| Drill 3 | 2.5 | 4.91 | 284.31 | 2788.13 | 567.85 | |
| FSSW 1 | 2.5 | 4.91 | 321.65 | 3154.31 | 642.43 | |
| FSSW 2 | 2.5 | 4.91 | 327.25 | 3209.23 | 653.61 | 615.95 |
| FSSW 3 | 2.5 | 4.91 | 276.29 | 2709.48 | 551.83 | |

From the calculation results of the drill variations, the specimen with the highest shear stress was in the drill 2 specimen with a value of 629.12 MPa, while the lowest was in the drill 3 specimen with a shear stress value of 567.85 MPa. Overall, the average of the drill variations has a shear strength of 598.82 MPa. The calculation results for the FSSW variation show that the FSSW 2 specimen has the highest shear strength with a value of 653.61 MPa, while the FSSW 3 specimen is the lowest with a value of 553.61 MPa. On average, the FSSW variation has a shear strength of 615.95 MPa.

In the graph that will be displayed, there is a Y axis for stress or tension, and the X axis is the stroke or movement of the clamp of the pulling tool that pulls the plate. The graphs are made from the best values for the drill and FSSW variations. In Fig. 15, can be seen a graph of the shear test results on various drills. Drill 2 specimen is the best, as shown by the green line. Meanwhile, for the FSSW variation, the graphic shows that the FSSW 2 specimen has the highest shear strength, as shown by the blue line.

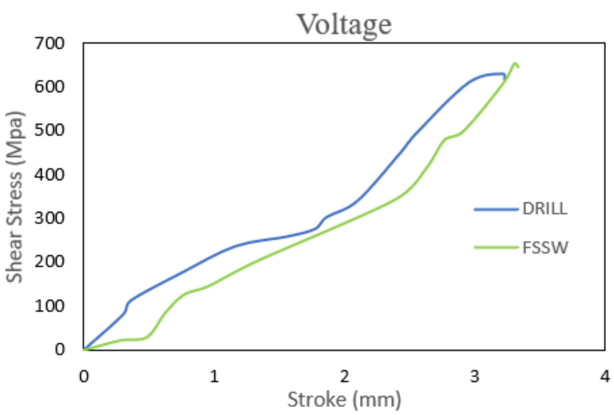


Fig. 15. Graph of drill shear and FSSW test results.

The calculation results shown in Fig. 16, show that the FSSW variation has a higher shear strength than the drill variation. This is also similar to research conducted by [14],where the FSSW variation has a higher shear strength than drill. This happens because of the heat energy when the FSSW tool rubs against the workpiece which causes plastic deformation; as a result of this deformation, it will create hooks or bonds between the plates[18].

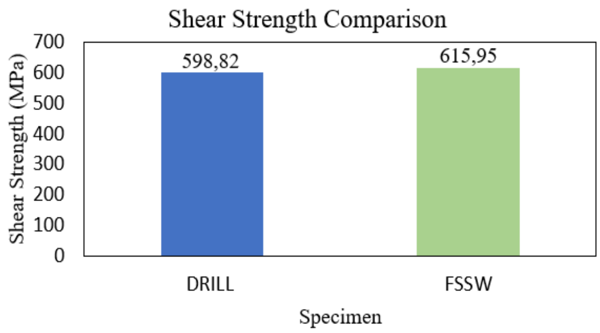


Fig. 16. Comparison of drill shear strength and FSSW.

### 3.3 Makro Test

Fig. 17 is a macro test from the side view of the connection. In each variation,several areas have been grouped. In the HAZ area, the workpiece interacts directly with the tool. The hardness test resultsshow that the HAZ section for the FSSW variation has a different color (red mark) than the base metal. The different color results indicate a new product from the FSSW results. Then, if we look in more detail at the bond between the up and down of the plate, the FSSW is more attached.This follows the shear test results showing that the FSSW is higher in terms of shear strength. However, for the hardness test, the HAZ for the drill variation is higher than the HAZ for the FSSW variation This occurs because the spot taken for the hardness test for the FSSW variation is in the red mark in Fig.17(b). Meanwhile, the hardness value is higher in the drill HAZ area because the HAZ section does not look much different from the base metal or RAW area.

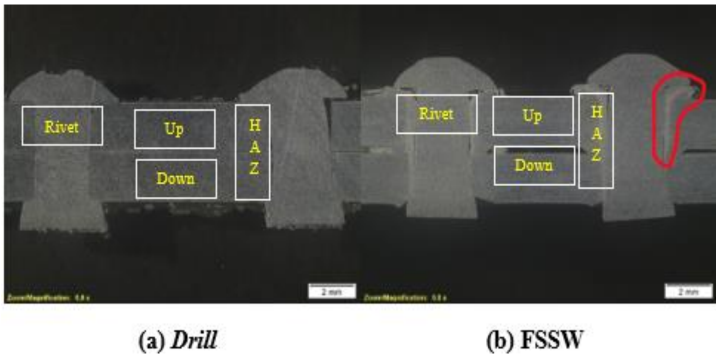


Fig. 17. Side view macro test.

In Fig. 18. are the results of the macro test on the connection when viewed from above.

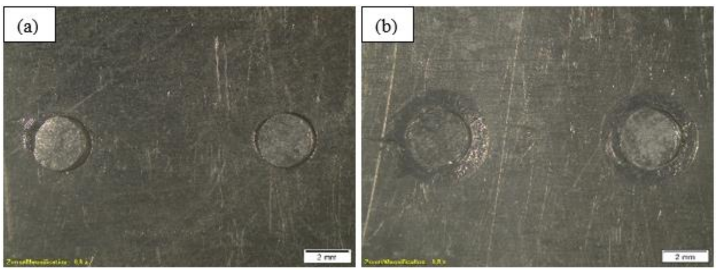


Fig. 18. Macro observations.

### 3.4 Microstructural Observations

Microstructural tests are carried out to determine the microstructural conditions in the HAZ area, where this area is the area that interacts directly with the tool. Fig.19(a)and 19(b) are the results of microstructural photos from various drills. It can be seen that there is no significant structural change in the HAZ when compared to RAW. This is proven from the hardness test results, where the VHN values of RAW and HAZ are not much different.

Fig.19(c) and 19(d) are the results of the microstructure test of the FSSW variation There are differences in the microstructure in terms of the length of the structure. The HAZ section is relatively longer due to deformation due to the rotation of the tool. This is also found in the hardness test results, where the values in the RAW and HAZ areassignificantly differ. According to[14]the change in the HAZ when compared to the RAW part is that it has a smaller and elongated microstructure.This is due to deformation due to the rotation of the tool.

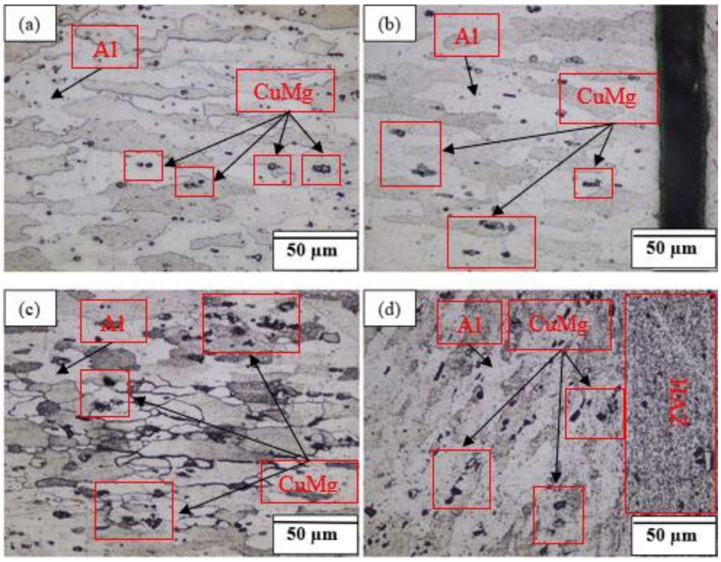

Fig. 19. Microstructural observations.(a) drill RAW, (b) drill HAZ, (c) FSSW RAW, and (d) FSSW HAZ.

## 4 Conclusion

The average value of the FSSW variation is 615.95 MPa, while the drill variation has an average of 598.82 MPa. Thus, the FSSW connection method is better regarding shear strength than the drill connection method. The hardness test results show that the HAZ area for the drill variation has a higher VHN value than the FSSW variation. The VHN value for the drill variation reached 148.18 MPa, while for the FSSW variation, it reached 122.18 MPa. Thus, in terms of material hardness, the drill connection method is better than FSSW for the HAZ area.

From metallographic observations of the FSSW variations, it can be seen that there are differences in the microstructure in terms of decreasing and elongating. The HAZ section is relatively longer due to deformation due to the rotation of the tool. This is due to deformation due to the rotation of the tool.

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