FRICTION STIR WELDING (FSW) APPLICATION TO JOINTS ALUMINUM FOR SEVERAL RADIUS

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The FSW solid weld joint method can be used to joint several radius joints, which will be investigated for the strength of welded joints with 6061 aluminum material. with a size of 100 mm x 250 mm and a thickness of 5 mm, cut into a radius of 700mm, 900mm, 1000 mm, 1100mm, 1200 mm, and 1500 mm. The butt joint is joined by the friction stir welding (FSW) method using a milling machine. This experiment was carried out manually using universal milling with good results, it can be applied to modern machine buildings. The microstructure of the good results did not occur defects and manganese formed small balls in the FSW with a radius of 700 mm, the highest hardness test results occurred in the FSW with a radius of 1100 mm, namely 45 VHn, and the highest tensile strength occurred at a radius of 700 mm, which was 92 MPa.

KEYWORDS

Friction Stir Welding, Pin, probe, Butt, Radius

1.INTRODUCTION

Friction Stir welding (FSW) is solid phase joining technique on fabrication industry. The good quality single and double sides butt joints so lap joints. It was invited in 1991 and originally used to produce aluminum alloy butt joint [Thomas 1991].

Friction Stir Welding is a method of welding solid metals, capable of connecting two different metals (disimillar metal) in plastic conditions.The probe is a solid welding aid to produce heat and make the material plastic. This connection occurs because the plastic material is continuously stirring along the joint line.The Friction Stir Welding (FSW) method was discovered and patented by The Welding Institute (TWI) by [Thomas 1991].

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he shoulder is attached and rotated on the workpiece so that it will generate heat, this design tool will generate high heat to make the material plastic, then form a mechanical bond [Bloodworth, 2009].

The experimental Tool Heat Input ranged from 155 W to 200 W for the tool/workpiece combination used over the entire range of process operating parameters tested, The percentage of the mechanical power that entered the tool ranged between 2.8% and 5.1% [Cavington, 2005]

The FSW process is highly dependent on the probe design, diameter, and material. The probe consists of a shoulder, arm and pin, each part has its own function, the probe is pressed with a force of 18.7 kN until the pins enter on both sides of the joint [Lienert, 2003]

Mishra & Ma, said that it takes low energy to carry out the FSW welding process, low residual stress. Other advantages of the FSW process are cheap, no electrodes are used, environmentally friendly, no flash, and no porosity [Mishra and Ma, 2005]

Designed a probe with a double pin and a single pin to conduct a comparative study using a double pass with the friction stir welding method [Kumari et al., 2015]

Friction Stir Welding (FSW) is the process of uniting two ferrous or non-ferrous metals into one without melting the metal, requiring pressure or no pressure, no change in basic characteristics, and no post weld heat treatment (PWHT) [Vaughn, 2004].

Sued et al., (2014) conducted a FSW study on various pin shapes and probe dimensions Some of the researchers above used the Friction stir welding method with straight butt joints, also using joints.

overlapping. Joining aluminum 6061 to form a radius is something new with the friction welding method. We tried to do to study the radius joint, the radius joint for Friction Stir Welding has never been done, and one day this connection will develop and make a big contribution to science.

In this study, it is known that the joints of several radius for example Radius 700, 900, 1000, 1100,1200, and 1500 mm with friction stir welding methods. The material is used aluminum 6061 and melting temperature is observed and studied. The success of this joint was carried out by preparing a 6061 aluminum joint radius design. The microstructure, microhardness, and tensile strength of the butt joint were evaluated and compared with those published in the previous paper.

1.1 FRICTION STIR WELDING (FSW)

Heat is generated FSW (friction stir welding) by friction between the tool and the workpiece through via plastic deformation. The fraction of the plastic deformation energy is stored within the thermomechanically processed region in the form defect densities increment [Nandan, 2008].

Friction stir welding (FSW) is a friction welding, requires no added ingredients. The heat generated from friction between probe and workpiece. Probe spin at a certain speed then placed on a connection that has gripped material. The friction of the two objects creates 0.8 Tm of workpiece heat [Tang, 1998].

Nugget is a Intense plastic deformation and frictional heating during FSW result in generation of a recrystallized fine-grained microstructure within stirred zone, whereas TMAZ is a Unique to the FSW process is the creation of a transition zone—thermo-mechanically affected zone (TMAZ) between the parent material and the nugget zone. Beyond the TMAZ there is a heat-affected zone (HAZ). This zone experiences a thermal cycle, but does not undergo any plastic deformation, so as a zone a temperature rise above 250^{0}C for a heat-treatable aluminum alloy [Mishra, 2007].

Increased shear stress is caused by the increase in probe rotation and the penetration of the length of the pin that enters the plate sheet of the lap connection with the Fsw method [Cao, 2010].

The stir zone has the highest stress and strain rate and high temperature, sothis combination causes this part to occur with dynamic recrystallization.The microstructure of the mixture is very dependent on the shape of the welding tool, the speed of rotation and translation, the pressure and characteristics of the material to be connected [Cui, 2012].

In addition, this section is also part deformed part of the effect of heat thermomechanical (thermomechanical affcted zone) occurs coarsening precipitates amplifier but no dynamic recrystallization. During the heat welding process that occurs in the section of the heat affected zone (HAZ) only grows grains. The Journal stated that Friction stir welding (FSW) is a method that can connect different materials (dissimilar) with a shoulder which has a variety of rotating pins over the plate pieces to be joined. When the rotating probe moves forward along the weld line, it will generate heat from the friction between the plate and shoulder, the heat generated is lower than the liquid welding method [Malarvizhi, 2012].

FSW process, the probe pin will wear out after welding due to rotation, shear, and pressure. The forms of wear of the probe have been studied [wang et al., 2014].

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].

T1 is probe conical screw thread pin, produce wide and thin weld nuggets, T2 is cylindrical-conical thread pin large and wide weld nuggets are produced, T3 is stepped conical thread pin small and short weld nuggets are produced, while T4 is neutral flared-triflute pin a large weld nugget is produced and there is an air hole [Salari ,2014].

A tool slope of 0° with a spiral on the pin will be obtained better welding results, but poor joints on appearance, external and internal defects and mechanical properties so, With a pin tilt of 2° there is a significant change. Excellent joints, reduced defects, good mechanical properties and high tensile stress values are produced [Bella et all., 2023]

Development of a fuzzy model to predict weld quality. Parameters of Friction Stir Welding that affect the quality of the weld are the geometry of the tool pin, tool rotation speed, welding speed, and tool inclination angle. Welding experiments were carried out on AA 5052-H32 aluminum plates with a central composite design to achieve maximum tensile strength of the welded joint [Shanavas and Dhas, 2017]

The FSW process is carefully controlled using the ML (Machine Learning) method to obtain a good quality FSW connection. Diagnosing tool failure and detecting tool damage during the FSW process using the ML method will result in good joints [Elsheikh, 2023].

The effect of welding process parameters on joint characteristics was investigated and evaluated using statistical methods. In order to obtain a good weld joint, it is strongly recommended to use high tool rotation speed, medium traverse speed and large bevel creasing. The highest tensile strength (22.41MPa) was obtained at a tool rotation speed of 1600 rpm, a welding speed of 0.2 mm/2^{o} sand chisel inclination [AbuShanab, et al.,2021]

The friction between the probe and the workpiece reaches a temperature distribution of 420 °C, will form a joint in a plastic condition to become a mechanical bond on the workpiece [Setiawan et al., 2018].

2.EXPERIMENTAL PROCEDURES

The FSW welding joint method can be used to form a radius joint, the strength of the weld joint will be studied to form several radius. Plate aluminum 6061 5 mm thick, with a size of 100 mm x 250 mm, as many as 12 specimens. Cut into a radius of 700mm, 900mm, 1000 mm, 1100mm, 1200mm, and 1500mm, given a gap or interface of 0.5 mm. The butt joint is joined by the friction stir welding (FSW) method using a milling machine.The tool / probe used is made of medium carbon steel is EMS 45, which has been processed hardening.

Compositions	Mg	Si	Cu	Mn	Fe	Cr	Ti	Zn	Al
Contens	0.9	0.6	0.25	0.086	0.18	0.1	0.192	0.01	Bal

Table 1. Chemical composition of aluminum alloy 6061 (wt.%) top side plate friction stir welding

Compositions	Cu	Zn
Contens	0.85	0.15

Table 2. Chemical composition of brass (wt.%) bottom side plate friction stir welding

Compositions	Mn	C	Si	Fe
Contens	0.486	0.450	0.156	Bal

Table 3. Chemical composition of carbon steel EMS-45 (wt.%) material of probe

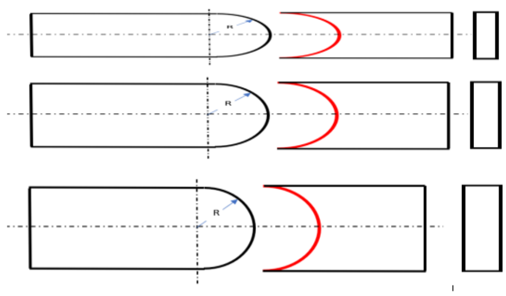


Figure 1. Joints radius design R 700, R 1000, R 1500

research design with a radius of 700mm, 900mm, 1000mm, 1100mm and 1500mm using 6061 aluminum sheet with a thickness of 5mm. The radius is formed with a gap of 0.5 mm at the interface, hopefully a good connection will be obtained. as shown in picture 1.

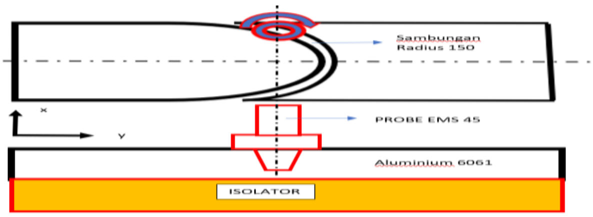


Figure 2. Joints design radius 100 Friction Stir Welding method

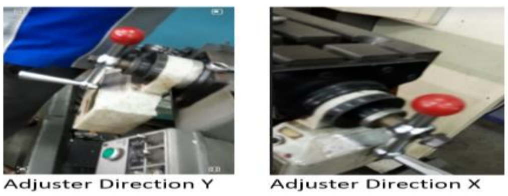


Figure 3. 6061 aluminum setting on lathe table ready for Friction Stir Welding radius joints

There are several steps to prepare are:

1. Make aluminum 6061 form some radius, make sure the gap is 0.5 mm.
2. Under aluminum 6061 must be insulated so that no heat is lost.
3. Make sure the 6061 aluminum is firmly attached.
4. The table is shifted manually in the x and y directions to form a radius

FSW welding process manually using a universal milling machine that can be adjusted rotation, speed in the x direction and in the y direction by adjusting the shift in the direction.

Figure 4. Variations in probe plan pin of radius with steel EMS 45

The probe material is EMS 45 made in such a way using a lathe, made a number of 3 for backup, then treated and hardened to reach 62 HRc .

The parameters used for welding with the lap joint friction stir welding method are 2000 rpm engine speed, and speed of 10 mm/min in the x and y directions is done manually measured with time, in order to get a good connection, a universal milling machine is us.

Figure 5. Adjuster direction X and Y Lathe NC Milling

The benefit of the regulator in NC Milling is to create a radius for joining. The method depends on the size of the radius manually, for a small radius of the controller we slide the x collar two turns, and the Y direction two turns. So next for the radius that we will create

3. RESULT and DISCUSSION

3.1. MACROSTRUCTURE

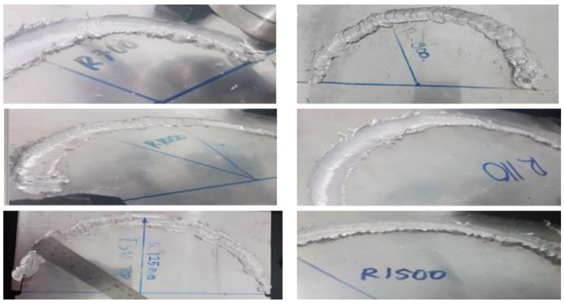


Figure 6. Visual FSW Welding Results R 700, R 900, R 1000, R 1100, R 1200, and R 1500 mm

Visually the material produced from the friction stir welding process with a radius variation of R 700 mm, R 900 mm, R 1000 mm, R 1100 mm, R 1200 mm and R 1500 mm (figure 6) are as follows:

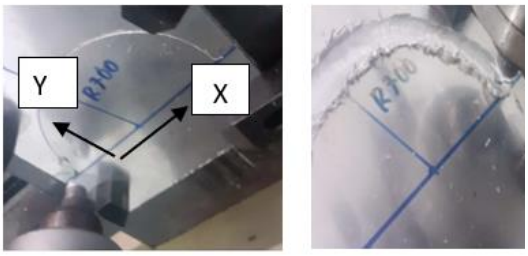


Figure 7. Aluminum 6061 process radius of 700 mm with a gap of less than 0.5 mm good results

The experimental results of Friction stir welding are very dependent on the machine process connection interface. With a small interface gap, good connections and visuals will be produced. Figure 7 shows the results of good machining and Friction Stir welding processes. This is because the narrow interface of the plastic material mixture will be pressed into it into a good mechanical bond. Joints at a radius of 700 mm, is done by shifting the table direction x 2 turns, and y direction 2 turns, so that a radius will be formed.

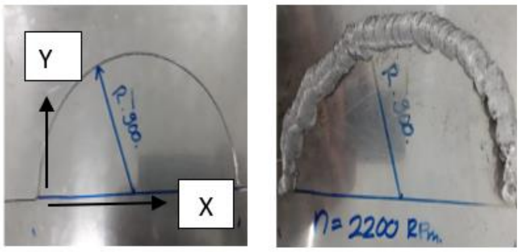


Figure 8. Aluminum 6061 process radius of 700 mm with a gap of more than 0.5 mm bad looking

Figure 8 shows the results are not good, this is mostly due to plastic material not being achieved so that it cannot form good mechanical bonds. Having a gap, even if it's small, will cause the heat to drop, resulting in a less plastic material. while the connection with the R 900 flat table is shifted in the direction of x 3 turns, rotated 2 turns in the y direction will result in a larger radius

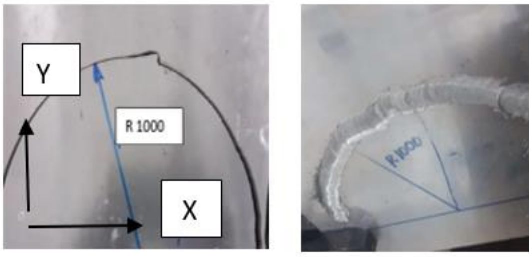


Figure 9. Aluminum 6061 process radius of 1000 mm with a gap of more than 0.5 mm not good.

Figure 9 shows a gap at the interface of more than 0.5 mm, the radius bond that is formed goes up slightly, this will also affect the bond that occurs and the plastic material that is formed. At a radius of 1000 the results are not good, due to the radius there is an interface gap above 0.5 mm, also a shift in the x direction is 3.5 turns and in the y direction there are still 2 turns.

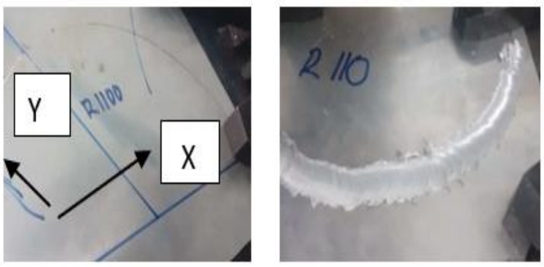


Figure 10. Aluminum 6061 process radius of 1100 mm with a gap of less than 0.5 mm good result.

experimental results on a radius of 1100 mm, good looking and smooth. This can occur with an interface gap below 0.5 mm, also the probe shift in the x direction is 4 turns, while the y direction is 3 turns. The plastic material that is formed is pressed by the probe to produce a good mechanical bond.

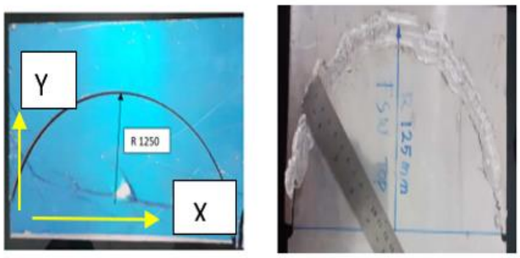


Figure 11. Aluminum 6061 process radius of 1250 mm with a gap of more than 0.5 mm not good result.

In experiments at a radius of 1250 mm, it looks less good. This can happen with interface gaps above 0.5 mm, also the probe shift in the x direction is 4.5 turns, while the y direction is 3 turns. Poorly formed plastic material pressed by the probe will result in poor mechanical bonding.

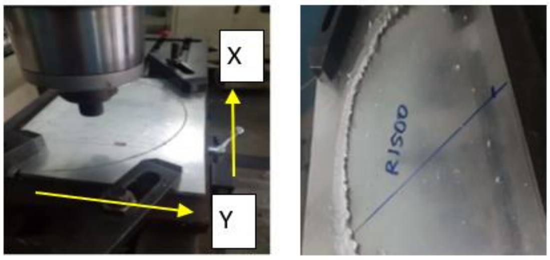


Figure 12. Aluminum 6061 process radius of 1500 mm with a gap of less than 0.5 mm good result.

Figure 12, shows good results from the process of forming a radius with a gap at the interface below 0.5 mm. This will also be followed by the Friction Stir Welding process with good results, both in terms of aesthetics and strength. In this experiment the plastic material formed is good, because the heat loss is low, but because the pressure of the probe on the surface of the workpiece is too large, the plastic material forms nuggets or cheap on the retreating side and advancing side.

3.2 MICROSTRUCTURE

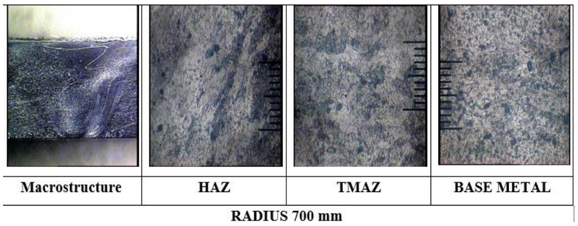


Figure 14. Microstructure Photo at a Radius of 700 mm

The microstructure of the R 700 is dominated by black spots on HAZ, TMAZ, and BASE METAL. This is because the Al_2O_3 oxide layer cannot be stirred by pins, at 2000 rpm the spindle rotation causes high heat input, but the material to be joined is quite large and wide, so that there is a large heat loss, then the heat energy drops will result in a low flow of plastic material and black spots will appear same, so The increase in temperature during the FSW process can cause oxidation on the aluminum surface exposed to air. Oxidation results in a black or other colored coating on the weld surface. Will reduce mechanical properties such as hardness and tensile stress study from (Wan et al, 2014) (Li et al., 2010).

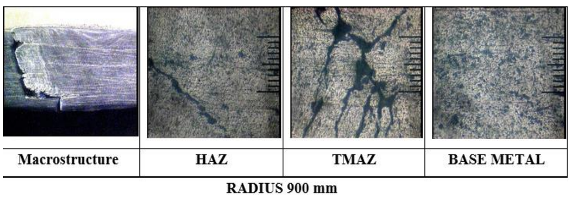


Figure 15. Microstructure Photo at a Radius of 900 mm

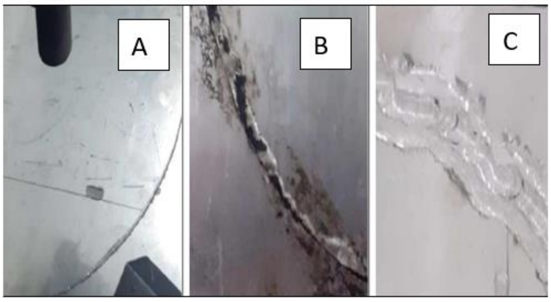


Figure 13. Macrostructure image FSW, A)Gap or interface, (B) Bottom drawing on weld for R 1100, (C) Top image at R 1100

Figure 13A shows a small 0.5mm gap interface for the R 1100mm, Figure 7B is the result of a macro photo of the bottom, showing a downward bulge, this is because the anvil is held in place with an insulator that is not strong. Figure 13C shows the shift towards Y and X is not stable, so the results are less smooth.

The result of this welding joints is very dependent on the gap interface of the milling machine process, the larger the gap interface will result in poor welds both physically Oxides will also react with aluminum 6061

The microstructure of the R 900 joint shows that there are black cavities in the HAZ and TMAZ areas, this is a mechanical joint that is not formed, because the interface/gap of the milling process occurs around 0.5 mm. It can also be strengthened with macrostructural photos and Temperatures that are too high during FSW can cause the aluminum material to overheat, which can result in discoloration or even surface deformation and a decrease in mechanical properties. Incorrect setting of FSW process parameters, such as rotational speed, tool pressure, or welding rate, can cause black spots on the weld, also black streaks on TMAZ are aluminum that is not connected at radius 900 mm, Also caused by welding temperatures that are too low or not suitable can also contribute to the formation of black spheres and unconnected metal.

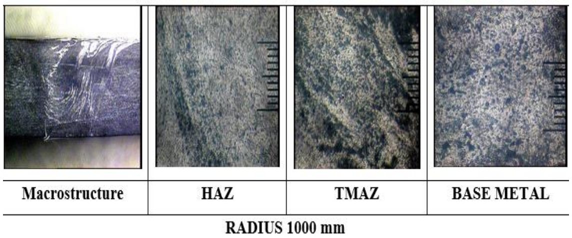


Figure 16. Microstructure Photo at a Radius of 1000 mm

The joints with R 1000 in the TMAZ area shows a lot of black Differences in the material composition of 6061 aluminum or variants of the material being joined can also cause differences in the color of the weld surface.. HAZ is a little bit of oxide trapped, Contaminants or other foreign materials may mix with the metal during the welding process and cause unwanted spots to occur stable below

200⁰C without changing the mechanical properties, but if the bond occurs above 200⁰C, it will form a precipitate and be stirred by the plastic material, spreading to make a black color. Welding 6061 aluminum FSW without additives will usually result in accumulation of magnesium in the joint zone. The addition of MgO can help increase the solubility of magnesium in metals, reduce accumulation, and prevent the formation of according to the probe pin, then forms MgO compounds that increase the mechanical properties of aluminum 6061, (Ghosh et al., 2010)

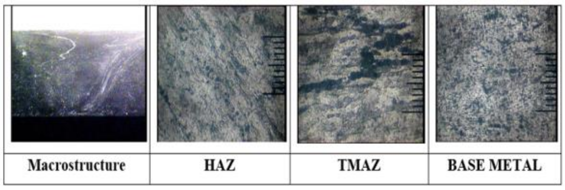


Figure 17. Microstructure Photo at a Radius of 1100 mm

The black spots on TMAZ and HAZ is Aluminum 6061 with Al-Mg-Si composition with high rotation will occur. The addition of MgO can help reduce friction between the tool and the material, reduce wear on the tool, and reduce heat generated during the process. This helps control thermal deformation and prevents defects from forming in the joints. The distribution is in accordance with the direction of the probe pin mixture on the plastic material, reducing the mechanical properties of the Al-Mg-Si material. The microstructure forms magnesium oxide (MgO) bonds at a low temperature of 150⁰C. As a result, the oxide on the aluminum surface also rotates according to the probe pin, then forms MgO compounds that increase the mechanical properties of aluminum 6061, (Ghosh et al., 2010)

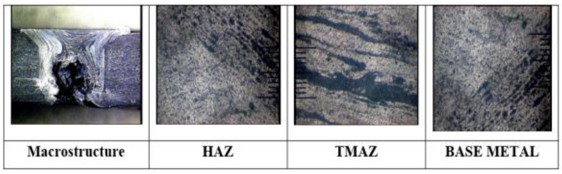


Figure 18. Microstructure Photo at a Radius of 1200 mm

hazardous phases that can reduce mechanical properties. This distribution is in accordance with the direction of the probe pin mixture on the plastic material, it will reduce the mechanical properties of the Al-Mg-Si material. The microstructure forms magnesium oxide (MgO) bonds at a low temperature of 150⁰C. As a result, the oxide on the aluminum surface also rotates

Mechanical bonding on the R 1200 did not work, because the gap that occurred at the interface was too large, there was a lot of heat loss, it was strengthened by the macro photos that occurred, as well as the base metal. With gaps at the FSW interface welding aluminum 6061 without additives will usually result in accumulation of magnesium in the joint zone. The addition of MgO can help increase the solubility of magnesium in the metal, also reduce accumulation, and prevent the formation of unwanted phases that can reduce mechanical properties. Also caused by the inclusion of foreign particles in the joint area formed during the welding process. These particles can come from metal surfaces or probes used during the FSW process.

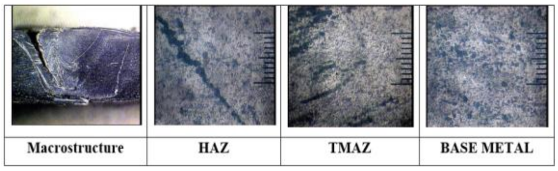


Figure 19. Microstructure Photo at a Radius of 1500 mm

The joint of the R 1500 mechanical bond is not successful, this is because of heat loss, the material is too wide, and there is a small gap at the interface. Strengthened by the results of macro photos that occur, so Material selection and reinforcement design are important factors in FSW. If the reinforcement tool is not suitable for welding 6061 aluminum, it can cause problems including black spots. If the temperature is too high or excessive heat buildup occurs, it can cause deformation of the material, resulting in black spots, and will reduce the strength of the mechanical properties.

3.4 MICRO HARDNESS

Tests of hardness on the specimens were carried out on the joint area (figure 20), with an indentation point of 15 points with 8 points towards the HAZ of the joint left and right, so 7 points towards the nugget zone the joint.

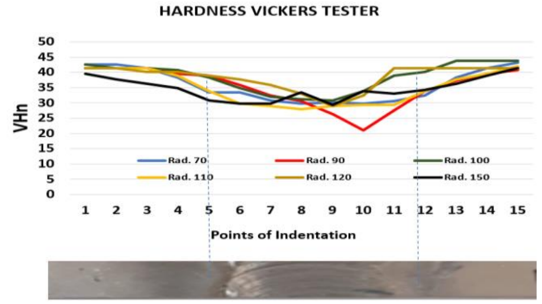
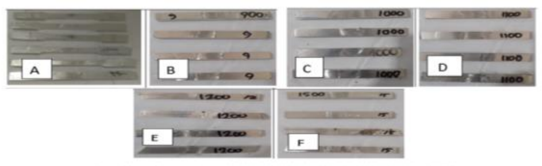


Figure 20. Micro Hardness Vickers number tests

3.5 TENSILE TESTS

Tensile test is carried out by preparing 4 specimens at each radius, in the hope of providing an overview of the mechanical strength to be studied, so the test specimens refer to the ASTM standard.



The highest tensile test occurs at the R 700 connection, which is 92 MPa, followed by the second order at the R 1100 connection, this is because the gap formed in the milling process is small and there is not much heat loss, Also the interface gap is low below 0.5 mm, so that the plastic material that is formed will be pressed by the probe to form. With the above reasons will produce a good mechanical bond. On the other hand, at the connection R 1200 and R 1500 the tensile strength is very low, namely 22 MPa and 19 MPa, due to a lot of heat loss and a large gap more than 0.5 mm, resulting in low mechanical bonding. Resistance to Stiffness: Radius variations will affect the stiffness of the welded joint. The larger the radius, the less the drop in strength due to

4. CONCLUSIONS

After conducting experiments and studies, conclusions can be drawn, including:

The hardness test showed a significant decrease in R 900, the mechanical bond was not well formed because the gap was large, namely 0.5 mm, strengthened by macro and micro structure photos. On average there is a decrease in Vickers hardness in the HAZ and TMAZ areas, this is caused the welding process involves local heating of the metals to be joined. The high temperatures achieved can cause recrystallization and growth of crystal grains in the metal structure, thereby reducing its hardness so the metal in the HAZ region undergoes rapid heating followed by rapid cooling due to the significant temperature difference between the heat affected area and the surrounding area. Rapid cooling can lead to the formation of a larger, disordered grain structure, which reduces its hardness.

Figure 21. tensile test specimen, A) R 700, B) R 900, C) R 1000, D) R 1100, E) R 1200, F) R 1500

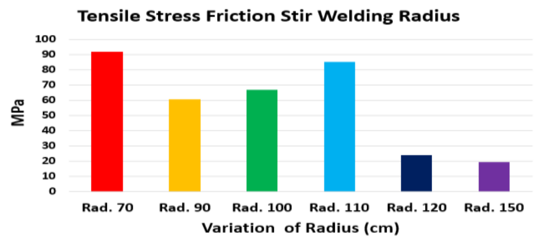


Figure 22. Tensile Stres Tests

stresses experienced by the welded joint. If there is a change in radius, there will also be a change in the stiffness properties of the welded joint, which can be seen through the tensile test. Al2O3 oxide was formed in the microstructure, as a result, The radius of the FSW groove can affect the quality of the welded joint. If the radius of the groove is too small, there is a possibility of cracks or defects in the welded joint due to the stress concentration. On the other hand, a larger radius reduces the likelihood of cracking, thereby increasing the strength of the welded joint.the hardness decreased in the HAZ and TMAZ , regions, while the highest tensile test was at R 700, which was 92 MPa. This is supported by micro-structure and macro-structure data (Figure 6-20).

1. Friction Stir Welding with several radius can be done well.
2. Gaps formed on the interface will have a major effect on the physical and mechanical properties of the connection.

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