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The Effect of Rotational Speed on Friction Stir Welding (FSW) Quality of Dissimilar Aluminum Alloy Series AA 1100 and AA 5052

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Abstract

Aluminum and its alloy have been widely used in various fields of industries. Aluminum has superior properties in terms of corrosion and has an excellent tensile strength compared to other lightweight metals. Aluminum AA 1100 series is an alloy such as copper, iron, chromium, manganese, and zinc, and the minimum aluminum content is 99.0%. Moreover, aluminum AA 5052 series is an alloy of aluminum with magnesium (Mg). Welding is the process of joining two or more base metals that are joined at the contact surface with or without additives or fillers. Friction Stir Welding (FSW) is an example of solid-state welding or non-fusion welding. FSW uses friction energy for the welding process, which generates from the indenter's twists to material surface and pressing force. Welding parameters and indenter shape change the spiral form with an indenter rotation of 1750 rpm, 2230 rpm, 3500 rpm, and a translation speed of 22 mm/min. The tests are tensile testing, hardness testing, and microstructure testing. This study found that indenter rotation and welding speed significantly affect the mechanical properties of aluminum series 1100 and 5052, which have been welded. The higher the rotation of the indenter, the higher the hardness value, the increase in hardness reaches 10.2%. However, the higher the rotation of the indenter causes a decrease in tensile strength, with a decrease of 18.6%.

Keywords:
Aluminum, friction stir welding, dissimilar metal, second phase.

1 Introduction

Aluminum is a chemical element that is in group 3 period 3 with the symbol Al with atomic number 13. Aluminum consists of 66% bauxite and 33% clay. Aluminum was first discovered as an element by Sir Humphrey Davy in 1809 then produced by HC Oersted in 1825 [1]. In the industrial application, joining and welding process is a common technology that has been applied for aluminum. Many researchers have successfully studied joining of different aluminum alloys for various applications such as automotive [2][3], aerospace [4], defense structural material [5], marine and transportation [6], and etc.

The metal joining process is divided into solid-state welding or a non-fusion welding category [7]. One of the solid-state welding is Friction Stir Welding (FSW) or torsional friction welding. FSW welding was first developed by The Welding Institute (TWI), that usually proceed below the melting point of the base metal or around 0.6 to 0.8 of the melting points [8]. FSW process start with twists the tool by utilizing heat energy and pressing without additives or fillers until a phase change occurs in the base metal, requiring at least one part to be joined along the required cross section and the base metal commonly used in the form of a plate [5][8].

Aluminum has a medium strength and good corrosion resistance, for the example in aluminum 1100 is an alloy such as copper, iron, chrome, manganese and zinc, the minimum aluminum content is 99.0%, and aluminum 5052 is an aluminum alloy with magnesium (Mg) [9]. Welding is a process of joining two or more base metals which are joined at the contact surface with or without additives or fillers. This problem can be solved by FSW welding [10] [11].

Previous research related to the effect of rotational speed has been carried out for the same material. While in this study, the materials to be joined have different types. Different types of materials that to be joined will also have different characteristics. The welding speed is sensitive to the mechanical properties of welded specimen in FSW and it shows that the highest strength may obtained by the joint welded with the optimum rotation rate. The tensile test, hardness test and microstructure test will be seen the difference with the results of previous studies [11] [12].
The purpose of this study is to determine the effect of the rotational speed of the indenter on the tensile strength and hardness of the welded material. Furthermore, the relationship with the parameters used on the micro structure based on the Welding Procedure Specification (WPS) process. The parameter to be studied is the speed parameter with 3 variations using the translation speed of previous studies, namely 22 mm/min. Therefore, this research aims to see the best quality of indenter shape and mechanical properties of aluminum base metal by varying the number of indenter rotation speed, i.e., 1750, 2230 and 3500 rpm. Then FSW was tested for tensile strength with E8/E8M-09 standard, tested for hardness and tested for microstructure [12].

2 Materials and Methods

In this study, we are using a VHF 3 milling machine. This study used a changing spiral form indenter with an indenter rotation of 1750 rpm, 2230 rpm, 3500 rpm, with a translational rate of 22 mm/min. The FSW welding process is as shown in Fig. 1(a) and the research process presented on Fig. 1(b) [4]. The thickness of the plate was 6 mm.

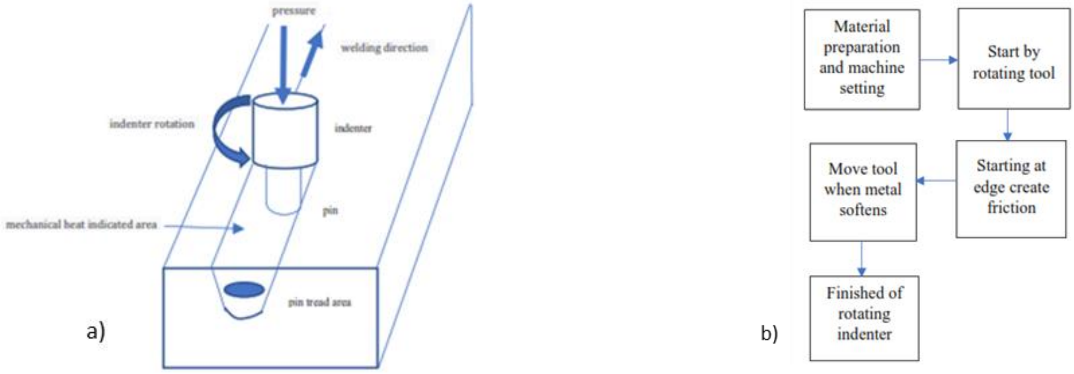

Fig. 1. Illustration of the FSW process (a) and the general flow of this study, and (b) adopted from other [4].

The FSW welding process has several stages. The first stage is the preparation and installation of the indenter on the drill chuck and gripping shoulder (Fig.1. After constant rotation, the first welding is 1750 rpm, the second is 2230 rpm, and the third is 3500 rpm. Then the gripping shoulder must be lower so that it is perpendicular to the gripped plate and place the indenter on the weld line at the boundary of the two plates.

The next step is to provide heat input for 5 minutes, starting when the indenter rubs against the plate surface. The next step is the welding process after the characteristics have begun to transition to the transition phase on the surface of the plate and sufficient heat for the melting point of the base metal. After the specimens are welded, hardness testing, tensile testing, and microstructure testing are carried out. The hardness test carried out is a Rockwell hardness test using the HRB standard. Meanwhile, the tensile test on the welding results was carried out using the ASTM E8/E8M standard.

The base metal melt (stir zone) experiences the highest stress and strain rates and high temperatures in mixing or stirring. This process combination causes a dynamically recrystallization area. The microstructure of the mortar's part is very dependent on the shape of the welding tool, the rotational and translational speed, the pressure, and the characteristics of the material to be joined [12]. The welding part is also deformed, and at the Thermo Mechanical Affected Zone (TMAZ), there is coarsening of the precipitate reinforcement but no dynamic recrystallization. At the Heat-Affected Zone (HAZ) area, the grain grows, as represented on Fig. 2 [11].

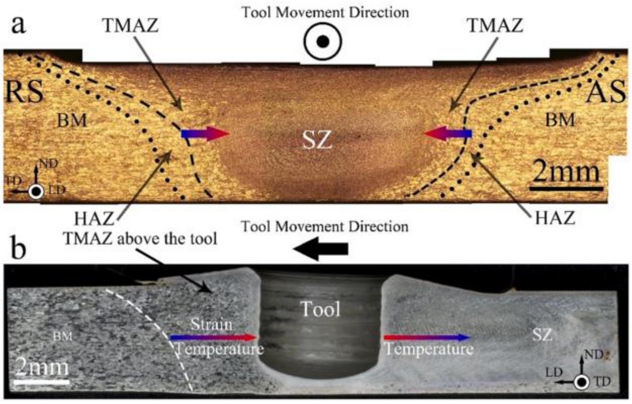

Fig. 2. FSW microstructure [11].

3 Results and Discussion

The above test results used different speeds in the 1100 and 5052 series, different metal splicing processes. FSW welding with indenter rotational speed of 1750 rpm, 2230 rpm, 3500 rpm, and translation of the indenter 22 mm/min. Welding result aluminum is not the same as series AA 1100, and AA 5052 which are presented in Table 1.

The next stage is mechanical testing to determine the value of tensile strength and hardness. Tensile strength testing is carried out using a universal tensile testing machine, and Fig. 3 is the tensile test result. Based on the tensile test results, there are differences in the ultimate stress and yield strength values. The most considerable influence of the test results is due to the rotation of the indenter and welding speed, especially in the shape of the indenter pin and temperature.


Fig. 3. Tensile test of spesimen. (a) before, and (b) after

The three rotational speeds of the indenters used have very significant differences; the results of the weld display can be seen in the Fig. 3. However, from the tensile test results it can be seen that the best results are obtained from the FSW results with the indenter rotational speed of 2230 rpm of 67.49 MPa, 55.75 MPa, and 52.21 MPa. The results are less than optimum for welding with an indenter rotational speed of 1750 rpm and 3500 rpm.

The effect of welding speed is sensitive to the mechanical properties of the specimens welded at 800 rpm, which failed on advancing side of the joint. It is shown that the highest strength was obtained from the joint welded with rotation rate of 600 rpm and traveling speed of 240 mm/min [13]. At low rotational-speed welding of a 0.5 mm-thick Al alloy ultrathin plate will have welding defects such as holes, tunnels, and weak bonding [14]. High Rotational-speed of FSW (HRFSW) may obtain high quality welded joints. When the spindle speed is 12000 rpm and the welding speed is 300 mm/min, a joint with a good weld surface and no obvious welding defects is obtained [12]. Based on the analysis of variance results, rpm has a greater, with an 80.33% contribution and the traverse speed has about 18.042% of contribution.

Table 1. Welding result of aluminum series 1100 and series 5052.

Parameter	Results	Specimen*)
Indenter rotating speed: 1750 rpm Translational motion speed: 22 mm/min	Defect of the hole Rough surface No welding stable	
Indenter rotating speed: 2230 rpm Translational motion speed: 22 mm/min	Rough surface More stable welding process	
Indenter rotating speed: 3500 rpm Translational motion speed: 22 mm/min	Smooth surface Stable welding	

*) Bars is equal to 10 mm; red arrow refer to weld area.

For the rotational speed of the 1750 indenter, the UTS is 60.31 MPa, 51.60 MPa, and 19.27 MPa for the lowest tensile test results obtained from the welds with the 3500 rotational speed of the indenter which is 54.07 MPa, 41.33 MPa, and 35.55 MPa. When viewed from the fracture results, there are cavities in the welds at the stir zone point, as on Fig. 4.

Most of the tensile test results are on the HAZ. However, there are some specimens that break in the weld metal and weld joints. Specimens 1A, 1B, 2A, 2B and 3C were broken in the HAZ region. Specimens 2C and 3C were broken in the weld area, while for the specimens 3A and 3B were broken in the weld metal area. The joint design has good tensile strength and will provide information about the newly designed joints in the FSW welding method. The nugget, TMAZ, and HAZ only function as locks, while their shear strength lies in the joint design, as also reported by other [15].

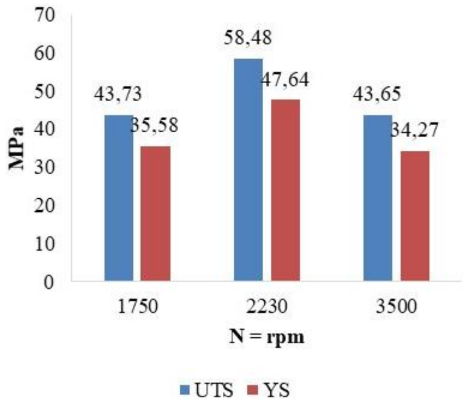

Fig. 4. Tensile test results.

The shape of the indenter pin visually changes the spiral form of the welded surface, and the fracture is located in the stir zone. After that, it was identified that there were no cavities and penetration to the bottom at 3500 rpm, whereas when viewed at 1750 rpm and 2230 rpm, the fracture was found in the stir zone there is a wormhole. However, when viewed thoroughly, friction stir welding must be carried out according to the standard clearance so that the tensile test results can be maximized. Things that affect the decrease in the value of tensile strength are defects such as: surface breaks, welding does not reach below the surface, porosity, grooves and weld waves, as on Fig. 5.


Fig. 5. Hardness test results.

From microstructural analysis it is evident that the material placed on the advancing side dominates the nugget region. The hardness in the HAZ of 6061 was found to be minimum, where the welded joints failed during the tensile test, as presented also elsewhere [16].

The hardness test in this study used a Rockwell tester on the FSW connection with variations in the rotational speed of the indenter. The test results are displayed in graphical form to determine the relationship between the hardness value and the distance of the test point from the Stir Zone (SZ) point, which presented on the Fig. 6.

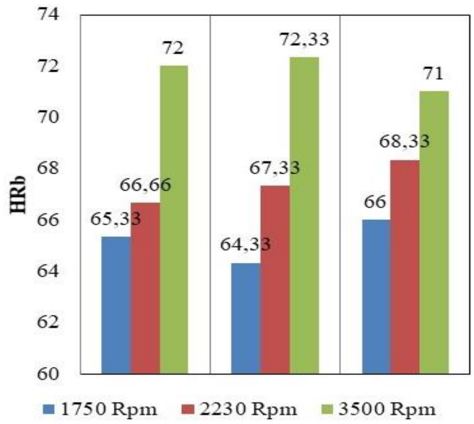

Fig. 6. Rockwell-B hardness test results.

The most considerable influence on the hardness test results above is due to the rotation of the indenter and the welding speed, especially the shape of the indenter pin and temperature. Especially the three rotational speeds of the indenters used have very significant differences. From the table, the hardness test results show that the hardness of welding at 1750 rpm at the stir zone point is obtained an average value of 65.22 HRB. The hardness test results showed that the hardness of the welding at 2230 rpm experienced an increase in the hardness at the stir zone point, with an average value of 67.44 HRB. Furthermore, the hardness test results showed that the hardness of the welding at 3500 rpm experienced an increase in the hardness at the stir zone point area, with an average value of 71.77 HRB.

The rotation of the indenter and translational motion played an essential role in the FSW welding process. The heat used to melt the weld material are generated from these factors. Fast rotation with low translational motion will produce excess heat, which will cause softening of the material. Low rotation with high translational motion will cause less heat to be generated. As a result, the softening of the material cannot soften completely, so it cannot connect properly, as presented by other elsewhere [13]. The softening process is critical in FSW welding. If the material does not soften, the indenter that acts as a friction material and a stirrer will not soften the material uniformly. The results of the observation of the microstructure can be seen in Fig. 7.

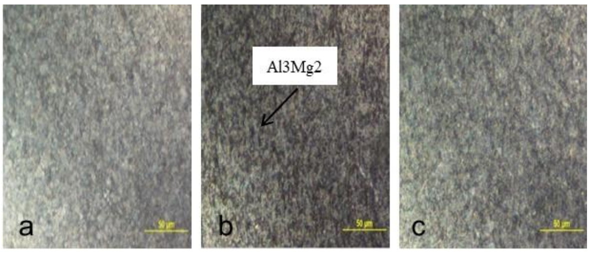

Fig. 7. Microstructure.

Based on the microstructure image above, there is no phase change in FSW welding on aluminum 1100 and 5052, but there is particle smoothing in the stir zone because FSW does not use filler metal, Fig. 7(a). This is also in accordance with the microstructure observation, which shows the presence of a black Al_3Mg_2 phase. The microstructure in the stir zone for a speed of 2230 rpm shows the presence of particles in the Al_3Mg_2 stir zone, which are smaller and more evenly distributed. This is due to recrystallization during the welding process, as shown in Fig. 7(b). Furthermore, the microstructure of the stir zone region at an indenter rotational speed of 3500 rpm also shows the presence of an Al_3Mg_2 phase which is indicated by a black area.

Changes in the microstructure in the weld zone area are influenced by the thermal cycle that occurs in the weld area, the mechanical cycle that occurs due to heat is influenced by friction (rotating speed of the indenter, translational speed of the indenter, pre-heating, and heat treatment) that occurs between the indenter pin and two side of the material to be welded. Heat treatment process may also affect the tensile strength of the welded area.

4 Conclusion

Based on the data and discussion of the tensile and hardness test results on the aluminum welding results of the AA 1100 and AA 5052 series, there is a very significant effect between the rotational speed of the indenter and the speed of translational motion. This type of indenter changing spiral form results in better weld performance at 3500 rpm with 22 mm/min transition and much easier penetration. There was an increase in the hardness value between the areas affected by the welding process, namely the Heat-Affected Zone (HAZ), Thermo Mechanical Affected Zone (TMAZ), and Stir Zone (SZ). The higher the UTS value obtained, the better the connection quality obtained.

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