Microstructure and Mechanical Properties of Friction Stir Welding Aluminum AA1100 with the Parameter of the Tool Pin Profile

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Abstract. The tool pin profile on Friction Stir Welding (FSW) has great influence toward the result of welding. The tool pin profile is one of the vital factors influencing the result of welding such as the microstructure and the mechanic characteristic on the joint of Weld Nugget (WN). This study aims to analyze the effect of the tool pin profile on the Friction Stir Welding of aluminum AA1100 toward the microstructure and the mechanic characteristic. The Process of FSW utilized the Universal Milling Machine and the observation of microstructure utilized the Metallography optic. Meanwhile, the Universal Testing Machine was utilized on the tensile test. The result of the microstructure on the weld nugget area showed smooth and tight result on FSW using the Threaded tool pin profile. This occurs because of the mixture of threaded pin that is evenly distributed and the dynamic recrystallization that was caused by heat. The maximum tensile strength results occur in the threaded pin tool with a value of 88.037 Mpa, so that the material becomes ductile.

Keywords: Friction Stir Welding, Milling Machine, Microstructure

1 Introduction

Welding is a method used to join two or more metals by partially melting the main metal with or without the use of filler material. The joining process takes place in the solid state, before the metal reaches its melting point. One of the commonly used metals or materials for welding is aluminum. This Aluminum material is also classified as a non-metal material. It possesses several advantageous properties, including corrosion resistance, good heat and electrical conductivity, as well as being lightweight[1]. In the industrial world, there are numerous job opportunities in the field of Welding, thus welding methods have advanced significantly. The development of welding methods can be observed through the increasing demand for the production of four-wheeled and two-wheeled vehicles, as well as other land transportation products. Furthermore, there is also a high demand for defense and security vehicles, and the production of such vehicles is inseparable from excellent welding methods and high-quality welding results[2].

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In the Friction Stir Welding (FSW) method, frictional heat energy generated by the contact of the shoulder tool with the welding metal is utilized. This method is considered simple because it relies on the heat energy produced from the friction. The heat generated from the friction between the two materials will transform them into a plasticized metal. Parameters applied in FSW, such as plate thickness, tool RPM, welding speed, tool dimensions, and the type of metal, are determined before the welding process begins.[3], Therefore, parameters in FSW welding are constantly engineered through various welding experiments. There are many materials produced in the industrial world, including copper, aluminum, zinc, brass, steel, and others. These types of materials can be combined using either fusion welding or FSW (Friction Stir Welding) methods.[4]. In fusion welding, defects such as porosity, low distortion, and residual stress are always considered in welding aluminium materials [5]. The research conducted by Wang et al. focuses on the differences in the fatigue properties of the welded joint region of Aluminium 5053 material using the Friction Stir Welding (FSW) method compared to the Tungsten Inner Gas (TIG) method. The results of the research show that fatigue characteristics in Friction weld joints are better compared to the results of TIG weld joints [6]. Raturi et.al has conducted research on the effect of the tool pin profile on the FSW AA6061-AA7075 process toward the physical and mechanical properties. The pin tool profile used was Cylindrical (CYL), Cylindrical Tapered (CT), Cylindrical threaded with three flat faces (3 L), Trapezoidal Tapered (TPZ)[7].

The observation on the differences in the shape of the pin tool (square and pentagonal) applied in the Friction Stir Welding (FSW) method of Aluminium materials, with the codes AA5052 and AA1100, has been studied by Kumar et al[5][8]. The study shows that the pentagonal pin-shaped application with a welding speed of 60 mm/minute exhibits satisfactory welding quality compared to the results obtained from other welding methods. FSW (Friction Stir Welding) method on various types of Aluminum materials has also been observed by Ramana et al. In that study, Ramana chose Aluminum materials with types or series AA5082 and AA6061. The variations in welding speed were observed, including using speeds of 15 and 20 mm/minute, combined with tool RPMs of 1600 and 2600 rpm. The research results indicate that the welding area of the material with type 5082 exhibits better strength. The favorable results are achieved at higher tool speed and feed rate, specifically at 2600 rpm and a feed rate of 20 mm/minute. The Feed rate parameter of 20 mm/minute with 2600 rpm increases by 22.2% at its maximum strength due to its significant influence on the welding results[9].

From the description of several literature, it is evident that Friction Stir Welding is highly suitable for joining aluminum alloys in order to obtain good welds. The quality of the weld or the weld nugget is influenced by factors such as the profile of the tool pin. Therefore, further research on the influence of using different tool pin shapes in the FSW welding method needs to be extensively studied. Hence, the objective of this research is to present the effect of the tool pin profile on the physical and mechanical properties in the FSW welding method of AA1100 aluminum.

2 Method

This study utilized aluminum material of AA1100 whose dimension was 160 x 75 x 6 mm as it was described in Fig. 1. The aluminium material AA1100 has a chemical composition as shown in Table 1**.** Steel with medium carbon content is used as the material for FSW tools and has an initial hardness value of 17 HRC. The tool used for Friction Stir Welding (FSW) must be wear-resistant, so the material used as the FSW tool needs to have its hardness value enhanced. One way to enhance it is by performing a heat treatment method accompanied by rapid quenching. The final hardness value after undergoing heat treatment becomes 52 HRC.

Table 1. The Chemical composition of Aluminum AA1100

Element	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn
%	99.95	0.064	0.182	0.009	0.016	0.007	0.009	0.005

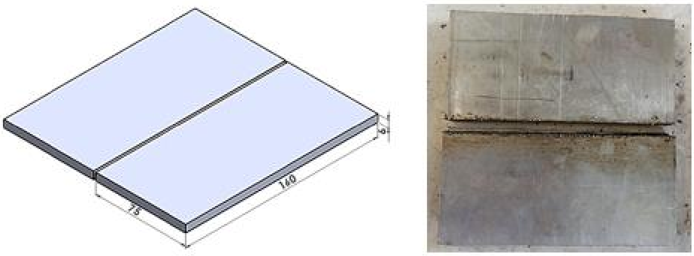
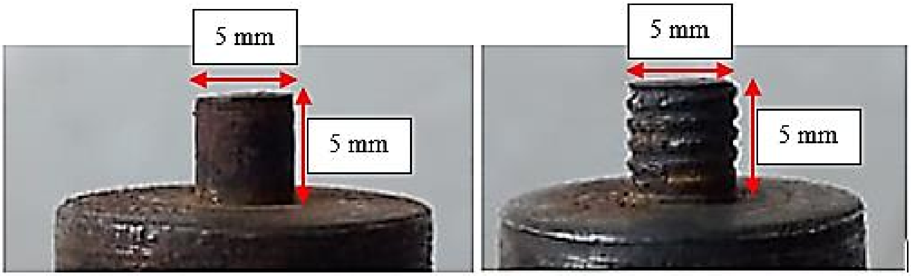


Fig. 1. The Material Dimension of Aluminum AA1100

There were two types of the pin profile that was utilized on FSW for instance Cylindrical and Threaded pin with its diameter and length of pin were 5 mm, its shoulder diameter was 18 mm and its shoulder length was 20 mm. These types of pin have been utilized by other researchers such as a study that was conducted by Singh et.al[10], The design and profile of pin that was utilized by Singh et.al was shown in Fig. 2 (a,b). The Parameter that was utilized on the FSW process was the different tool pin profile that was Cylindrical and Threaded pin with the rotation pin of 1000 rpm and the feed rate of 10 mm/minute. This parameter was based on a research conducted by Rahmatian [11].

The machine used for the FSW process is a CNC Milling machine, and temperature measurement during the FSW process is done using an infrared thermometer. The requirements for performing welding with the FSW method should be prepared thoroughly, including the base plate, aluminum plate, FSW pin, clamping devices, and others. The pin tool to be used in FSW should be properly installed, which means it should be placed in the middle between two aluminum plates. Once all the materials and tools are ready, the CNC machine is run according to the research requirements. This study uses an RPM parameter of 1000 with a welding rate of 10 mm/minute. The pin tool is pressed into the aluminum plate to a depth of 0.5 mm. The welding schematic is shown in Fig. 3.



(a) (b)

Fig. 2. Design and profile of a). Cylindrical tool pin, b). Threaded tool pin

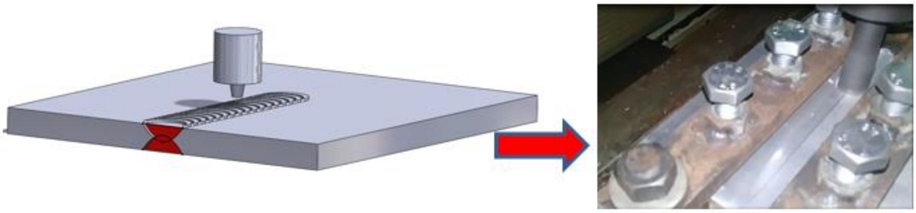
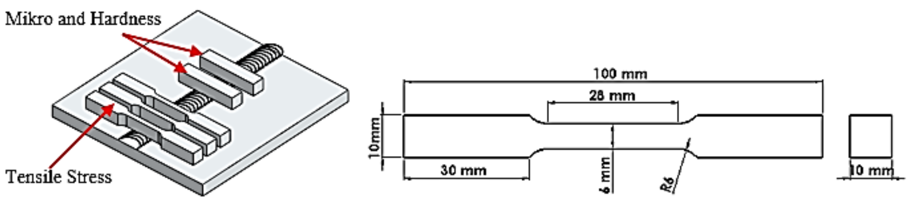


Fig. 3. The Schematic of Friction Stir Welding

During the sample collection phase for microstructure observation and tensile testing, the aluminum plate that has completed welding is cut on one side using a wirecut tool, as shown in Fig. 4(a). The sample specimen for tensile testing follows ASTM E8M-11 standards, as indicated in Fig. 4(b). The microstructure material to be used is first resin-coated to facilitate polishing. The microstructure material is then sanded with grades 120, 220, 400, 800, 1000, 1500, and 2000. The etching solution for the microstructure specimen complies with ASTM E407-07 standard number 3, which consists of 2 mL of HF, 5 mL of HNO3, 3 mL of HCl, and 190 mL of distilled water[12].



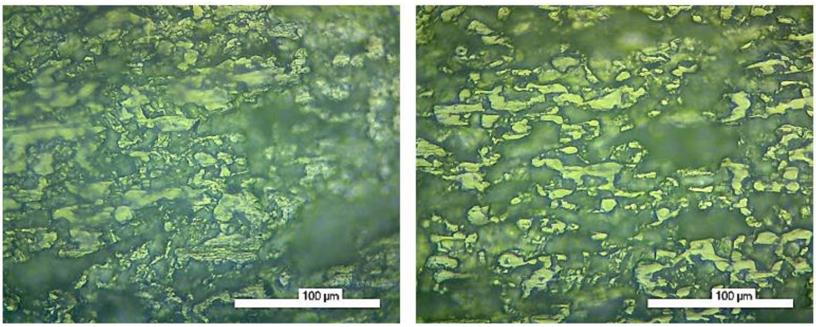
(a) (b)

Fig. 4. a). Sample Area, b). Standard Specimen for tensile test (ASTM E8M)

3 Result and Discussion

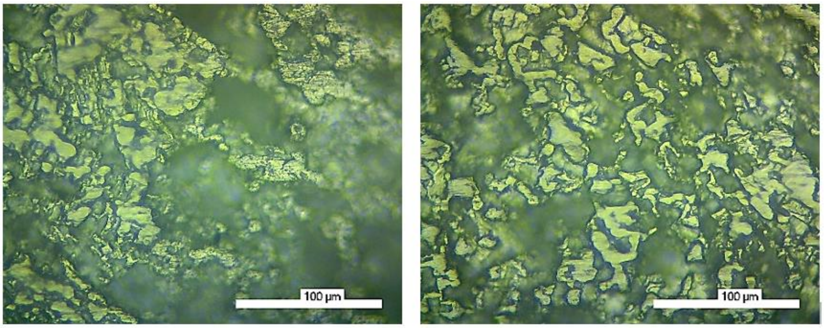
3.1 Microstructure

The optic metallography testing is performed to see the microstructure of materials that have undergone FSW. The investigation result of the FSW on AA1100 aluminum is firstly to observe the microstructure of the Base Metal (BM) as presented in Fig. 5, the second is the Heat Affected Zone (HAZ) shown in Figure 6 and the third is the Weld Nugget (WN) area shown in Figure 7. The observation of the microstructure of the friction stir welding on the AA1100 aluminum showed no significant particle refinement on the Weld Nugget (WN), HAZ and BM areas as it is a type of material that cannot be given a heat treatment, so recrystallization will not occur [13]. The black particles evenly distributed in the aluminum matrix are FeAl3, as shown in Figure 7 (a, b). FeAl3 is a compound formed from the reaction between aluminum and Fe, in which aluminum reacts to bind Fe above 0.4% Fe. The more FeAl3 grains that are formed the more difficult the dislocation movements that cause the increasing of strength and hardness of the metal. The grain structure also has grain boundaries and they disrupt the movement of dislocations. A large number of grain boundaries will make dislocation movements more difficult and at the same time it will also improve the mechanical properties of the metal. The microstructure within the HAZ area as shown in Fig. 6 shows that the area is affected by heat only and recrystallization does not occur. That's why the grains found in the HAZ area are coarse and large [14]. The microstructure within the BM area is on an elongated ellipse form that is in direction of the x-axis and this occurs due to the material formation process. When the material rolling process is usually done to form a metal plate with a certain thickness, the elliptic thickness of the grain is affected by the reduction ratio of the plate thickness [15]. The HAZ area is a location affected by thermal cycles without any plastic deformation on the FSW process. The microstructure here is able to change its area, that's why the grain size in the HAZ area will change depends on the material characteristics, temperature, heating time, and cooling rate[16]. as it is shown in Fig. 6.



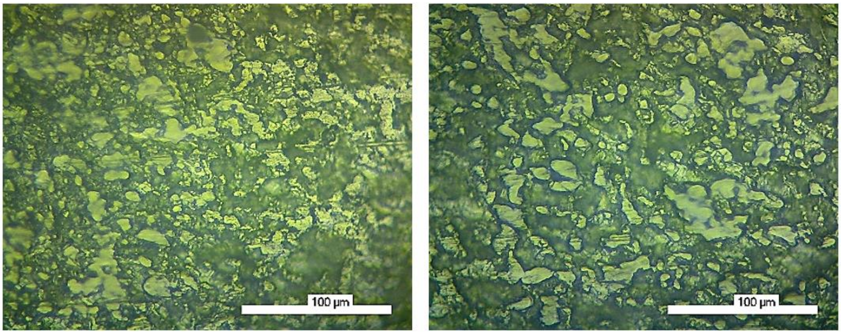
(a) (b)

Fig. 5. Microstructure of Base Metal a). Cylindrical pin, b) Threaded pin



(a) (b)

Fig. 6. Microstructure of HAZ a). Cylindrical pin, b) Threaded pin



(a) (b)

Fig. 7. The Microstructure of Weld Nugget a). Cylindrical pin, b) Threaded pin

3.2 Tensile Strength

In order to observe the mechanical properties of the Friction Stir Welding results, a tensile test was performed using the Universal Testing Machine. The results are as shown in Table 2.

Table 2. Tensile Stress

Parameters	Yield Stress	Max Stress
Raw Materials	94.154	103.237
Cylindrical Tool Pin	75.708	87.282
Threaded Tool Pin	80.324	88.037

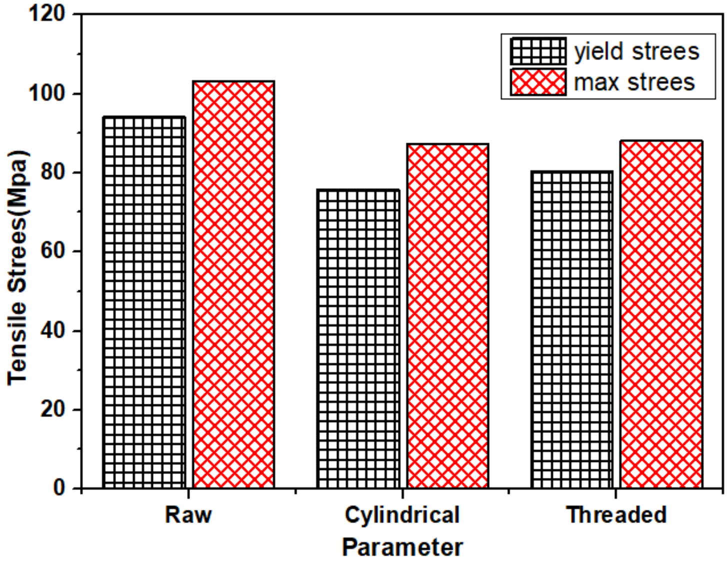


Fig. 8. Tensile Stress

The results of the tensile test (Fig. 8) show that the highest yield stress and max stress values are located in the FSW using the Threaded tool pin profile, namely 80.324 MPa and 88.037 MPa respectively and it in line with Kumar teal's research [8]. Besides, this result is also consistent with the microstructure observations shown in Fig. 7 (b), that the grain boundaries of the microstructure in the weld nugget area are dense and smooth, as the dynamic recrystallization occurs in the weld nugget area. The lowest yield stress and max stress values are found in the FSW parameter with a cylindrical tool pin profile, with values of 75.708 MPa and 87.282 MPa. This value correlates with the microstructural observations in the weld nugget area shown in Fig. 7 (a), that the grain boundaries look coarser and larger.

4 Conclusion

Friction Stir Welding on AA1100 aluminum shows that the grain boundaries in the weld nugget area look smooth and dense in the parameter of using with a Threaded pin profile. This occurs because the mixing process between the two materials is even and there is a dynamic recrystallization reaction, resulting in very good and ductile welds. The use of threaded pin tool profiles also produces good tensile strength with the highest value of 88.037 MPa.

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