The Effect of Pin Shape on the Friction Stir Welding Quality of Aluminum AA1100 Series

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Abstract

Aluminum is a material that is soft, lightweight, resistant to corrosion, and has good electrical and thermal conductivity. Aluminum has a specific gravity of about 2.65-2.8 kg/dm³, a melting point of 658ºC, and tensile strength of 90 MPa. Aluminum 1100 series is an aluminum alloy mixed with other materials, such as copper, iron, chrome, manganese, and zinc, with an aluminum content of 99,0%. Welding is the joining of two metals in a liquid state with or without filler. FSW (friction stir welding) is friction welding; the process does not require filler material. The heat used to melt the metal is obtained from the friction between the indenter and the workpiece. In the research, the shape of the indenter pin used is, oval shape, cone shape, and changing spiral form with a tool rotation of 2000 rpm and a welding rate of 16 mm/minute. The tests carried out are Rockwell hardness testing and tensile tests. From the results of research conducted, it was found that the shape of the indenter pin greatly affects the quality of the weld. The indenter pin changing spiral form results in better weld quality compared to the other two pin shapes.

Keywords: *Aluminum, AA1100, pin shape, friction stir welding*

I. INTRODUCTION

Aluminum is a chemical element with the symbol Al and has the atomic number 13. Pure aluminum contains 66% bauxite and 33% clay. Aluminum has several physical properties, including a specific gravity of about 2.65-2.8 kg/dm³, a melting point of 658ºC, a tensile strength of 90 MPa in pure aluminum or about 200-600 MPa in aluminum alloys, the atomic arrangement of an aluminum lattice is FCC or Face Centered Cubic. In addition, aluminum is soft, lightweight, corrosion resistant, and has a relatively good electrical and heat conductor [1].

The use of aluminum metal is increasing from year to year, such as in the world of printing for photoengraved plate materials, the construction sector and the industrial world of machinery as a material for motor vehicles and also materials for aircraft fuselages, even for household appliances. However, in general, the use of these metals uses the type of rivet and solder connection. Both kinds of splicing have drawbacks and limitations; for example, splicing using a rivet will increase thickness, the use of added material, and the presence of wasted material from the rest of the drilling. To overcome this, the connection process uses the welding method. However, because aluminum has different physical characteristics from other metals, the welding process is challenging, and the welding results are not good. One welding method suitable for aluminum is Friction Stir Welding, as mentioned elsewhere [2].

FSW welding was initially developed by Wayne Thomas of The Welding Institute (TWI) in 1991 to research aluminum alloy material applications. FSW is a welding method in the solid-state welding category. The process takes place below the melting point of the workpiece. Therefore, FSW can be applied to connect similar materials or dissimilar metals [3].

The FSW method produces a smaller Thermo-mechanical Affected Zone (TMAZ) area than the Shield Metal Arc Welding (SMAW) welding method. Therefore, this welding method can reduce the potential for welding failure due to additives. In the FSW welding method, several parameters can affect the quality of welding, including tool rotation speed (rpm), tool translation speed (feeding), tool slope during welding, downforce, plunge depth tool, and tool design and material [2].

II. Materials and Methods

In this study, Aluminum AA1100 series was carried out for friction stir welding method using different variation of tool design. In the following information the detail of samples preparation, FSW process, and the mechanical testing of the welded materials will be presented.

A. Materials

In this study, friction stir welding process was carried out using a VHF3 milling machine under the tool's rotation speed of 2000 rpm and 16 mm/minute of welding speed. The figure of VHF3 milling machine is presented on Fig. 1.

Figure 1. Milling machine

Aluminum series AA1100 is an alloy containing other elements, including copper, iron, chrome, manganese, and zinc. The minimum content of Aluminum was 99.0%. Aluminum and its alloys are classified as the light metals with high strength, corrosion resistance, and good electrical conductivity. Aluminum alloys, especially the AA1100 series has been applied broadly in the industrial fields. It was widely used as pressure vessels, heat exchangers, pipes, and others [4]. The 1100 series aluminum welding process uses a length of 65 mm, a width of 50 mm, and a thickness of 6 mm, as on figure 2.

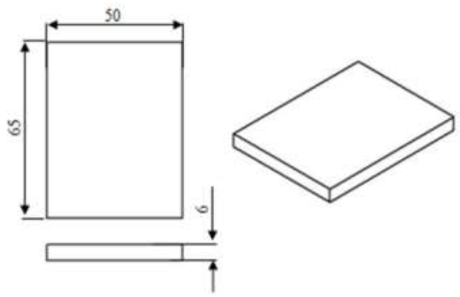

Figure 2. Specimen dimensions

The indenter used for this welding is VCN steel, with three variations, i.e.: oval shave, cone shape, and changing spiral form, as presented on figure 3. VCN steel is a type of steel with very high strength (ultrahigh strength steel). This type of steel has very high flexibility, toughness, and strength. This material is widely used to withstand impact loads with high strength. VCN steel is a type of low alloy steel or low alloy steel with an alloying element content of less than 5%. The chemical composition of this type of VCN steel is 0.38% C, 0.20% Si, and 0.70% Mn. 1.50% Cr, 96.79% Fe, 0.20% Mo and 1.64% Ni [5].

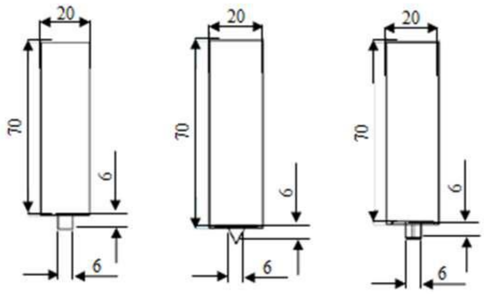

Figure 3. FSW Pin Shapes (a) Ovale shape, (b) Cone shape, and (c) Changing spiral form

B. Specimen for Mechanical Testing

After the specimens AA1100 are welded, hardness tests and tensile tests are carried out. The hardness test is a Rockwell hardness test using the HRf standard, as presented on figure 4. The tensile test was carried out on the welding results using the ASTM E8/E8M standard, with the dimensions of the test specimen as shown in fig. 5 below.

Figure 4. Hardness test equipment

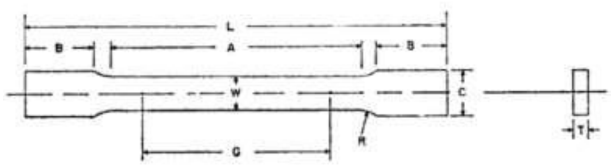

Figure 5. Tensile test specimen

III. RESULTS AND DISCUSSIONS

A. Rockwell Hardness Test

Material hardness can be defined as the material's resistance to the compressive force of a different, more rigid material. There are three pressing methods: the scratch, the reflected, and the press. The amount of load and the type of indenter to be used varies according to the kind of material to be tested. However, in the Brinell test, the type of indenter and the load used are smaller so that a slight indentation and a smooth surface are obtained. This method is widely used in the industrial world because the procedure is carried out faster [6].

The hardness test used is a Rockwell hardness test with a scale of "f" with a steel ball indenter with a diameter of 1/16", a minor load (F0) of 10 kgf, a major load (F1) of 90 kgf, with a total load (F) of 100 kgf. The tests included six specimens from friction stir welding and one original sample (raw material). For samples resulting from friction stir welding, hardness tests were carried out in the Weld Nugget (WN), Thermo-mechanically Affected Zone (TMAZ), and Heat-Affected Zone (HAZ) areas with three points each. The following are the results of the Rockwell hardness test as presented on table 1.

Table 1. Rockwell hardness test data

No	Pin shapes	N (rpm)	V (mm/min)	HRf			HRf Average		
				BM	TMAZ	HAZ	BM	TMAZ	HAZ
1	Oval Shape	2000	16	47	44	41	45.33	41.33	41
				45	41	41			
				44	39	41			
2				47	40	40	41	41.33	40.67
				36	40	41			
				40	44	41			
X (average)							43.165	41.33	40,835
3	Cone Shapes	2000	16	45	43	38	42.67	42.67	38.33
				42	40	35			
				41	45	42			
4				42	43	38	42.33	42.67	40
				43	42	41			
				42	43	41			
X (average)							42.5	42.67	39.165
5	Changing Spiral Form	2000	16	45	42	39	45.33	43.67	40.33
				45	44	41			
				46	45	41			
6				44	41	41	44.67	42.67	41
				45	43	40			
				45	44	42			
X (average)							45	43.17	40,605
Raw Material				52	53	51	52		

The results of the Rockwell hardness test in the Weld Nugget (WN) area showed that the highest hardness value is in the indenter changing spiral form, which is 45, and the lowest value is in the indenter cone shape, which is 42.5. In the Thermo-mechanically Affected Zone (TMAZ) area, the highest hardness value is found in the indenter changing spiral form, which is 43.17, and the lowest value is in the ovale shape indenter, which is 41.33. In the Heat-Affected Zone (HAZ) area, the highest hardness value is found in the ovale shape indenter, which is 40.835, and the lowest hardness value is in the cone shape indenter is 39.165, as presented on fig. 6.

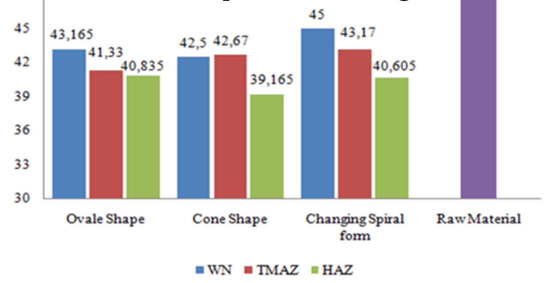

Figure 6. Graph of Rockwell hardness values

The hardness values of the three types of indenter pins used in the weld area being tested for hardness, namely Weld Nugget (WN), Thermo-mechanically Affected Zone (TMAZ), and Heat-Affected Zone (HAZ), almost always decrease compared to the base material area.

In the WN area, the hardness value decreases because this area is completely recrystallized; the decrease is also caused because the FSW welding process does not use filler material. In the TMAZ area, the hardness value also decreases below the WN value; this is because, in that area, the plastic deformation of the material is caused by the influence of heat. Finally, in the HAZ area, the decrease is most significant because, in this area, the material undergoes a thermal cycle which causes changes in the microstructure.

B. Tensile Test

The tensile test is a method used to determine the strength of a material by applying a load with an axial force. The test is carried out by clamping at both ends of the test specimen on the tensile test load frame and the results were presented on Table 2. At the time of testing, the tensile force used for testing is obtained from a universal testing machine which will cause an elongation of the specimen until it breaks [7].

The tensile test results have the highest ultimate stress value of 96,218 MPa with an indenter changing spiral form and the lowest maximum stress value of 63,153 MPa with a cone shape indenter.

Table 2. Tensile test results

Specimen	Pin Shapes	N (rpm)	v (mm/min)	UTS (MPa)	Yield Strength (MPa)	Fracture Area
1	Oval Shapes	2000	16	64,105	50,001	SZ
2				65.045	50.943	SZ
x (average)				64.575	50,472	
3	Cone Shapes	2000	16	64,935	54.586	SZ
4				59,370	49,260	SZ
x (average)				62.153	52,058	
5	Changing Spiral Form	2000	16	100.570	59,660	SZ
6				91,866	59,295	SZ
x (average)				96.218	59,478	
Raw Material				209,764	92.587	

Meanwhile, the highest yield strength value is 59.478 MPa with an indenter changing spiral form, and the lowest yield strength value is 50.472 MPa with an ovale shape indenter.

From the results of the tensile test, the shape of the indenter changing spiral form is superior compared to the ovale and cone shape indenter. This is because the shape of the indenter changing spiral form has a larger mixing area so that when welding, the surface of the specimen is penetrated more broadly and evenly.

In addition, this shape of the indenter also has a larger surface area, so the holding time of five minutes can be done quickly and produce a better heating area and heat. The following is a graph of the tensile test results as on Fig. 7.

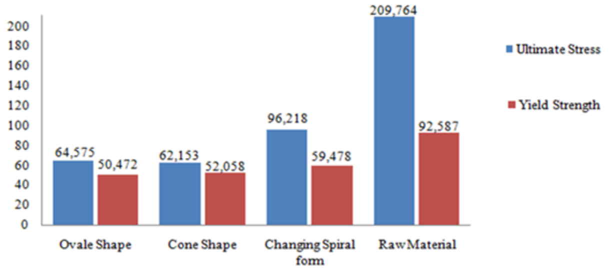

Figure 7. Graph of tensile test value

C. Welding Defects

In friction stir welding, several defects often occur, namely lack of penetration, surface tearing, and internal voids. Lack of penetration is a defect in the weld nugget (WN) where the weld does not entirely reach the bottom of the welded specimen. This defect occurs because the length of the indenter pin is less than the thickness of the sample being welded. The data of welding defect is presented on Table 3.

Table 3. Welding defects

Type indenter	Type of defect		
	Surface tearing blue circle	*Lack of penetration* Red circle	*Internal video* green circle
oval shape			
Cone shape			
Changing spiral form			

At the same time, the surface tearing defect occurs on the surface of the weld where the surface is cracked or uneven. This defect occurs due to several factors, including the rotation speed of the indenter and the welding speed being too fast or too low, the indenter pressure on the specimen not perfect, and the sample placement being uneven.

From the results of visual observations on the effects of friction stir welding of aluminum 1100 series, as shown in table 8, there are defects in each welding performed; only the quantity of defects is different. In specimens that use the ovale shape indenter, there are many defects of lack of penetration, surface tearing, and internal voids. Samples using cone shape indenters experienced the most lack of penetration and internal voids when compared to specimens using other types of indenters.

The specimens that use the kind of indenter changing spiral form the slightest defects. Welding defects that occur in the sample significantly affect the quality of the welding of the specimen. The results of welding using an indenter changing spiral form have slight imperfections, so the quality of the welding results is outstanding, as indicated by the high hardness and tensile test values. While welding using an Ovale Shape indenter which has many defects, the quality of the welding results decreases with the results of the hardness test and tensile test being low.

IV. CONCLUSIONS

The highest hardness value in the Weld Nugget (WN) area is found in the changing spiral form indenter, which is 45, and the lowest value is located in the cone shape indenter, which is 42.5. In the Thermo-mechanically Affected Zone (TMAZ) area, the highest hardness value is found in the changing spiral form indenter, which is 43.17, and the lowest value is in the ovale shape indenter, which is 41.33. In the Heat-Affected Zone (HAZ) area, the highest hardness value is found in the ovale shape indenter, which is 40.835, and the lowest hardness value is in the cone shape indenter is 39.165. The highest ultimate stress value is 96.218 MPa with a changing spiral form indenter, and the lowest ultimate stress value is 63.153 MPa with a cone shape indenter. The highest yield strength value is 59.478 MPa with an indenter changing spiral form, and the lowest yield strength value is 50 472 MPa with an oval shape indenter. This type of indenter-changing spiral form has a high quality of welding, resulting in both hardness and tensile strength.

References

[1] Prasetyana. D. 2016. “Pengaruh Kedalaman Pin (Depth Plunge) Terhadap Kekuatan Sambungan Las Pada Pengelasan Adukan Gesek Sisi Ganda (Double Sided Friction Stir Welding) Aluminium Seri 5083”. Skripsi. University Muhammadiyah Surakarta, Kartosuro - Surakarta.

[2] Rahayu, D. 2012. “Analisis Proses Friction Stir Welding (FSW) pada Plat Tipis Aluminium". Laporan Skipsi. Universitas Indonesia, Depok, Indonesia.

[3] Pratisna, P., Anggertyo, I., Adhiptya, P. N. A. 2017. “Sifat Fisik dan Mekanik Sambungan Las Friction Stir Welding (FSW) AA 5083 dengan Variasi Bentuk dan Kecepatan Putar Probe Pada Konstruksi Kapal". Prosiding Seminar National XI - Rekayasa Teknologi Industri dan Informasi. Sekolah Tinggi Teknologi Nasional (STTN), Yogyakarta.

[4] Sukmana, I., & Sustiono, A. 2016. “Pengaruh Kecepatan Putar Indentor Las Gesek Puntir (Friction Stir Welding (FSW) Terhadap Kualitas Hasil Pengelasan Aluminium 1100-H18”. Jurnal Mechanical. Vol. 7, No. 1, p. 15-19.

[5] Herlina, F., Firman, M., Najib, M. 2016. “Analisa Kekerasan Baja VCN 150 pada Poros Baling-baling Pisau Mesin Crusher”. UNISKA Journal of Mechanical Engineering Vol. 01 No. 02, pp. 26-32.

[6] Sakura, R. R., Junus, S., Jatisukamto, G., & Septian, R. 2017. “Pengaruh Variasi Waktu Gesek Friction Welding pada Baja AISI 1045 Dengan Sudut Chamfer 150 Terhadap Sifat Mekaniknya. Elemen Jurnal Teknik Mesin, Vol. 4, no. 2, pp. 113-116.

[7] Dowling, N. E. 2013. “Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue”. 4th Edition. Prentice Hall, New Jersey 07458, United States of America.