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Mechanical properties analysis on FSW butt joint of aluminum alloy that applied in marine industries

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Abstract

Friction Stir Welding (FSW) was promoted as new welding method, a cheap and eco-friendly welding with good quality joint. Aluminium Alloy used widely in industries, including marine industry. AA 5XXX and 6XXX series are materials used for shipping manufacture and offshore construction, because of its corrosive resistant and good strength properties after joining. Similar butt joint welding using the FSW method for a number of aluminum alloy series AA 5052, AA 5083, AA 6061, AA 6063. Welding samples were made using AWS standards and then given radiographic testing to determine the general condition of the welds. Then a tensile strength test was carried out using a ZwickRoell tensile testing machine and a hardness test using a micro hardness Vickers Buehler with ASTM standards on the welding results to analyze the mechanical properties of the welded joint zone, as well as compare each result and get the ratio of the quantity of mechanical properties of the joint results the weld to the base material. After that, the results and discussion were obtained that the weld area showed different mechanical properties for each series of aluminum alloys. The value of the tensile strength when compared to the tensile strength of the base metal is around 60-75%, while the hardness value is around 75-80.6 HV for all the welded samples.

Keywords:

FSW, AA 5052, AA 5083, AA 6061, AA 6063, mechanical properties.

1 Introduction

Welding is a joining process that utilizes heat energy between two or more parts of materials, which can be similar or dissimilar. Welding has an important role in the engineering and repair of materials, which generally are metallic. So this makes it one of the supporting factors for the industrial, especially industries that use metal or like as the main material for production. And the marine industry is one of the producers that use a lot of metal as a production material, mainly aluminum metal or its alloy (Aluminum Alloy).

Aluminum Alloy has many series of types, and with different properties and uses. One of that is often used in the marine industry is the 5XXX and 6XXX series. The 5XXX series aluminum alloy is a type of aluminum alloy series which generally has a dominant composition of magnesium and chromium compared to other alloy compositions. Meanwhile, the 6XXX series is generally combined with magnesium and silicon as the dominant elements.

Friction Stir Welding (FSW) research on Aluminum Alloy has been carried out, including comparative studies of residual stress and mechanical properties of FSW and TIG welds on structural steels [1]. Study of tool rotation speed and welding speed on mechanical properties of welded aluminum alloy with the FSW welding process [2]. Research on the effect of tool parameters on mechanical properties, temperature, and force generation during FSW [3]. Research to evaluates the welding results between AA 5083 and AA 6061 with the FSW process, which aims to determine the effect of the process parameters and their optimization on the quality of the welds and the formability of the material after the FSW process [4]. Research about the effect of process parameters on the welding of two different series of AA materials AA 6061 and AA 7075 was also carried out [5]. The experimental study on FSW between AA 6061 and AA 5083 using the Taguchi technique [6]. Then research [7] conducted an experimental FSW study of AA 5058 and AA 6061, measuring the relationship between tool rotation speed, welding speed, and tool angle, with the aim of analyzing the effect of FSW process parameters on the test response. Furthermore, research on the analysis of mechanical properties differences in AA 5083 welding which is distinguished by the position of the welding direction, parallel direction and perpendicular direction to the material roll [8].

Research on friction spot welding of dissimilar AA 6063 and AA 5083 [9]. Experimental study on the hardness and fatigue behavior in joining of AA5083 and AA6063 by FSW method [10]. Mechanical properties of AA 6063 joined by FSW method and tungsten inert gas welding [11]. Research on the effect of friction stir welding on microstructure and mechanical properties of AA 6063 [12]. Research on the effect of tool pin profile on mechanical and microstructural properties of friction stir butt and scarf welded of aluminum alloy 6063 [13]. The study investigated the weldability of AA 5052 by underwater friction stir welding [14]. Experimental study of weld defects and mechanical properties during underwater FSW welding of AA6061 - AA6063 [15]. Research on the effect of FSW welding parameters on the microstructure and mechanical properties of 6061 aluminum alloy joints [16]. Research on the mechanical properties of AA7075-AA5182 joined by the FSW method [17]. Research on the mechanical properties of friction stir welding results of AA5083-AA6061 [18]. Research investigated the effect of tool offset on the mechanical properties of AA6061-T6 and AA7075-T6 joint in parallel FSW welding process [19]. Experimental study of friction stir welding of AA 6061 [20].

The marine industry certainly requires welding activities. So far, various welding methods have been applied, including the FSW welding method, which has been widely used for welding in the marine industry because it is relatively better and environmental friendly when compared to other welding methods. Aluminum Alloy material series 5 and 6, generally widely used in the marine industry. This type of alloy has good mechanical properties such as high tensile strength and corrosion resistance, which makes it often applied to shipbuilding and offshore construction.

Regarding the mechanical properties, a problem is found, how the value of the tensile strength and hardness of the results of similar welded joints from aluminum alloy series AA 5052, AA 5083, AA 6061, AA 6063. So it is necessary to conduct a research to analyze the mechanical properties of the welding of that four series of aluminum alloys. Thus, the purpose of this study is to analyze the mechanical properties of the results of similar welding on several series of aluminum alloys that are widely used in the marine industry, as well as to compare each result and be able to determine the quantity ratio of the mechanical properties of the welded joint to the base material.

2 Research Methods

Aluminum alloy series AA 5052, AA5083, AA 6061, AA 6063 is used in this research, with thickness 5mm for each of them. Friction stir welding process uses a milling machine with parameters feed rate of 21 mm/minute, tool rotation of 910 rpm, tilt angle of 0^{o}. As for the pin tool used is AISI H13 steel with a shoulder diameter of 20 mm and depth of 5 mm, and the indent depth reaches 4.6 mm. FSW is carried out by applying the AWS D17.3/D17.3 M:200X standard. Then the results of the welding are given radiographic testing to determine the general condition of the welds. After that for mechanical testing of tensile strength using a ZwickRoell tensile testing machine by applying the ASTM E8M-04 standard and hardness testing using a Vickers Buehler Microhardness tool by applying the ASTM E384-69 standard.

After carrying out welding and testing, the results of the test value are obtained, and then processed in such a way to be data that will be analyzed and discussed. At the end, from the results and discussion, conclusions are drawn. In generally, the flow of this research is shown by the following flowchart.(Fig. 1)

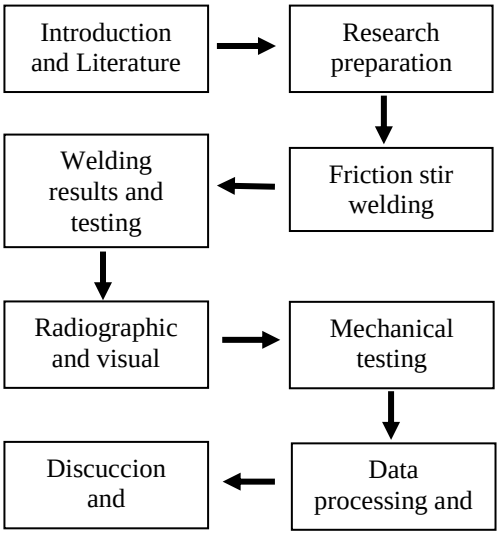

Fig.1. Flowchart of Research Methods

3 Results and Discussion

3.1 Friction Stir Welding

After the friction stir welding process is carried out, the results are obtained as below. Furthermore, this sample will be analyzed first to see if there is significant defect, either outside or inside the weld, before we make specimens for mechanical testing in accordance with the applicable standard of testing rules / SOP. The welding results for AA 5051 and AA 5083 are as shown in Fig. 2 and 3. It can be seen clearly that the welding results obtained are quite good and there is no major defect.

Fig. 2. Welding Results of AA 5051

Likewise, the results of AA 6061 and AA 6063 welding are as shown in Fig. 4 and 5. The results can be classified as quite good and there is no significant defect that can be seen. So, that welding results can be continued to the radiographic testing to check the conditions in the weld.

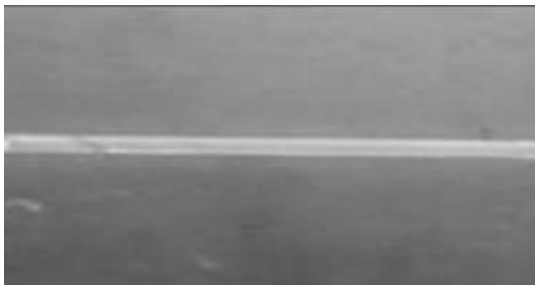

Fig. 3. Welding Results of AA 5083

If the radiographic results are deemed well enough, it can be proceed to the mechanical testing, otherwise the welding will need to be repeated.

Fig. 4. Welding Results of AA 6061

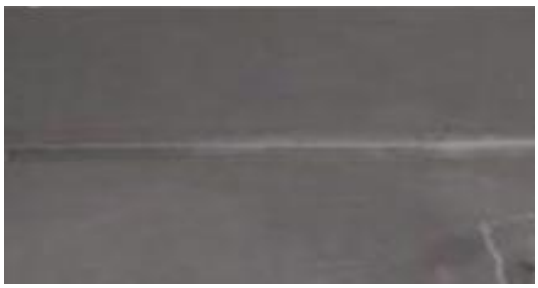

Fig. 5. Welding Results of AA 6063

3.2 Radiography

Radiography testing is needed to detect a defect possibility in the weld area, which is a non-destructive test. Here are the results of the radiography.(Table 1)

Table 1. Radiography Results

Type	5052	5083	6061	6063
Root defect	-	-	-	-
Crack	-	-	-	-
Incomplete Penetration	-	-	-	-
Incomplete fusion	√	√	√	√
Defect	-	-	-	-
Reject	-	-	-	-

From Table 1, it can be seen that for welding AA5052, AA 5083, AA 6061, AA 6063, there are no serious indications that indicate damage or defects in the weld results, even though there are indications of incomplete fusion. Thus, this does not make it a sample/welding result that must be rejected, or in other words this acceptable. So because of the radiographic results show that all welding samples are classified as good or acceptable, the welding samples can be continued to the mechanical testing.

3.3 Tensile Strength

The tensile test aims to know the tensile strength of the material weld area. Fig. 6 is the data on the average tensile test results at the maximum point (break point) for each sample of aluminum alloy, which is presented in graphical form

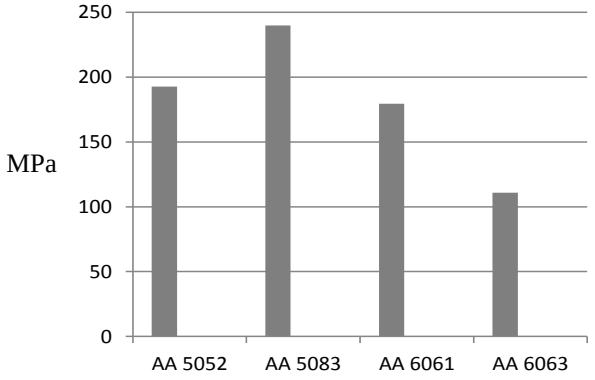

Fig. 6. Graph of Maximum Tensile Strength Value (Break Point)

The graph above shows that the tensile strength of weld results for each series of aluminum alloy is different. If we pay attention to AA 5083, it is the one that has the highest tensile strength value of weld results, which is 239.8 MPa. Compared to the value of the tensile strength of AA 5083 material itself which is 317 MPa, the value of the tensile strength in the weld area has a ratio about 75% of the value of the material tensile strength. From this result, it can be said that FSW welding on the AA 5083 is quite effective and optimal.

The result of welding AA 5052 is 192.7 MPa. That value is about 66% of the maximum tensile strength value of AA 5052 material which is 291 MPa. Then for AA 6061 material has a tensile strength value in the range between 290 MPa, so based on the tensile strength value of AA 6061 welding as shown in the graph above, the ratio is about 62%. After that, the last one is AA 6063. The tensile strength value of AA 6063 welding shows data that the tensile strength is 110.8 MPa, which is compared to the strength of the base metal, the ratio is about 60%. Tensile Strength Comparison of Weld Area and Base Metal is shown in Table 2.

Table 2. Tensile Strength Comparison of Weld Area and Base Metal

Aluminum Alloy	Weld Area	Base Metal
AA 5052	192,7 MPa	291 MPa
AA 5083	239,8 MPa	317 MPa
AA 6061	179,5 MPa	290 MPa
AA 6063	110,8 MPa	186 MPa

The tensile test results obtained in this research are also in line with other linear research. Among them are related to aluminum alloys of type 5052 [14], [22], [23] and type 5083 [6], [8], [10], [18], [21], and *aluminum alloy* 6061 [4], [6], [16], [18], [20] and AA 6063 [10]–[13], [15]. All of them generally confirm that the tensile test value in the welded area is below the value of the base metal. The results and discussion of this research indicate that the weld area have a tensile strength under level value of the base metal tensile strength, with a decrease in strength about 25% - 40% of the initial tensile strength of the base material.

If we look at all the samples, all of them have the tensile strength of weld is relatively smaller than the tensile strength range of base material. This could be because the heat supply intake generated due to the rotation of the tool pin for joining the material is not proportional enough for its supply and spread. The reference quoted from the scientific literacy of Aluminum Welding, informs that FSW welding results on aluminum or aluminum alloys without incomplete fusion and significant defects will be able to increase the tensile strength of the weld area to be greater. As for the average percentage ratio of tensile strength to the base metal, either in this research or other literacy research, the average percentage ratio is around 50s/60% to 75%.

3.4 Hardness

Fig. 7 is a graph of the results of hardness testing for the weld of each sample of aluminum alloy used in this research. The hardness test of the weld in this research was carried out by dividing the testing area into three zones. The first is the base material/parent material zone, this zone is a zone that is not exposed to direct welding and does not receive/directly affected by heat during the welding process. Then the second area is the Heat Affected Zone (HAZ) which is the area which is directly affected by the heat generated in the welding process. And next is the weld zone, the zone where welding occurs directly, which in this case for FSW is often also referred to as the stir zone. The stir zone is the area that is exposed direct to pin rotation also softening and bonding of the material occurs.

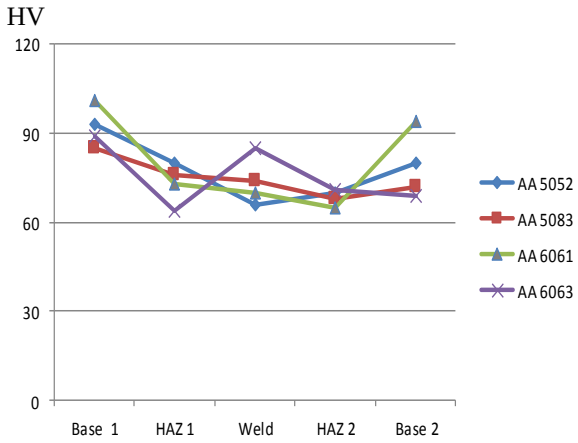

Fig. 7. Graph of Hardness Value (HV)

The graph above shows the results of the hardness test in the three zones previously described of the four aluminum samples used. Index 1 and 2 show the position of the two sides of the sample, namely the left and right of the weld. For AA 5052, the hardness value is 93 HV for base 1, 80 HV for HAZ 1, 66 HV for weld, 70 HV for HAZ 2, and 80 HV for base 2. Then for AA 5083, hardness value for base 1 is 85 HV, HAZ 1 is 76 HV, for weld 74, while for HAZ 2 and base 2 is 68 HV and 72 HV respectively. Furthermore, for AA 6061 the hardness value is 101 HV on base 1, 73 HV on HAZ 1, 70 HV on weld, 65 HV on HAZ 2, and 94 on base 2. Last for AA 6063 the hardness value for base 1 and HAZ 1 respectively 89 HV and 64 HV, for the weld is 85 HV, for HAZ 2 has a hardness value of 71 HV, while base 2 is 69 HV.

The results of the hardness test are also in line with other linear research. Among them are research on aluminum alloy 6061 [4], [6], [16], [18], [20] and AA 6063 [10]–[13], [15]. As well as aluminum alloy series 5052 [14], [22], [23] and series 5083 [6], [8], [10], [18], [21]. The value of the hardness test in the welding results are varies according to the weld area (base, HAZ, weld/stir zone). However, the value for the weld area in a range and average from the hardness test data, it can be stated that for AA 5052 has a hardness value range of 66-93 HV and an average of 77.8 HV. While the AA 5083 has a range of values 68-85 HV and an average of 75 HV. Then for AA 6061, it has a value range of 65-101 HV with an average value of 80.6 HV. And for AA 6063 it has a range of values 64-89 HV with an average value of 75.6 HV.

The results of the hardness test in this research as well as the research literacy show that in general the hardness value of all aluminum alloy samples in the weld/stir zone and HAZ is fluctuating and does not exceed the value of the base material. This could be due to the imperfect stirring process causing low heat supply and uneven distribution, as well as indications of imperfect joining. Therefore, the hardness value in the weld area (weld/stir zone and HAZ) is lower than the hardness value of the parent metal.

4 Conclusion

Based on the results and discussion of the research that has been carried out, it is concluded that the FSW welding of AA 5052, AA 5083, AA6061, AA 6063 can be said to be quite good and acceptable although imperfect. This has an impact on the mechanical properties of the weld area.

The average tensile strength results for each sample obtained are 192.7 MPa for AA 5052, 239.8 MPa for AA 5083, 179.5 MPa for 6061, and 110.8 MPa for 6063. Which means it is presented as a percentage to the tensile strength of the parent metal, the percentage ratio is about 60% to 75%. In line with that, the results of the tensile strength values in other research literacy also confirm the same thing.

The hardness value at the five point of three zones, the results of the hardness test in this research indicate that in general the hardness value of all aluminum alloy samples in the weld/stir zone and heat affected zone fluctuates and does not exceed the value of the base material, and this also occurs in other research literacy. As for the hardness values, each obtained 77.8 HV for AA 5052, 75 HV for AA 5083, 80.6 HV for AA 6061, and 75.6 HV for AA 6063.

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