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Effect of Post Weld Heat Treatment on Friction Stir Welding Dissimilar Aluminum Alloy 5052-6061/T6 Joints

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Abstract **- In this research, the focus is on joining dissimilar aluminium alloys 5052 (heat treatable) and 6061/T6 (nonheat treatable) using the friction stir welding (FSW) method with tool rotation speed parameters of 1460 rpm and travel speed of 30 mm/s. The results of the FSW joint were given post-welding heat treatment (PWHT) in the parameters of solution heat treatment, quenching in water, and then artificial ageing. Macro photographic observations showed the width of the TMAZ on both sides of the welding zone is reduced on speciment with post welding treatment compared to as welded speciment. The hardness value of the specimens increased on the 6061/T6 side, while the 5052 side experienced a decrease in hardness value. In tensile testing, the UTS value of all specimens produced relatively similar results in the range of 215 - 218 MPa. In contrast, PWHT specimens experienced a decrease in elongation refered to as welded specimens.**

Keywords: FSW, Aluminium Alloy, PWHT, Dissimilar, AA 6061, AA 5052, Solution Heat Treatment, Artificially Aging.

I. INTRODUCTION

The integration of aluminum alloy materials in shipbuilding provides various benefits but also comes with certain limitations and challenges. Compared to steel, aluminum alloys offer advantages such as lower weight, superior resistance to corrosion, and reduced maintenance requirements [1]. One application is high-speed aluminium ships used in commercial and non-commercial marine transportation due to the many benefits provided by aluminium ships. Data reported by INCAT shows a rapid increase in aluminium vessels with larger dimensions and weight. [1]. The joining of aluminium and its alloys, such as aluminium alloys in heat-treatable and non-heat-treatable groups, is a challenge in welding due to variations in their chemical and material properties [2]. Metal inert gas (MIG) and Tungsten inert gas (TIG) are typically used for welding similar or dissimilar aluminium alloys. Unfortunately, these techniques also reveal some issues related to the thermal properties of aluminium. The weakness of arc, MIG and TIG can be avoided by friction welding performed below the melting point of the base material. FSW is a solid state joining process, which avoids weld defects such as porosity formed in fusion joining techniques and, therefore, has been widely used in welding aluminium alloys [3].

FSW is considered as the most important advancement in metal joining in the past decade and is considered a 'green' technology because of its energy efficienc, environmental friendliness and usability. Compared to conventional welding methods, FSW consumes much less energy. The process is environmentally friendly as it doesn't require gas or flux, and no filler metal is used during the joining. As a result, any aluminum alloy can be welded without worrying about compositional compatibility, which is a problem in fusion welding [4]. It has been observed that friction stir welded joints have excellent microstructure and mechanical properties [5]. The heat generated during FSW changes the microstructure of the weld zone and the region around the weld zone in aluminium alloys. Even though no melting takes place because of the heat produced during FSW, the material's mechanical properties still decrease, and softening behaviour or strength reduction occurs in the weld zone of FSW aluminium alloys, but much less extensively compared to fusion welding. [6][7].

Different techniques are employed to enhance the strong mechanical properties and favorable microstructural features of FSW joints, including post-weld heat treatment (PWHT). PWHT modifies the size, shape and distribution of secondary strengthening precipitate so that it can be used to restore the microstructure and improve the mechanical properties of FSW joints. PWHT stabilises the microstructure and can be a more appropriate option for improving the mechanical properties of FSW joints than other techniques [8]. Post-welding processes can be performed on welded samples to improve the strength losses in Al alloy welds by recovering precipitation-hardening particles and eliminating residual stresses or average grain size reduction in the weld zone [7]. The post weld heat treatment (PWHT) process on different aluminium alloys has been carried out by [9] using AA2024 and AA7075 base materials. Variable solution heat treatment and ageing at a solution treatment temperature of 400-500°C, ageing treatment at a constant temperature of 180° C for 5 hours, 8 hours, 12 hours PWHT at 480°C for 1 hour with cooling in water at 0°C

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followed by an ageing temperature of 180ºC for 12 hours showed significant improvement in tensile properties, resulting in 90% welding efficiency after PWHT [10] Conducted a shorttime annealing study on FSW joints of 7075 aluminium alloy with post-weld heat treatment at 460°C. Solution time parameter variations of 10 seconds and 300 seconds were the focus of the study, and ageing was carried out for 24 hours at 120°C. PWHT used in this study can increase the hardness and tensile strength of FSW joints, and welding efficiency can reach 102%. Studies discussing FSW joints of different aluminium alloys between heat-treatable and non-heat-treatable with PWHT variations were conducted by [7] On 6061/5083 aluminium alloy, with a rotation speed variation of 1200 rpm and a welding speed of 400 mm/min, obtaining a joint efficiency 71%.

Adding PWHT variations with solutionizing parameters at 535°C for one hour, shock cooling with water, and Artificial ageing at 175°C for 8 hours significantly increased the joint efficiency to 93%. Previous research on PWHT in FSW joints of heat-treatable and non-heat-treatable alloys is still tiny. One of the previous studies was conducted [7] with dissimilar material 5083-6061. Therefore, it is necessary to determine the effect of post welding heat treatment process on FSW joints of 5052 and 6061/T6 aluminium alloys with PWHT variations with shorter time duration variations. Solution heat treatment at 530°C for 5 minutes and 60 minutes, followed by partial annealing at 175°C for 8 hours, are the variations used in this study.

II. MATERIALS AND METHODES

2.1 Materials

The materials used in this research are 5052 and 6061/T6 aluminium alloys. Aluminium alloys 5052 and 6061 are better known as marine-grade aluminium. The length, width and thickness dimensions for FSW joining are 100 x 50 x 3mm, respectively, as shown in Figure 1(a). The chemical compositions of the aluminium alloys are showed in Table 1. The FSW tool material will use H13 steel (tool steel); the dimensions of the tapper with thread tool design are shown in Figure 1(b).

Table 1: Chemical composition of 5052 and 6061/T6 aluminium alloy

Material	Mg	Si	Mn	Cr	Cu	Fe	Al
5052	2.56	0.08	0.02	0.20	0.01	0.28	95.78
6061-T6	0.81	0.55	0.03	0.08	0.22	0.30	97.90

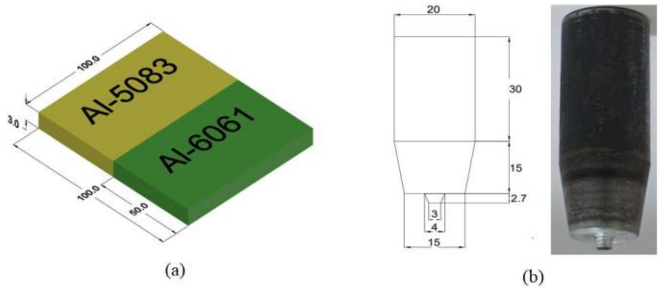

Figure 1: (a) Base Materials Dimenssion, (b) FSW Tool

2.2 Methods

The leading equipment in FSW joining is a vertical milling machine. The spindle is part of the central milling machine system that functions to grip and rotate the tool to produce movement and rotation. The milling machine used in this study is Emco FB-3. 5052 aluminium was placed on the forward side (AS), and 6061 T6 aluminium was placed on the reverse side (RS); various parameters were used in this study to compare the parameters of the as-welded and heat-treated FSW results.

Table 2 shows the welding parameters starting from as welded using a tool rotational speed of 1460 rpm and travel speed of 30 mm/min with Depth of plunge (DOP) 0.2 mm and 1º tool tilt angle. Furthermore, the PWHT parameters are the results of each FSW followed by heat treatment in the parameters of solution heat treatment (SHT) at 530ºC for 5 minutes and 60 minutes, rapid cooling (quenching) with water, and artificial ageing at 175ºC for 8 hours.

The microstructure evolution was observed using a Carl Zeiss axio Lab.A1 optical microscope. Previously, the specimens were smoothed successively with sandpaper of grits 240, 400, 600, 800, 1500, and 2000, followed by autosomal polishing. The microstructure of FSW joints will be visible by etching the samples using 1 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, and 95 ml H_2O. Micro hardness testing was carried out on the cross section of FSW sample using a Mitutoyo MH200 micro Vickers hardness test with load of 0.3 kg and a residence time of 10 seconds according to ASTM E384 standard. To determine the tensile strength value of FSW joints using an interest 400 universal testing machine with speed 2 mm/min.

Table 2: FSW parameters and PWHT

Specimen Name	TRS (Rpm)	DOP (mm)	TS (mm/min)	Tilt Angle	PWHT
As welded	1460	0.2	30	1º	
5M8H	1460	0.2	30	1º	SHT 5 Min + AA 8 H
60M8H	1460	0.2	30	1º	SHT 60 Min + AA 8 H

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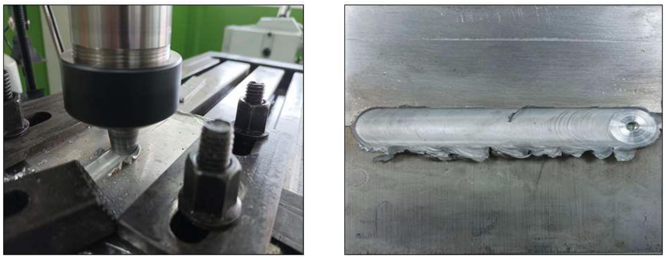
III. RESULTS AND DISCUSSIONS

3.1 Macrograph Observation

The surface result of FSW welding on the top of the plate, which is the place of friction between the tool shoulder and the workpiece, is shown in the figure 1. From the initial visual observation with the parameters of rotation speed of 1460 rpm and welding speed of 30mm/min, the visual appearance of the welding surface is smooth; there are no defects of lack of penetration or cracks visible on the welded specimens. The tool tilt with an angle of 1° is also another factor that produces a good appearance of the welding results, which show no irregularities and no surface defects, as has been done by [11] However, there is a noticeable flash on the retreating side. Flash on the RS side of FSW joining results was also reported by [12] who performed FSW joining of 5083-6082, where flash appeared due to excessive heat generation. The flash generated during FSW can be control by optimising the heat generated during welding, which depends on the rotational speed and welding speed of the tool. A very high tool rotation and a very low welding speed generate more heat simultaneously.

Therefore, an optimal combination of speed and RPM must be maintained to prevent flash formation. Flash defects can be controlled by shoulder design and plunge force and are commonly used as an indication that the required tool depth has been achieved for particular application [13] [14].



(a) (b)

Figure 2: (a) FSW joint process (b) Surface result of FSW joint

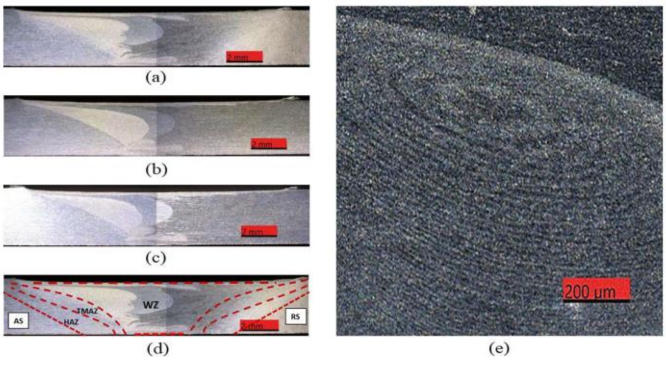


Figure 3: Macrograph of (a) As welded (b) PWHT 5M8H (c) PWHT 60M8H (d) As welded FSW zone (e) Onion ring

Figure 3(e) shows the onion ring pattern in the joint at the weld zone region. The onion ring indicates proper mixing of materials at the advancing and retreating sides during the FSW process. Previous research conducted by [15] by observation using an Electron Probe Microanalyzer (EPMA), the Mg content in the dark colour part of the onion ring, which is the composition of 5052-H32 aluminium alloy on the advancing side, is higher than in the light colour part, which is the composition of 6061-T6 aluminium alloy onion ring. A threaded tool pin profile also contributes to good mixing in FSW joints.

Figure 3(b)(c) shows macro photographs of the post-weld heat treatment of 5052 and 6061 FSW joints, heat treatment with parameters Solution heat treatment at 530ºC, Quenching in water, followed by artificial ageing. From the macro photos observation specimens with soaking time solution heat treatment for 5 minutes and 60 minutes it can be seen that there is no difference in the welding zone between that two PWHT specimens. Figure 3(a)(b)(c) shows the cross section of PWHTed Al5083-Al6061/T6 under various welding parameters. The welding zone after heat treatment generally looks similar to the as-welded condition. The width of the TMAZ on both sides of the welding zone (AS and RS), is reduced. The reduction of the TMAZ shape is closely related to the grain growth after heat treatment. The thinning of the TMAZ zone was also found by [16] the TMAZ microstructure of PWHT specimens was reduced compared to the as-welded condition, and the grain size in welding zone increasing to several hundred microns and up to several millimetres.

3.2 Hardness Profile

The microhardness values distributed across the cross section along the centre line of both welded and PWHT FSW joints are show in Figure 4. The welded joints show that the hardness value in the weld zone fluctuates, and then the hardness value decreases in TMAZ and HAZ. The lowest value of hardness is found in the HAZ on the RS side, 53.2. The decrease in hardness value in HAZ is due to HAZ ageing, dissolution of reinforcing deposits and grain development occurring in HAZ during FSW due to heat flow; HAZ in welded samples are soft on the RS side, especially on the 6061-T6 side, which is heat treatable aluminium [7] [17].

In the specimen pwht 5m8h hardness value on the advance side (5052) evenly around 56 HV, then decreased in the centre of the weld zone at 53 HV, then increased slightly on the side of 6061/T6. The low soaking time of these conditions may not be sufficient to completely dissolve the coarse deposits in the centre of the specimen. Thus, the presence of coarse deposits formed on the FSW is responsible for the low hardness values in the central part of the specimen

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[10]. Meanwhile, the specimen ath shows that the lowest hardness value is located in the weld zone 50.1 at HV. However, there is a significant increase in the hardness value on the area of RS.

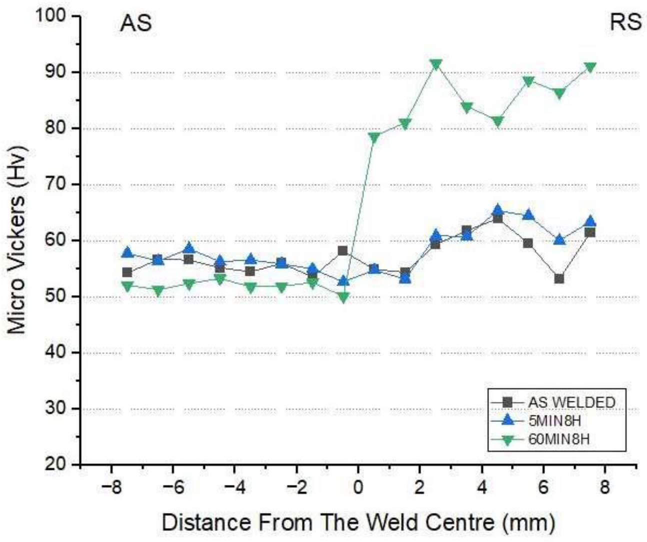

Figure 4: Microhardness of FSW joint

The hardness properties of Al6061 T6) are improved due to the homogeneous distribution of precipitation hardening after PWHT; precipitation hardening is the main factor that increases the strength of A6061 (T6) than the average of grain size. On the other hand, the hardness value of Al5052 has decreased. The hardness decrease in 5052 is due to coarsening of hard particles and grain growth in 5052 [7].

3.3 Mechanical Properties

Figure 5 shows the tensile test results of specimen FSW AA5052-6061/T6 on specimen BM 5052, BM 6061/T6, As welded and PWHT. The UTS value of the welded specimen is 218 MPa with an elongation of 11.1% at tool rotational speed 1460 rpm, travel speed 30 mm/s. By comparing the tensile strength value in BM 5052, joint efficiency in FSW joints reached 78.8%. This is almost same with previous research conducted by [17] which uses a parameter of 1400 rpm 60 mm/s while AA5052-6061 joining by FSW, producing a UTS of 225 MPa with an elongation of 11.5%. Using rotation speed of 1400 rpm is essential to provide good heat input and ensure that the weld obtained has good tensile strength.

The heat treatment on specimens 5M8H and 60M8H has a minimal effect or can be said not to affect the tensile strength of FSW joint; the difference is in elongation, which has decreased to 7%. This is in contrast to previous studies conducted by [7] which perform FSW of non heat treatable aluminium alloy 5083 and 6061/T6, after post welding heat processing, whereby that specimens can increase tensile strength by 20% higher than as welded specimens.

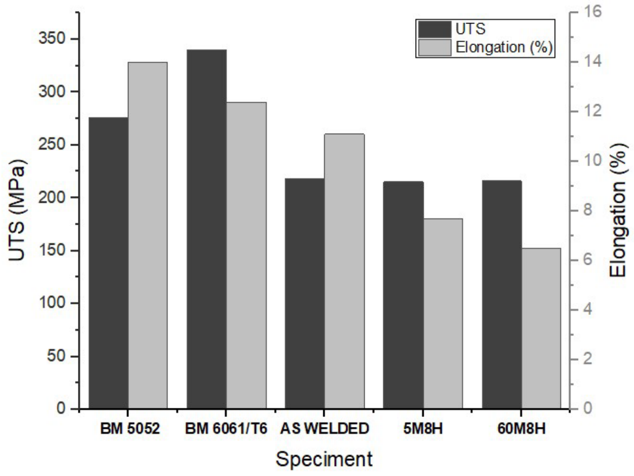

Figure 5: Result of Ultimate tensile strength and elongation

The difference in the results of this study is due to the hardness of the materials 5052 and 5083; although this material is a non-heat treatable 5xxx series, the hardness value of 5083 is about 93 HV and 5052 is about 68 HV. On what specimens in the study [7] the lowest hardness value on the 5083 side ranged from 70 to 82 HV, while the lowest hardness value in this study was 50.1 HV on the 5052 side.

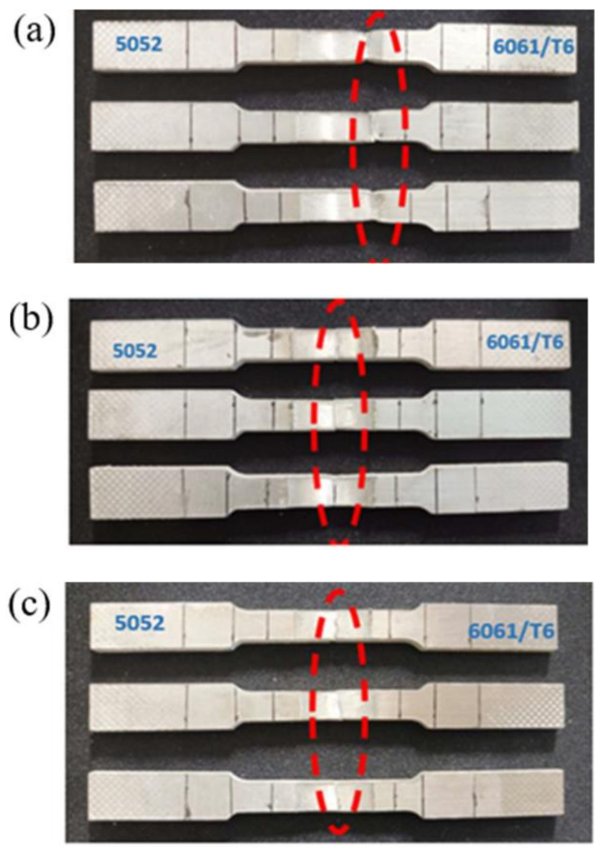

Figure 6: Fracture location of tensile strength specimen : (a) As welded, (b) 5M8H, (c) 60M8H

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Figure 6 shows the location of the fractography from the tensile test. Specimen as a welded fracture in the area of HAZ 6061 T/6; this correlates with the results of microhardness testing where the lowest hardness value is located on the part of RS. In contrast to as welded, the location of the fracture in the pith specimen is located in the middle of the weld zone, which is the limit of the lowest hardness value on AS and then increases on the RS side.

IV. CONCLUSION

This study aimed to determine the effect of post-welding treatment on the results of FSW aluminium alloy heat-treatable and non-heat treatable joints. With the use of differences in soaking time on what parameters obtained the following conclusions.

1. Friction stir welding has been successfully performed on aluminium alloy 5052 and 6061/T6 with tool rotational speed parameters of 1460 rpm with the travel speed 30 mm/s, producing good material connection and mixing; this is characterized by an onion ring pattern that appears in the weld zone area. Soaking time for 5 minutes and 60 Minutes on the specimen PWHT has no significant effect when observed with macro photos; there is a slight difference in the size of TMAZ zone, which is reduced compared with the specimen as welded.
2. The lowest microhardness value in welded specimens is found in the HAZ section on the 6061/T6 side, while the lowest hardness value for specimens of 5 minutes and 60 Minutes is found in the welding zone area (WZ). PWHT significantly affects the hardness on the side of 6061 / T6, especially on the HAZ; on the contrary, there is decrease in hardness on the non-heat treatable side (5052), caused by roughening of hard particles and grain growth on 5052.
3. Tensile testing on welded and what specimens resulted in almost the same tensile strength value of 215-218 MPa. There was decrease in elongation value from 11.1% as welded to 7.7% for 5M8h specimens and 6.5% for 60M8h specimens.

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