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EFFECT OF AGING TIME ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AA6061 FRICTION STIR WELDING JOINTS

R. Ahmad* and M.B.A. Asmael

Department of Manufacturing and Industrial Engineering,
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor, Malaysia
*Email: roslee@uthm.edu.my
Phone: +6074564103; Fax: +6074536080

ABSTRACT

This study was to determine the influences of post-weld heat treatment (PWHT) on the tensile and microstructure properties of friction stir-welded AA6061 aluminum alloy joints. Friction stir welding (FSW) of aluminum alloys has the potential to retain good mechanical and metallurgical properties. 3 mm plate AA6061 aluminum alloy was used to fabricate the joints. Solution heat treatment, quenching plus an artificial aging treatment with different times of aging were adopted. The fracture surface of the welded specimens was analyzed by using a scanning electron microscope, and an optical microscope was used for microstructure analysis, where finer dimples were obtained and formed inter-metallic compound at the highest aging time. Tensile properties were improved by about 4.7% after PWHT for 16 hrs. In addition, hardness increased with the increase of the aging time at the top region. A simple artificial aging treatment was able to enhance the tensile properties of the friction stir-welded AA6061 aluminum alloy joints.

Keywords: Aluminum AA6061; friction stir welding; post-weld heat treatment; mechanical property; microstructure.

INTRODUCTION

Welding is the most common way of permanently joining metal parts. In this process, heat and pressure are applied to metal to form a permanent join. Welding is used in shipbuilding, automobile, manufacturing and aerospace applications [1]. In the friction stir welding process, a unique tool attached to a revolving chuck runs along the two plates in face to face contact. The friction between the tool and the base metal creates a plasticity deformed zone through the stirring area [2]. The tool pin is slightly shorter than the thickness of the base metal. A stirrer tool is used to reduce the risk of having too excessive amount of things, lead welding and void-free uniform [3]. Since the total heat input is less than the current combination of welding, heat distortion is reduced and thus also the amount of residual stress. Friction stir welding can be considered as a “green” joining technique. The consolidated welds are solid state phase in nature and do not show fusion welding defects such as lack of filler and shielding gas. The distortion is significantly less than that caused by any fusion welding technique [4-8]. Typically, after the welding takes place, the properties of the base material will be lost due to the high temperature during the welding process, and this has the possibility to change the strength of the material [9]. A method of strengthening aluminum is solution heat treatment followed by rapid water quenching, which then proceeds by precipitation heat treatment. Solution heat treatment is achieved by heating the material to a desired temperature, holding at the temperature for a long time enough time to allow the constituent to enter into a solid solution, then cooling the material rapidly at room temperature. The result of this heat treatment is to produce a metallurgical structure within the material that provides superior tensile strength [10]. The main precipitation in the series 6000-silicon-magnesium aluminum alloy is Mg_2Si system. The formation and distribution of precipitation depends on the solution treatment and aging treatment. Most of the strengthening precipitate is dissolved in the FSW process and, therefore, reduced density of the precipitate is observed after welding [11]. Aluminum AA6061 is a precipitation hardening aluminum alloy. It contains magnesium and silicon as its main elements. Originally called “61S alloy”, it was developed in 1935 [12]. FSW is seen as environmentally friendly because it does not involve the use of filler metal and also because there is no melting. Any aluminum alloy can be joined without concern for compatibility of composition or the solidification cracking issues associated with fusion welding. Also, dissimilar aluminum alloys and composites can be joined with equal ease [13, 14]. The FSW weld zone consists of a stirred zone, a thermomechanically affected zone (TMAZ) and a heat-affected zone (HAZ) [15]. Mishra and Ma [3] also reported that the fine grain size of the stirred zone and the solid state transformations acting in the TMAZ and HAZ lead to high tensile strength and enhanced fatigue properties. Thus, the purpose of this study is to investigate the characterization of joining using FSW and to examine the effect of post-weld heat treatment, with different aging times, on the microstructure and mechanical properties.

MATERIALS AND METHODS

The base material used in this study was 3 mm thickness AA6061 aluminum alloy plates with chemical composition and mechanical properties as shown in Table 1. As listed in Table 1, the main elements such as Mg , Si , Fe and Cu in aluminum AA6061 alloy lead to the increase in the mechanical properties [16], such as tensile strength and elongation, as shown in Table 2.

Table 1. Chemical composition of AA6061 aluminum alloy.

Chemical composition (wt.%)								
Mg	Si	Fe	Cu	Cr	Mn	Zn	Ti	Al
0.9	0.62	0.33	0.28	0.17	0.06	0.02	0.02	Rest

Table 2. Mechanical properties of AA6061 aluminum alloy.

Yield strength	Ultimate strength	Elongation (%)	Reduction in cross-sectional area	Hardness (VHN)
302 MPa	334 MPa	18	12.24	105

The steel AISI1020 was used for fabrication of the FSW tool. A screw thread maker tool, M6×1.0, was used to make the thread at the tool pin or probe. The diameter of the shoulder was 18 mm, the height of the shoulder was 30 mm, and the diameter of the tool pin was 6 mm. A square butt joint configuration was prepared to fabricate the

FSW joints, using a single pass welding procedure. A schematic of the process is presented in Figure 1 [4].

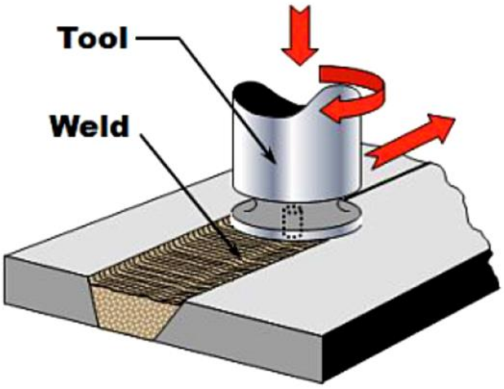


Figure 1. Schematic diagram of the FSW process [4].

Welding samples are divided into two groups; as-welded and heat-treated samples. The heat treatment processes involved in this experiment were solution heat treatment, followed by water quenching and lastly artificial aging. The samples were heated in a furnace at a temperature of 530 °C for 1 hour. This temperature was below the melting temperature, Tm = 582 °C. So, a homogeneous solid solution was created. After the welded samples were in solid solution, the material was quenched in water immediately. Then, the samples were age-hardened at temperatures of 160 °C for 4, 8 and 16 hours. A tensile experiment was carried out based on the standard ASTM E8M-04 with 3 mm thickness and the main focus was on the weld region of the specimen for AW and PWHT for each group. PWHT was divided into three groups, which were 4, 8 and 16 hours. The tensile test is the most common procedure for studying the stress–strain relationship, particularly for metals. After the PWHT, the tensile test was carried out using a Universal Tensile Machine. The FSW fractured surface of the joints was analyzed by using a scanning electron microscope (SEM), and the microstructure was analyzed by using an optical microscope (OM). Electron dispersive X-ray (EDX) was used to determine the composition of the specimens. A Vickers micro-hardness testing machine HMV Shimadzu was used for measuring the hardness across the joint.

RESULTS AND DISCUSSION

The experiment was to evaluate the transverse tensile properties of welded AA6061 joints, the results of which are shown in Figure 2. From the two groups which are AW and PWHT, the AW shows the lowest tensile stress of 146.05 MPa, while the highest tensile stress was 153.02 MPa with PWHT for 16 hours. Figure 2 shows an increment of tensile strength from 0.3% to 4.7%, where it increased as the time of aging increased. The elongation decreased with the increase in the time of aging, as plotted in Figure 3. The elongation of AW obtained the highest value at 1.6%, while the value decreased slightly at 4 hrs to 1.57% and continually decreased with the increase in aging time, resulting in a lower value of 1.3% at 16 hours. The improvement in the strength of PWHT is due to the uniform precipitation throughout the weld [17]. In addition, the change in fracture and microstructure morphologies had a significant effect on the mechanical properties of AA6061.

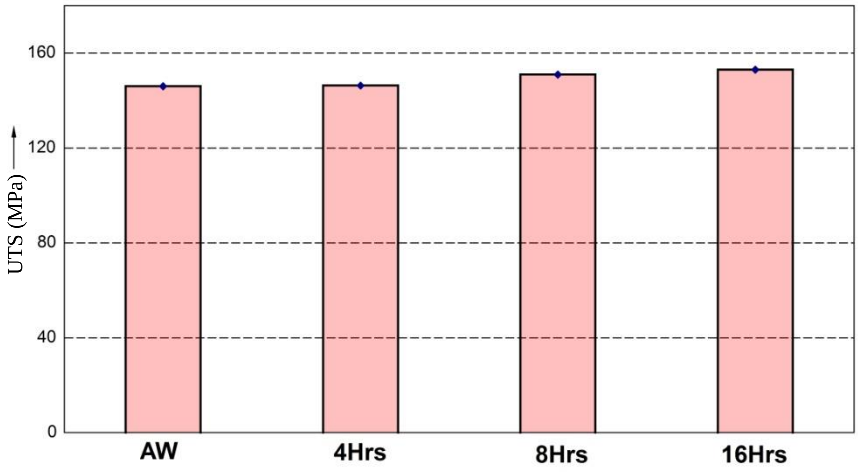


Figure 2. Tensile strength between AW and PWHT group.

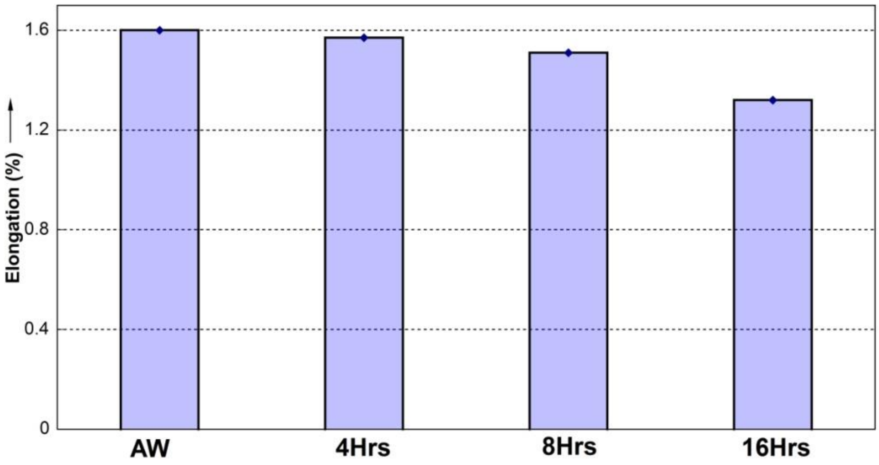
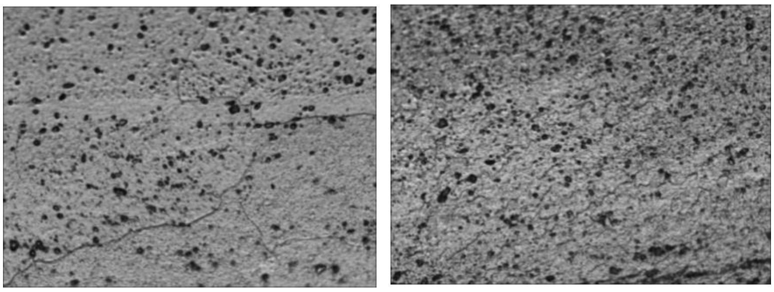
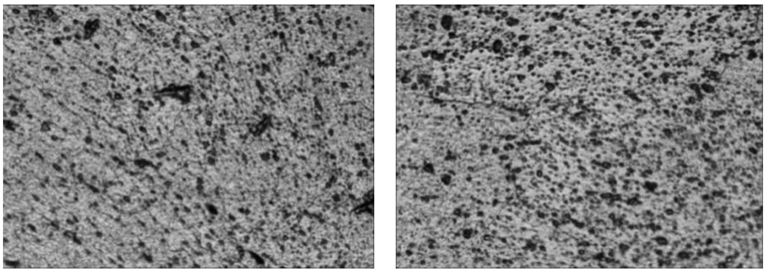


Figure 3. Elongation between AW and PWHT group.

From the microstructure analysis, an abnormal and rare feature was observed in all the PWHT specimens, where numerous small and round black particles were observed, which were less apparent in the AW base metal, as shown in Figure 4. It was found that the main reason why the PWHT specimens were better in strength than AW was because of the Mg_2Si content, which after the aging process, produced the tiny black particles that started to appear [17]. The fracture surfaces for each specimen were analyzed by using SEM in order to understand the failure pattern. SEM images were taken at three different locations; the top weld region, center weld region and bottom weld region, as shown in Figure 5. AW shows intergranular cracking with large dimples. For every PWHT joint, the dimples were finer and the grains that emerged were smaller than AW as the time of aging increased. The size and distribution of grains and dimples as well as the dislocation between the grains play a major role in determining the mechanical properties such as tensile strength and hardness value. These are the reasons for the higher tensile strength and improvement in hardness values for the PWHT samples.

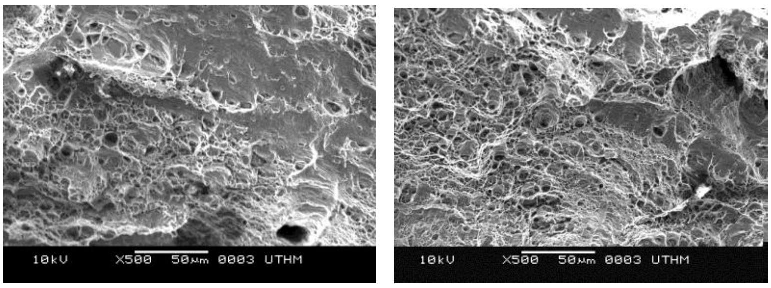


AW PWHT 4 hours

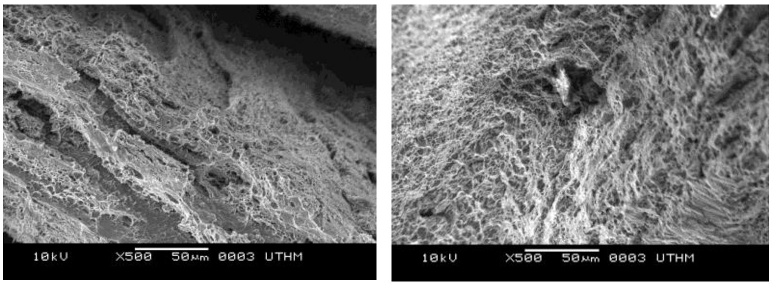


PWHT 8 hours PWHT 16 hours

Figure 4. Optical micrograph of the weld centerline region for AW and PWHT for each joint.



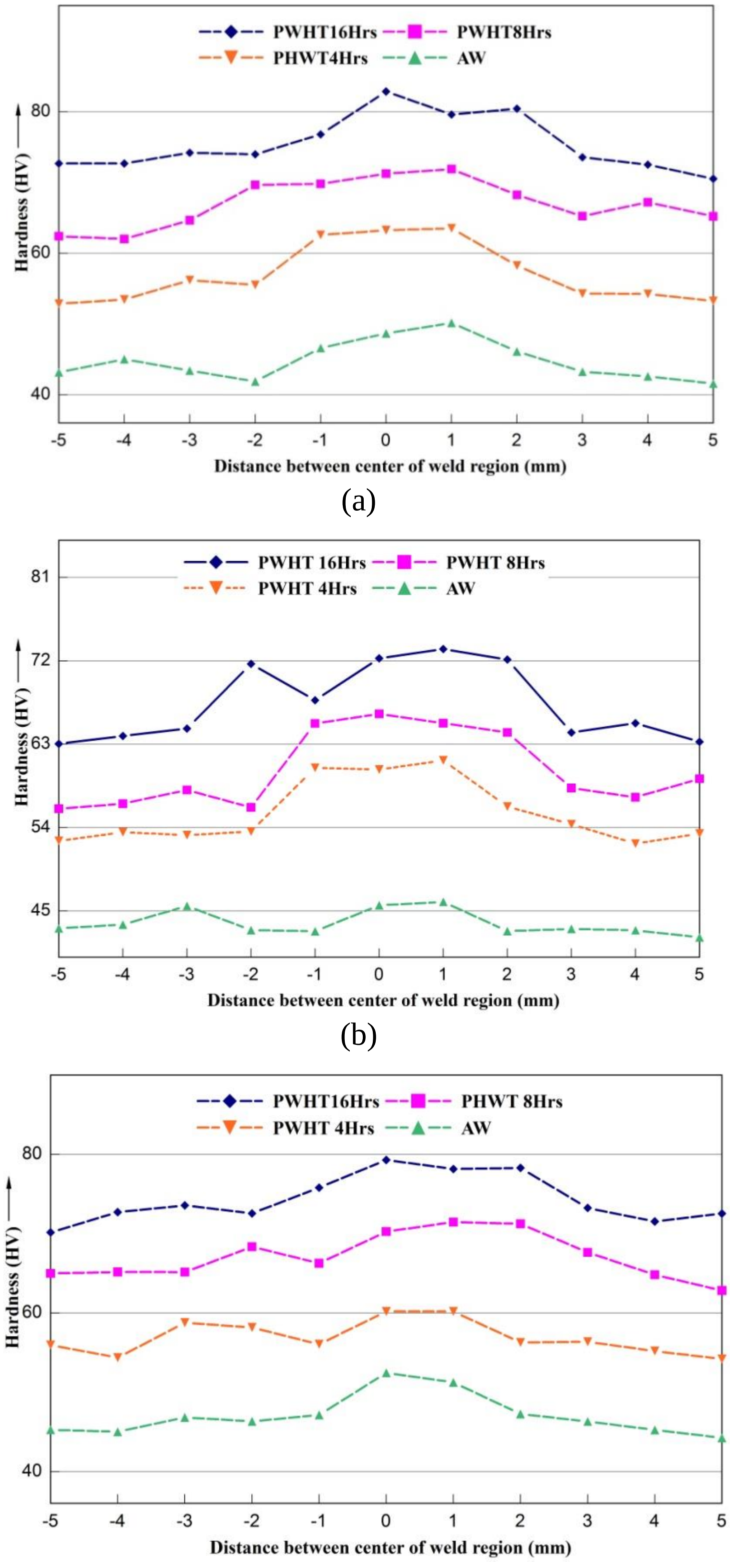
AW PWHT 4hours



PWHT 8 hours PWHT 16 hours

Figure 5. Fractograph of the center surface for AW and PWHT for each joint.

Figure 6 shows that the PWHT joint had higher hardness than AW for all weld regions. In addition, the aging time had a significant effect on the hardness at the bottom region, while the hardness increased slightly in the centerline from 61.2 HV to 73.2 HV with the increase in aging time from 4 to 16 hrs.



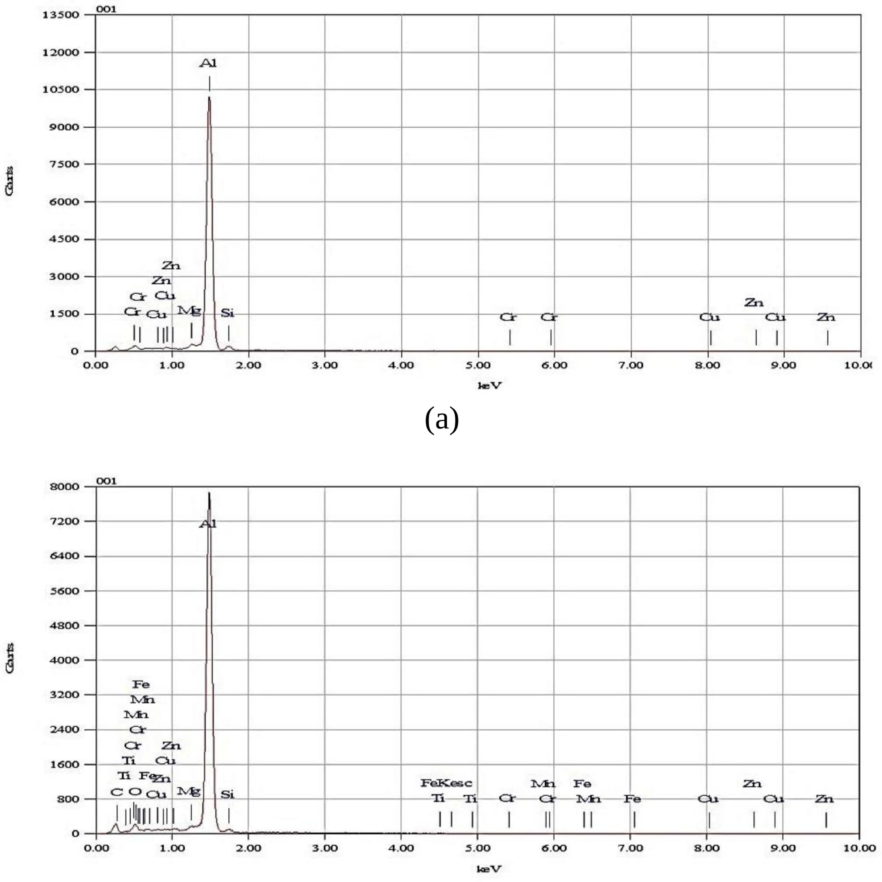
(a)

(b)

(c)

Figure 6. Comparison of hardness along (a) top, (b) bottom, and (c) center weld region between AW and PWHT for every aging time.

The same scenario was observed with the center and top regions, where the highest values of hardness were achieved at 79.2 HV at 4 hrs and 82.8 HV at 16 hrs in the centerline respectively. As shown in Figure 5, the specimen PWHT after 16 hours had the highest hardness. From simple observation, it can be seen that the average of highest hardness was dominated by the top weld center, which was because the location at the top center was the most exposed to the stirring action during the weld process, while at the bottom centerline, the tool pin did not totally reach the bottom, so that only minor stirring action occurred at that location [18]. The increase of properties with PWHT was due to the forming intermetallic compounds with Mn or Cr, Al-Mn as shown in Figure 7 at the top region, which produced intergranular fracture hardened alloys irrespective of grain size. When Al-Mn intermetallics were introduced, the slip became more distributed and the fracture toughness increased [19].



(a)

(b)

Figure 7. EDS result for each specimen: (a) base metal, (b) weld centerline (PWHT 16 hrs).

CONCLUSIONS

From the results, the effect of post-weld heat treatment on the mechanical properties and microstructure of AA6061 aluminum alloy by using FSW was analyzed. Heat treatment processes such as solution heat treatment at 530 °C for 1 hour followed by water quenching and finally artificial aging at 160 °C for 4 hours, 8 hours and 16 hours were managed to change the structure of AA6061. The highest strength recorded during the tensile test was 204.08 MPa for the heat-treated samples after 16 hours and the highest recorded value for as-welded samples was 166.08 MPa, with a 23% increment in tensile strength. From the overall results obtained from mechanical testing and microanalysis of AA6061 aluminum alloy, after implementing post-weld heat treatment (PWHT), significant increment was achieved.

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