Improving the Mechanical Properties of Aluminum Alloys 6061-T6 Friction Stir Welding Joints Using Ultrasonic Peening

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Abstract: The aim of this paper is to study the possibility of joining plates from aluminum alloy 6061-T6 by friction stir welding method. Plates were prepared to dimensions (200 × 60 × 6) mm by using (CNC) milling machines. The FSW was then applied to join the operated plates by a vertical milling machine using different rotation welding speed of 1000, 1200, 1400, rpm and linear welding speed of 30 mm/min for the production of many weld joints. Microstructure and micro hardness, tensile, bending, temperature distribution testing were implemented. The results observed that the effect of the increasing of rotating speed for friction stir welding leads to increase the mechanical properties due to the increase of heat input. The best result was obtained at rotational speeds (1400) rpm, the specimens that are welded at 1000 rpm and had decreases in mechanical properties are subjected to ultrasonic peened surface treatment at 1, 2, 3 passes to improve the mechanical properties of welded joint. Compared to the non-peening weld joint, the mechanical properties increased when the number of ultrasonic peened passes increased due to the surface hardening and compressive residual stresses produced by the ultrasonic peening process.

1. Introduction
Due to desirable properties, the friction stir method is used to connection aluminum alloys which were used in several industries. These alloys are essential for the manufacture of parts and structures that require high strength and low weight in the aerospace and automotive industries owing to excellent formability, welding capacity, machinability, resistance to corrosion and excellent strength[1]. Friction Stir Welding (FSW) is a relatively latest method using a non-consumable rotating welding device to produce frictional heat and plastic deformation at the welding place while the material is in solid condition. FSW has many advantages, including low distortion in weld joint, absence of melt-related defects and increased joint strength. In relation to significant parameters such as tool rotational speed, welding velocity and axial force, tool design and material play a crucial role[2,3]. In general, by using friction stir welding process, problems of hot cracking, porosity, and element loss can be avoided. Furthermore, no filler wire is required for Aluminum alloys and it is workplace friendly. The carefully chosen of welding variables had significant effects on the mechanical properties of the welded samples[4]. Ultrasonic peening method has as a hopeful method for improvement of fatigue strength of welded joints. The process includes post-weld deformation treatment of weld joint by influences from single or many denting needles exasperated at ultrasonic frequency, producing force impulses on the work surface. The method is chiefly controlled using the output of the ultrasonic transducer (frequency), the chosen pressure, the feed rate and the figure of passes The technique is also recommended due to its high process stability and low operating costs. Very low initial loads are used to produce deep work hardening with a low surface roughness, and given certain conditions, a Nano-crystalline layer may form on the component surface. The aim of the treatment is to present a valuable
compressive residual stresses at the treated weld joint, and to decrease stress concentration using educating the weld joint shape[5]. The ultrasonic peen was effectively implemented to increase the fatigue life of components and welded components, eliminating distortions induced by welding and other technological procedures, and improving the hardness of metals by relative residual stress. The findings of fatigue tests showed that UP is the most effective method to enhance the fatigue life of welded components compared to etc. Ultrasonic peening (UP) therapy application can increase / restore the designed stress variety of welded components up to the fatigue strength of base material's. Increasing fatigue life through UP is accomplished primarily by relieving damaging tensile residual stresses and introducing compressive residual stresses into metal and alloy surface layers, reducing the stress concentration of welded areas and increasing the stress concentration. [8] the improvement effects on fatigue strength by Ultrasonic Peening for welding joints The application of Ultrasonic Peening to weld is effective way to improve fatigue life of the weld joints as that of weld grinding[6,7]. Recently, several researchers made attempts to investigate the microstructural and mechanical Properties of Aluminum alloys by friction stir welding techniques.

Patil H. and Soman S. [8] The metallurgical and mechanical behavior of alloys 6061-T6 was studied. The joints are manufactured at different welding speeds from 55 mm / min to 70 mm / min and with the same rotation speed of 1700 rev / min. The test results show that a maximum tensile strength of 184 MPa at a welding speed of 55 mm / min was obtained.

Asmara M. Abdullah [9] The effect of various parameters such as rotating velocities and welding velocities on Friction Stir-welded (FSW) aluminum alloy 6061-T6 micro structural and mechanical behavior was studied.

Abbasi, et al [10] The effect of ultrasonic peening (UPT) technology on the rolling mill graphite steel surface GSH48 is passed by one, two, three passes. Thermal fatigue creates the crack on the surface in the rolling mill rolls which contributes to roll breakage. By UPT technique Hard plastic deformation was developed on surface film and production delayed the crack. The results of this study showed an increase in the fatigue and thermal fatigue life of the components following the UPT technique . The results indicate an increasing trend in fatigue and thermal fatigue caused by cracking on the surface and its moving depth in the roll and this was improved when yield quality increased after the method was conducted .

Tiana, et al [11] Introduced the effect of ultrasonic peening treatment on surface quality of Al alloy CMT-welds Experimentally, they proved that the porosity number and porosity area percentage of weld beads close to the weld surface decreases after treatment with ultrasonic peening . The grains are substantially refined in extreme deformation layers and transition layers.

Xing, et al[12] Experimentally and numerically investigated the effect of ultrasonic peening time, frequency and amplitude of the peening needle on AISI residual stress of 10Mg alloy. The results showed that the simulated residual stress is in good agreement with the experimental measurements and that the peening time, frequency and amplitude improve the effect of ultrasonic shock on residual stresses.

The available literature focuses on the process parameters, welding speed, and tool rotational speed on the FSW zone. Therefore, an attempt has been made to understand the effect of the ultrasonic peening on the material characterization of Aluminum alloy 6061-T6. The current work presents the results of experimental study of similar Aluminum alloys 6061-T6.

2. Experimental Work

2.1. Materials

The chemical analysis of aluminum alloys 6061-T6 was done using the ARL spectrometer in the General Company for Heavy Engineering Equipment and the results are presented in Table 1.
2.2. Sheet preparation and welding process.
Sheets of Aluminium alloy 6061-T6 were cut into the required dimensions (205 × 65 × 6.5 mm). After that, the sheet surface was mechanically operated to obtain the final joint dimensions (200 × 60 × 6 mm) by CNC Milling machine (TX-32) at rotating velocity 1300 rpm and linear velocity (40) mm/min. Then two Aluminium alloy plates were perfectly clamped in vertical semi-automatic milling machine bed and the tool for welding process. The tool shoulder measurement is (20mm diameter&140mm in length) and tool pin is (5mm diameter& length is 5 mm) fixed in perpendicular to the plates as depicted in Figure 1A and B. The rotational speed for welding process are (1000,1200,1400) and linear welding speed were kept constant at speed 30. The plates are positioned in the fixture to avoid the separating of plate through welding.

Table 1. Chemical analysis of Aluminum alloy 6061-T6.

| Elements wt% | Si | Fe | Cu | Mn | Mg | Cr | Zn | Al |
|--------------|----|----|----|----|----|----|----|----|
| Real value   | 0.6| 0.4| 0.3| 0.12| 1.0| 0.2| 0.18| Rem.|
| Standard value | 0.4-0.8 | 0.7 Max | 0.15-0.4 | 0.15 Max | 0.8-1.2 | 0.04-0.35 | 0.25 Max | Rem. |

Figure 1. A- Friction stir welding process. B- Welding joint

The temperature during welding process is evaluated by resistance temperature detector (RTD) having temperature ranging from 200°C to 650°C. The generated temperature is measured by placing a sensor at different points on the weld plat perpendicular to weld line. The value of measuring temperature will be used to understand the behavior of tensile and bending stresses. Welding Joint Grouping as shown in table 2.

Table 2. Welding Joint Grouping

| Specimens | Condition |
|-----------|-----------|
| A         | as received |
| B         | Welding joint at the rotational speed 1000rpm |
| C         | Welding joint at the rotational speed 1200rpm |
| D         | Welding joint at the rotational speed 1400rpm |

Samples for tensile examination cut from base and weld plate according to the ASTM1700 specifications with dimensions shown in Figure 2. The tensile examination completed using testing device measuring control Software type WDW-200E model with a capacity of 200KN. The examinations were performed at a constant rate or speed of 1 mm/min till failure. The bending samples were manufactured according to ASTM (E 190-92) as shown in Figure 3 from base and weld plate. Universal testing machine with 100 kN at a speed of 3.5 mm / min was used. Three-point method was used to perform the test where The samples are placed horizontally across two supports and then the energy is transferred to the top of the welding line to deform the specimens in a (U) shape.
3. **Ultrasonic process.**

Ultrasound device which shown in Figure 4 was used to peen the surface of tensile and bending specimens for weld joint which welded by rotational speed of 1000 rpm by ultrasonic peening at (one, two and three) passes and, Frequency: 20KHZ, Voltage: 220v, power: 500w, high-power ultrasonic drive impact tools up to twenty times which offer the energy on the surface of metal during touch. This energy is inserted into the metal by the shape of ring / harmonic fluctuation of an acoustically toned frame to mechanical shot on a surface make the metal surface produce a larger plastic deformation Ultrasonic wave change the original stress field at the same time has a certain value of compressive stress; and to strengthen ultrasonic impact areas.
4. Compressive residual stresses
After the ultrasonic peened for weld joint at 1000 rpm the compressive residual stress was measured by computerized diffraction meter XRD-6000 shiatsu X-Ray. The strain values were determined and replaced in Brag law in order to determine the residual compressive which is come from device and listed in table 3.

| Specimens symbol | Specimen (B 1) at one pass | Specimen (B 2) at two pass | Specimen (B 3) at three pass |
|-------------------|---------------------------|---------------------------|---------------------------|
| Residual stress for tensile test specimens MPa | -97.99 | -130 | -143 |
| Residual stress for bending test specimens MPa | -101.2 | -136 | -163 |

5. Microstructure Test
Specimens for the microstructure were cut out mechanically from based metal and the weld joints, and grinded by emery paper of SiC with grits (240,350,500, and 1000). After that, the specimens were polished using diamond paste of size (0.5μm), unusual polishing cloth and lubricant. Etching process is done using etching solution composed of 99% H2O+1%HF. After the etching process is completed, the specimens were washed and dried by water and alcohol. Optical microstructural characterization of specimens were performed by optical microscope model (MTM-1A, Japan) prepared with NIKON camera and connected to a computer.

6. Micro hardness Test
The Vickers micro hardness with 200 gm load was applied for 20 sec to measure the Hardness for all specimens weld joint on a cross section perpendicular to the welding line.

7. Results and Discussion
Friction heat is created in FSW techniques because of the fraction action between the rotating tool and the material. The friction heat softens material underneath the tool. Therefore, plastic deformation occurred and then the material flows around the probe. When the tool move the material split up behind the tool to form a solid-state for continuous joint. It is obvious from figures 5 and 6 that the highest temperature was recorded with specimen (D) and the lowest temperature was recorded with specimen (B). This behavior can be attributed to high rotational speed for welding of specimen (D) compared with the other specimen. Causes in decreases in surface roughness and as a result of that the contact between the shoulder and the surface of specimen will increase. Thus great heat will generate.

![Figure 5. Temperature Distribution with distance near weld joint surface](image_url)
Additionally, the temperature was recorded with time to see the effect of welding time on the generated temperature, Figure 6. It is obvious that specimen (D) has the highest increase of temperature compared to the other materials. This can also be attributed to the low surface roughness of specimen (D) which increases the contact between the rotating tool and the material and hence high heat generating.

The base metal AA 6061-T6 which contains coarse and elongated grains with regular repartition strengthening sediment of (Mg2Si,) which formed by combined the main alloying elements silicon and magnesium. which contributed in increasing of the strength of the alloy as shown by darkens particles [13,14].

The microstructures of the weld joint from base metals (B.M), heat affected zone (H.A.Z) and weld zone (W.Z) are presented in Figures 7A and B. It is noticed in the micrographs that the particulates are scattered all over the W.Z. However, the grain size decreased in the weld zone as well as in the H.A.Z. The frictional heat developed during FSW is sufficient to cause plasticization of the metal and the pressure of pin tool cause in finer grain size. Which increase in Rotational speed increase due to decreases in surface roughness giving good contact between tool pin and surface of plate to be welded. The magnified view of the W.Z for all specimens is presented in Figure 7B. The W.Z is characterized by a small granules and it is very obvious in specimen (D). This remark designates that temperature generated in the W.Z through FSW was in height enough to increase the deformation and hence break the newly generated grains.

![Figure 6. Temperature distribution with time](image)

**Figure 6.** Temperature distribution with time

![Figure 7A. Optical micrograph of the three zones](image)

**Figure 7A.** Optical micrograph of the three zones
Figure 7B. Optical micrograph of the weld zone at 40x

Figure 8 suggests that the micro hardness of specimen (D) was the highest. Also, the micro hardness is higher in W.Z in all specimens. This behavior can be explained by the rise in rotational speed increase the residual time of frictional heat and hence the amount of plastic deformation as in specimen (D) was increase. The generation of fine grain structure in W.Z contributes to an rise in hardness. Therefore, the reduction in grain size with increased rotational speed advances the hardness.

Figure 8. Micro hardness weld joint for all weld joint specimens

Typical stress–strain curve for all the specimens for tensile test are shown in Figures 9A and B. It is obvious that the decrease in grain size has a significant effect on tensile properties. Also, the increase in rotational speed has a very pronounced effect on tensile properties. Such observations can attributed to the effect of high plastic deformation which occurred because of low residing time of frictional heat. However, plastic deformation for specimen D is higher than the other specimens. That can be attributed to its low surface roughness and relatively high heat generated during welding. And specimens B is lower tensile properties due surface roughens which decreases the contact between pin tool and plats surface. Ultrasonic peened contributed in improvement mechanical properties for this weld joint due ultrasonic peened producing compressive residual stress and plastic deformation that increases when number of passes increase [12].
Figure 9A. Stress-strain curve for all specimens

Figure 9B. Stress-strain curve by tensile test after ultrasonic peened

The bending curve for all the specimens are shown in Figure 10. It can be seen from the figure that with increase in rotational speed (and hence grain size), bending strength increases slightly. That can be attributed to the effect of high plastic deformation shown in specimens D due to high heat generated in W.Z. Additionally, tensile strength for the mentioned specimens were the highest among the other and that affect the bending strength as well. Also specimens B show decreases in bending strength comparing with the other specimens C,D for the reason clear above and this can improved by ultrasonic peend due to the compressive residual stress which increase when number of pass increase.

Figure 10A. Relationship between stress and strain for by bending test. For all specimens
8. Conclusions

- The maximum tensile strength of 160 MPa (specimen D) was obtained on the joint fabricated at rotational speeds (1400) rpm and linear speed (30) mm/min.
- The maximum bending strength of 50.62 MPa (specimen D) was obtained on the joint fabricated at rotational speeds (1400) rpm and linear speed (30) mm/min.
- Fine grain structure in W. contributes to an increase in hardness.
- Decrease in grain size has a significant effect on tensile and bending properties. This behavior is very pronounced in Specimen C and D.
- The mechanical quality of the joint which is made at rotational speeds of (1000) rpm and linear speed (30) mm/min were increased when number of passes by ultrasonic peened is increases.

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