



The Influence of Ultrasonic Impact Peening on the Mechanical Properties of Similar Friction Stir Welded Joints of AA 7075-T73

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HIGHLIGHTS

- Welded joints of Al 7075-T73 were achieved by FSW.
- The joints were treated by one pass and two passes of ultrasonic peening.
- Tensile Strength of joints was enhanced by 14% by one pass and 11% by two passes.

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ABSTRACT

The purpose of this study is to study the ultrasonic peening influence upon the mechanical properties of the welded joints of 3 mm AA 7075-T73. Friction stir welding (FSW) was carried out by using milling machine and cylindrical tool with tapered pin. The used welding parameters were 710 rpm , 35 mm/min for rotational and travel speed , respectively .Tensile tests results showed that the welding efficiency was about 60% for welded samples , and this value increased by using one and two lines ultrasonic peening treatment to 74% , and 71% , respectively , this improvement is due to generating compressive stresses along the surface of welded joints. The microhardness of the welded samples showed that there were fluctuations across the welded centerline and minimum hardness occur in the heat affected zone (HAZ).

1. Introduction

The friction stir welding (FSW) has been widely utilized to weld aluminum alloys, such as 2xxx, 7xxx series which are difficult to be welded with TIG technique [1, 2]. The 7xxx series is especially applied to aircraft fittings, gears and shafts, fuse part, missile parts, regulating valve parts, worm gears, keys, aircraft, aerospace and defense applications [3], and applications of AA 7075-T73 have been specially aged to make the material resistant to stress-corrosion [4]. Important properties, like formability, corrosion resistance, and high strength to weight ratio of Al alloys have created them used widely in the automotive and aerospace industries. The new application of Al sheet in the automobiles body panels is a remarkable technique, which can considerably decrease the vehicle's weight. The producers of automobile are moving from the steels toward the alloys of Al for producing lighter, harmless, and highly effective automobiles [5, 6]. FSW is carried out with a non-consumable rotating tool that possesses a shoulder and a pin at the shoulder end to plunge into the base metal and progresses in the direction of welding, when the shoulder touches a top surface; then the pin shifts the solid state of weld about it [7]. Friction stir welded joints contain (3) different zones: Stir Zone SZ or Nugget Zone NZ, Thermo-Mechanically Affected Zone TMAZ and Heat-Affected Zone HAZ. The stir region undergoes the severe plastic deformation and relatively a high heat input resulting in the fine and equiaxed grains formation, the thermo-mechanically affected region lies near to the stir region and experiences comparatively less plastic deformation, and the heat-affected region doesn't undergo any plastic deformation and endures merely the thermal influences [8]. The defects, such as tunnel, groove and cavity can be formed due to improper of welding speed and welding pressure. Friction stir welding is one of the most energy efficient processes. The major challenge for the aluminum producers, is to achieve a high quality and defect free welded joints, especially 2xxx and 7xxx series. The defects, such as tunnels, kissing bonds and flash are familiar in the FSW joints. The kissing bond reduces the life of fatigue, whereas it doesn't influence considerably the tensile strength [9, 10]. It is important to carry out the FSW of the Al alloys in a wider variety of rotational speeds and welding speeds, since the mechanical properties of joints depend on many conditions, such as travel speed, rotational speed, tool geometry and thickness of material [11, 12]. Ultrasonic peening treatment UPT is a recent technique that improves the chemical and mechanical properties of the welded joints, and also lengthens the fatigue life of these joints loading conditions [13, 14]. Many researchers were investigated the effect of the ultrasonic impact treatment

UIT on the microstructure, hardness and residual stress distribution of welded joints [15]. These studies have been focused on the enhancement the mechanical properties of welded steel plates that welded by conventional gas metal arc welding by using ultrasonic impact peening, while this study is the first try to modify the friction stir welded joints by using this technique.

The present work aims to show the influence of ultrasonic peening technique that generate compressive stresses in order to improve the mechanical properties of similar friction stir welded joints for aluminum alloy 7075-T73.

2. Experimental work

2.1 Material selection

Aluminum alloy plates of AA7075-T73 with a thickness of 3 mm were selected in order to be joined via FSW. By using punch cutter, these plates were cut into dimensions of 150×75×3 mm. The chemical analysis of this alloy was obtained via utilizing the spectrometer analysis device available in the General Company for Examination and Rehabilitation Engineering, as depicted in Table 1. The mechanical properties of this alloy are summarized in Table 2. These tables also list the standard values for the conformity and comparison purposes.

Table 1: The actual and standard chemical composition of AA 7075-T73

| Component | Fe | Si | Cu | Mn | Mg | Cr | Ni | Zn | Ti | Pb | Al |
|-------------------|-------|-------|------|------|------|-------|-------|------|------|------|------|
| <i>Standard</i> | 0.5 | 0.4 | 1.2- | 0.3 | 2.1- | 0.18- | 0.05 | 5.1- | 0.2 | 0.15 | Bal. |
| <i>ASM wt%</i> | Max | Max | 2 | Max | 2.9 | 0.28 | Max | 5.6 | Max | Max | |
| <i>Actual wt%</i> | 0.228 | 0.099 | 1.47 | 0.07 | 2.13 | 0.21 | 0.003 | 5.61 | 0.02 | 0.13 | Bal. |

Table 2: The mechanical properties of 7075-T73

| Property | Yield Strength(MPa) | Ultimate Strength (MPa) | Elongation, % | Modulus of Elasticity (GPa) |
|----------|---------------------|-------------------------|---------------|-----------------------------|
| Standard | 386 | 462 | 16 | 72 |
| Actual | 392 | 489 | 14.5 | 72.5 |

2.2 Welding process

Milling machine type (GmbH Knuth Werkzeug machine, Germany) and fixture system were used to obtain similar butt welded joints of aluminum alloys AA7075-T73 by friction stir welding, as shown in Figure 1. In this study, FSW was conducted by using tool made from tool steel type BS-82 with an average hardness value of 62 HRC. The diameter of the tool shoulder is 15 mm, whereas the base and top pin diameters are 5 mm and 3 mm, respectively with a height of 2.85 mm, which is somewhat lower than the thickness of plate 3 mm, as shown in Figure 2.



Figure 1: Milling Machine and Fixture System

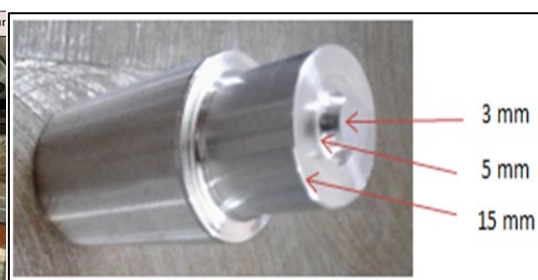


Figure 2: Cylindrical tapered Pin Tool

2.3 Parameters of welding

FSW processes operations were performed at various parameters of welding, including a travel speed of 35, 45 and 60 mm/min, a rotational speed of 500, 710 and 900 rpm, tilt angle 2° and dwelling time 30 sec.

2.4 Ultrasonic impact peening

To improve the mechanical properties of welded joints, an ultrasonic peening device type HC-S-1, as shown in Figure 3 was used to introduce the energy of ultrasound into the material through the surface impulse contact, and such energy is introduced into the metal in order to convert the harmonic oscillation of an acoustically tuned body into mechanical impulses [16]. One-line peening 1UP or one pass and two lines peening 2UP or two passes post welded peened treatment were achieved on welded specimens in order to remove tensile stresses and obtain compressive stresses, as shown in Figure 4 and Table 3.



Figure 3: Ultrasonic peening device type HC-S-1

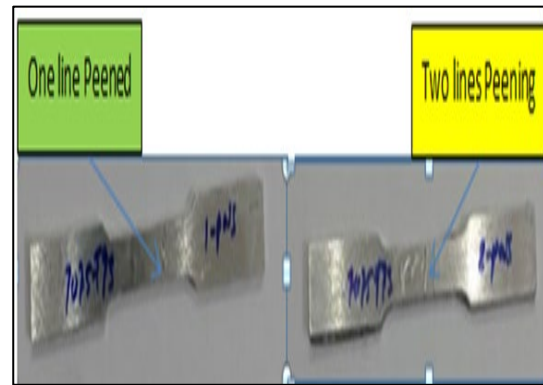


Figure 4: Ultrasonic peened specimen

3. Tests and Inspections

3.1 Radiography, X- Ray inspection

To ensure if that the welded joints are sounds without defects, such as cracks or gaps or not, the radial unit which operate at 130 kV, 3 mA for 2 min was used to identify these defects. Radiographic apparatus was utilized in this investigation, which is available in the General Company for Engineering Inspection and Qualification.

3.2 Microstructure inspection

The microstructure of FSW joints were assessed by Optical Microscope and this operation was accomplished by using water and emery paper of SiC in several grits of 400, 600, 800, 1000 and 1200. The polishing was performed on the samples by using 0.5 μ m diamond paste and special cloth for polishing and lubricant. The etching solution Killer's reagent (Composition: 95 ml H₂O, 2.5 ml HNO₃, 1.5 ml HCl, and 1.0 ml HF) was utilized [17].

3.3 Mechanical tests under ultrasonic peening

The ultrasonic peening process is one of the popular and modern techniques used to improve the mechanical properties of the welded joints. Numbers of ultrasonic peening treatments were carried out on the welded specimens, such as one-line peening 1UP (one pass) and two lines peening 2UP (two passes).

3.4 Tensile test

Tensile tests were performed to each friction stir welded sample in order to determine the tensile properties of the friction stir welded joints with and without ultrasonic peening treatment (one line 1UP or two lines 2UP) at the room temperature by utilizing a universal testing machine (model WDW-200E). Tensile specimens were cut and machined by using CNC milling machine type Rapimill-700 in a direction perpendicular to the welding direction according to the ASTM standard E8M-09 for the subsize specimens, as revealed in Figure 5 [18].

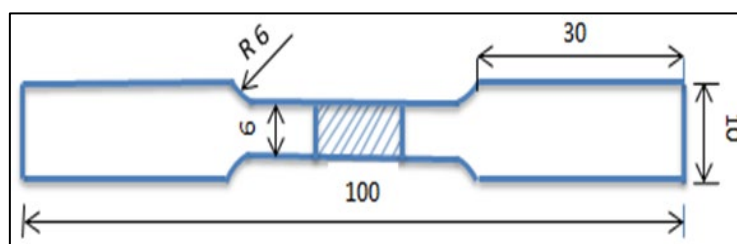


Figure 5: Sample for tensile test (all dimensions are in mm) [18]

3.5 Microhardness test

The Vickers hardness was conducted on welded samples (with and without ultrasonic peening treatment) which were cut from across section of FSW joints via utilizing digital microhardness tester, type Laryee, Model HVS-1000 and according to the ASTM standard E92-82 [19]. A 200 g load for 15 secs was applied along the cross section of welded joints.

4. Results and Discussion

4.1 . X- Ray inspection

The x-ray radiographic inspection was conducted on all the FSW welded joints, it was found that the images did not contain any defects, such as revealed voids, cracks or penetration according to ASTM standard E155 [20]. as evinced in Figure 6.

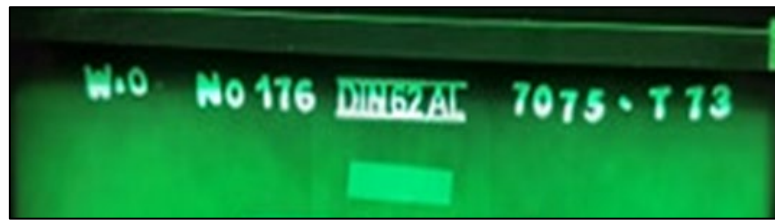


Figure 6: X-Ray radiographs image

4.2 Microstructure result

The test revealed that are three different microstructural zones, including SZ, TMAZ, and HAZ in the friction stir welded joints after one line peened of AA 7075-T73. It was observed from Figure 7 that there were elongated grains with certain precipitates dispersed in the aluminum alloy mold having a cross section alike the friction stir welded joints. There's no variation in the structure of grain, and there's no plastic deformation in the HAZ, while there was a plastic deformation in the microstructure of SZ and TMAZ due to the largest heat that resulted too fine grains.

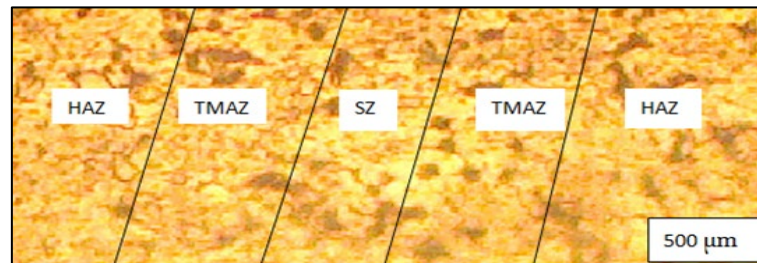


Figure 7: Micrograph of FSW One line peened zones of 7075-T73

4.3 Tensile results

The tensile tests result of similar welded joints were obtained with the best parameters of welding, including a rotational speed of 710 rpm, a travel speed of 35 mm /min, and a cylindrical tool with tapered pin geometry, as evinced in Figures 8-9. The tensile strength of the welded joints was lower than of the base alloy due to inhomogeneity in chemical composition and microstructure in different welding zones as reported by Singh et al. [21]. The ultrasonic peening treatment was conducted on the welded joints at the best parameters of welding, as manifested in Table 4 and Figure 10. From this table, it is seen that the tensile strength of welded samples with one-line peening 1UP is higher than of two lines peening 2UP. The tensile strength average with three readings measured for four conditions (Base, Welded, one line peened and Two lines peened), as summarized in the Table 3, which includes the results before and after the ultrasonic peening treatment. The comparison reveals that the ultimate tensile strength of specimen under ultrasonic peening UP more than the welded untreated joints. The ultimate strength values were 74.6%, 71.6% and 60.3% under 1UP, 2UP and welded conditions, respectively. The situation of specimen before and after tensile tests for all cases is shown in Figure 11.

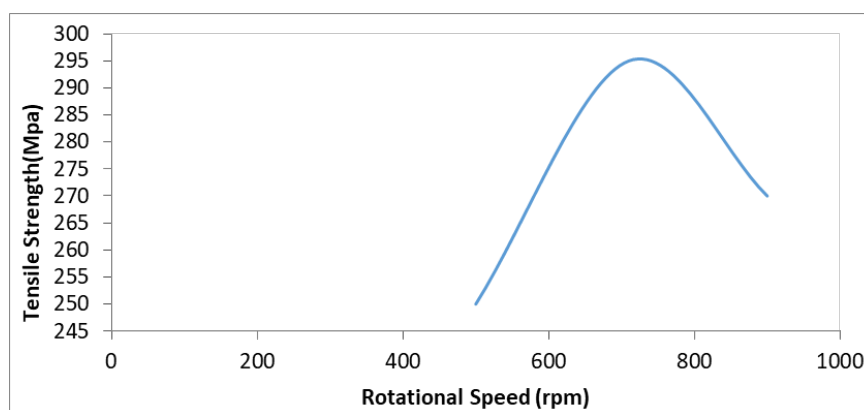


Figure 8: Effect of Rotational Speed on the Tensile Strength

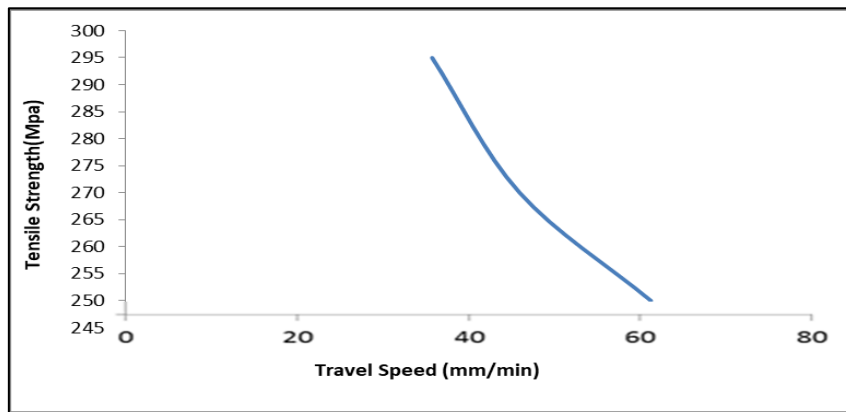


Figure 9: Effect of Travel Speed on the Tensile Strength

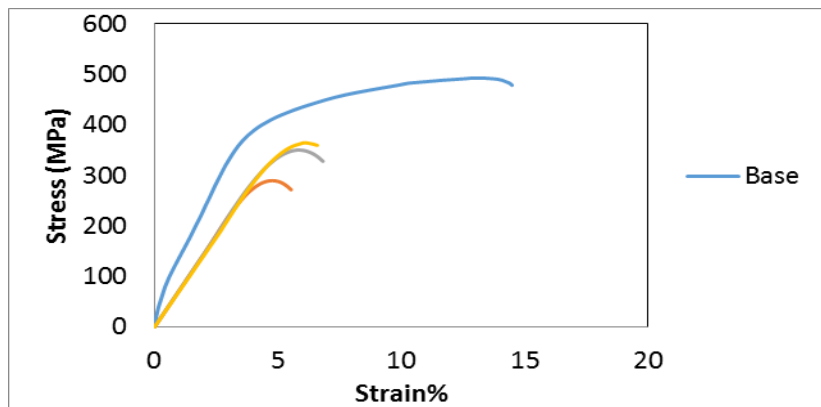


Figure 10: Stress-Strain diagrams of 7075-T73 for different conditions

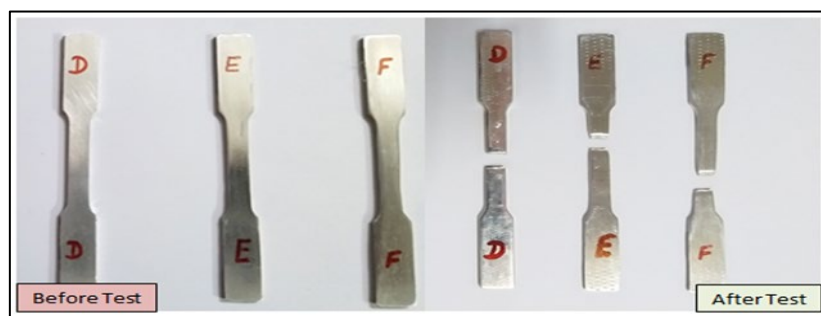


Figure 11: Tensile specimens before and after test

Table 3: Different Conditions of Ultrasonic Impact Peening

| Symbol | Ultrasonic Impact Peening Conditions |
|--------|--------------------------------------|
| D | Welded without Peening |
| E | Welded with One line Peening |
| F | Welded with Two lines Peening |

Table 4: Tensile test results

| Specimen | Yield strength (MPa) | Tensile strength (MPa) | joint efficiency % | Elongation % |
|----------|----------------------|------------------------|--------------------|--------------|
| D | 225 | 295 | 60 | 5 |
| E | 300 | 365 | 74 | 6.3 |
| F | 285 | 350 | 71 | 6.1 |

4.4 Microhardness results

The microhardness results of welded joints before and after ultrasonic peening treatment are shown in Figure 12. For welded joints before ultrasonic peened treatment, the hardness increased in stir zone SZ to 234.7HV compared with TMAZ and HAZ, which reached to maximum values of 158.1 HV and 196.6 HV, respectively. The hardness for welded joints with one-line peening 1UP in stir zone was 382.5 HV compared with TMAZ and HAZ, which reached to values of 260.3 and 182.1 HV. The hardness for welded joints with two lines peening 2UP in stir zone of 264.6 compared with TMAZ and HAZ, which reached to values of 246.2 HV and 223.3 HV, while the hardness value is 155 HV for the base metal BM. The difference in the microhardness values among the HAZ, TMAZ, and NZ is owing to the refinement of the grain and the equiaxed dynamic recrystallization in nugget zone NZ. The softened HAZ is due to the coarsening and dissolution of the strengthening precipitates or the second phase particles throughout the FSW process, and this result was confirmed by many researchers such as Barcellona et al. [22]. Most of the tensile specimens were failed in the HAZ because of the microhardness values, in which the lowest value, while the local material softening took place in the weld area resulted via the thermal action of the process of welding.

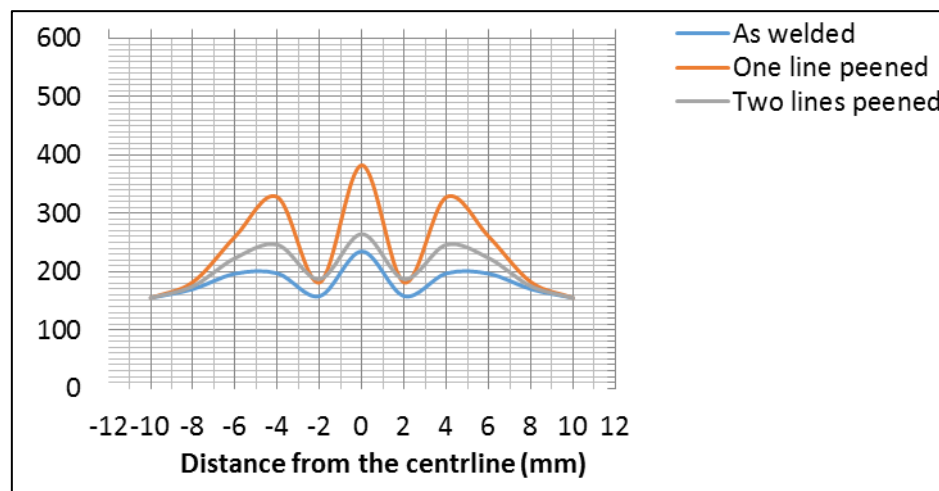


Figure 12: Microhardness distribution of 7075-T73 for different conditions

5. Conclusions

- 1) The similar welded joints of aluminum alloys Al 7075-T73 were successfully performed via the FSW process.
- 2) The ultrasonic peened treatment was performed on the welded joints with one and two lines peening, and more suitable improvement for mechanical properties was with one line peening.
- 3) The microhardness in the stir zone SZ was greater than that of the thermo-mechanically affected zone (TMAZ) and the heat-affected zone HAZ due to the grain refinement.
- 4) The enhancement of the tensile strength with one-line peening 1UP was 14% compared with the as welded samples.
- 5) The enhancement of the tensile strength with two lines peening 2UP was only 11% compared with the as welded samples.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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