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Effects of Laser and Shot Peening on fatigue life in Friction Stir Welds

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ABSTRACT

The effects of laser, and shot peening on the fatigue life of Friction Stir Welds (FSW) have been investigated. The surface roughness resulting from various peening techniques was assessed, and the fracture surfaces microstructure was characterized. Laser peening resulted in an increase in fatigue life approximately 60%, while shot peening resulted in 10% increase when compared to the unpeened material. The surface roughness of shot peening was significantly higher compared to the base material, while specimens processed with laser peening were relatively smooth.

Keywords: FSW, laser peening, shot peening, fatigue

1. INTRODUCTION

Friction stir welding (FSW) is a relatively new welding technique that was invented by the Welding Institute in England in 1991 [1]. The technique uses frictional heating combined with forging pressure to produce high strength bonds. This welding technique transforms metals into a plastic state at a temperature below the melting temperature of the material [2], and then mechanically stirs the material together under pressure to form a welded joint as shown in Figure 1. The threads on the welding tool produce a downward component to the material flow, inducing either a counterflow extrusion toward the top or circumferential flow around the pin [3].

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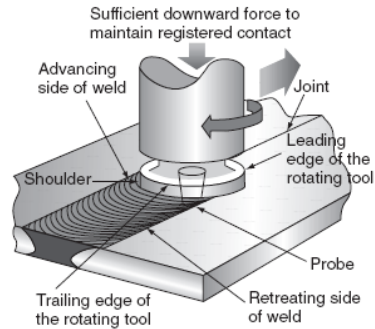


Figure 1: Principle of the friction stir welding process.

FSW takes place at a low temperature level compared to fusion welding; therefore, residual stresses may be considerably less than those in fusion welds. However, the heating cycle the material experiences during welding, and the rigid clamping arrangement used in FSW can have an impact on residual stresses in the weld [4, 5].

The residual stresses developed during the welding process can have a significant effect on the service performance of the welded material with respect to fatigue properties, and fatigue crack growth process [6]. Residual tension stresses in the weld can lead to faster crack initiation and propagation, and could also result in stress corrosion cracking (SCC).

The use of FSW is expanding rapidly and is resulting in welded joints being used in critical load bearing structures. Therefore, it is of the utmost importance to investigate methods and techniques that can alleviate the tensile residual stresses in welds, and extend the fatigue life of those components welded using FSW. Several studies [7, 8-14] have investigated the fatigue behavior of FSW butt-welded aluminum alloys, but none of these studies had investigated the effects of laser peening on the fatigue life.

Laser peening (LP), as shown in Figure 2 is a rapidly expanding technology that introduces a state of residual compressive stresses that significantly increases fatigue life and fatigue strength by inhibiting the initiation and propagation of cracks [15]. LP ability to develop deep, high compressive stresses in the areas treated has been demonstrated on a number of metals and alloys. The first commercial application for laser peening was in 1997 [16].

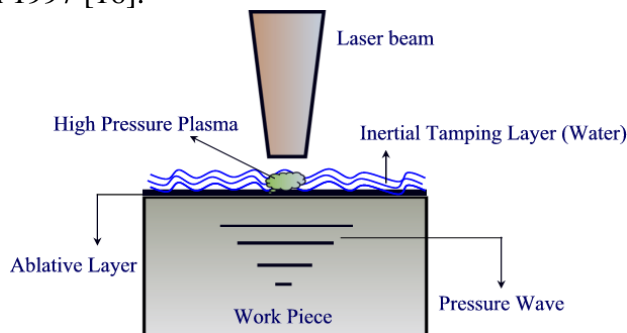


Figure 2: Laser peening process

The LP process provides high energy laser pulses (several GW/cm²) that are fired at the surface of a metal coated with a dark paint, and covered with a thin layer of transparent material (usually water). The interaction of the laser and the paint creates a pressure shock wave which is contained by the layer of water. When the peak pressure of the shock wave is greater than the dynamic yield strength of the material, it produces extensive plastic deformation in the metal. The use of the transparent layers such as water has been found to increase the shock wave propagating into the metal. The actual depths of the LP induced stresses will vary depending on the type, intensity of the processing conditions chosen and the material properties [17].

The LP process provides a smooth surface with better surface quality than shot peening, good process control, and good repeatability. Benefits from laser peening have been demonstrated in attributes such as fatigue, wear, and stress corrosion cracking [18] of aluminum, steels, and titanium alloys. The maximum residual stress for laser peening is usually at the surface, and the residual stress gradually decreases with increasing depth below the surface, whereas for shot peening the maximum residual stress is just below the surface, thus creating a hooked shaped residual stress profile [19].

In this study, the surface modification from laser, and shot peening will be used to introduce compressive residual stresses into FSW AA 7075-T7351, and their influence on the fatigue life, surface roughness, and microstructure will be assessed and evaluated.

2. EXPERIMENTAL PROCEDURES

The alloy selected for this investigation was the AA-7075. This precipitation-hardened aluminum alloy is widely used in aerospace applications due to its high strength. The base metal was supplied in a T651 temper with an ultimate and yield strength of 561 MPa, and 536 MPa respectively and an elongation of 11%. The chemical composition of this alloy is shown in Table1 below.

Table 1 Chemical Composition of AA7075 (wt. %)

Material	Composition
Zn	5.81
Mg	2.62
Cu	1.59
Cr	0.19
Mn	0.01
Ti	0.02
Si	0.08
Fe	0.23
V	0.01
Al	Bal

The FSW specimens for this investigation were produced at the NASA- Johnson Space Center in Houston, Texas using a 5-axis milling machine. The plates were placed on the welding platform in a butt-weld configuration, and the welding direction was such that it was aligned with the rolling direction. The tool to work piece angle was fixed at 2.5 degrees, and the tool rotation was set at 350 rpm in the counterclockwise direction. The traverse speed was set at a rate of 2.54 cm/min stirring the interface and producing a solid-state weld. The FSW panels produced at NASA were 122 cm x 20 cm x 0.65 cm. Following the welding process, the welded plates were aged from the T651 condition to the T7351 condition, and then inspected for defects.

To verify the mechanical properties of the weld, tensile testing was performed at room temperature. The tensile specimens consisted of conventional tensile coupons with a width of 12.7 mm in accordance with ASTM E8. The coupons were oriented such that the weld was in the center of the specimen and the load was applied perpendicular to the weld direction. The tensile testing results for the welded specimen indicated an ultimate and yield strength of 339 MPa, and 226 MPa respectively and an elongation of 5.5%. A microstructural investigation of the weld zone was also done specimen using optical and digital microscopes. The specimen was cut and sectioned in a direction perpendicular to the welding direction.

The LP was performed at the Metal Improvement Company in Livermore California, and was performed using a double layer (200%). A special LP technique was taken into account to process the specimen corners. A square laser spot size of 4.72 x 4.72 mm² was used, and the spots within a layer were overlapped 3%. Peening between layers had an off-set of 50% in each direction. A peening frequency of 2.7 Hz and a 1 micron wavelength laser was employed. Other samples were shot-peened with 0.0234" glass beads, with an Almen intensity of 0.008-0.02A and a 100% coverage rate.

The fatigue specimens were milled on the top side of the weld removing about 0.4 mm of material. The coupons were oriented such that the weld was in the center of the specimen and the load was applied perpendicular to the weld direction as illustrated in Figure 4. The fatigue testing was performed under axial loading at constant amplitude using a servo-hydraulic machine. All the tests took place at a room temperature environment. The maximum stress level used in the test was 190 MPa, and was carried out at a stress ratio R=0.1. The loading frequency used in the tests was 22 Hz.

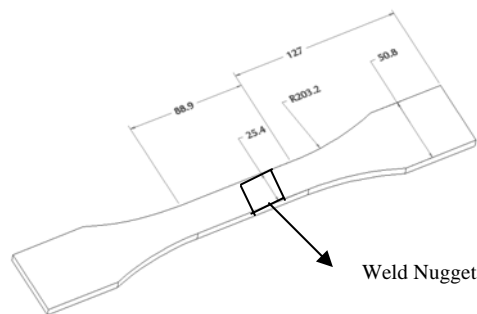


Figure 4: Fatigue test coupon used for testing

3. RESULTS & DISCUSSION

3.1 *Weld microstructure and hardness*

A cross section showing the different regions of the weld is illustrated in Figure 5. The weld nugget reveals grains that are fine and equiaxed. Relative to the nugget, the Thermo Mechanical Affected Zone (TMAZ) experiences a lesser degree of plastic deformation, and grain structure in this region appears to be elongated, with some considerable distortions that may be attributed to mechanical action from the welding tool.

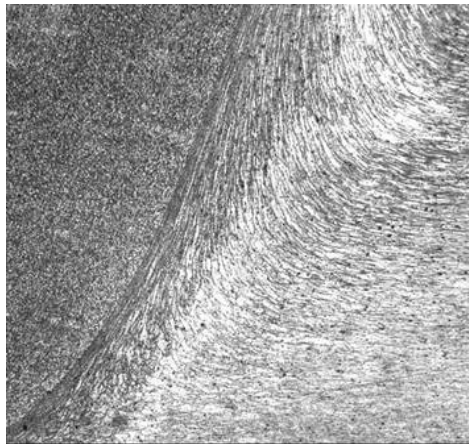


Figure 5 A Cross section of the welded specimen at 250x

The Heat Affected Zone (HAZ) is unaffected by mechanical effects with a grain structure that resembles the parent material grain structure. Figure 7 below reveal the fine and equiaxed grains at the nugget, and reveal fairly uniform grains with no apparent defects. The grain size in this region is significantly smaller than the parent material grain due to the higher temperature and extensive plastic deformation.

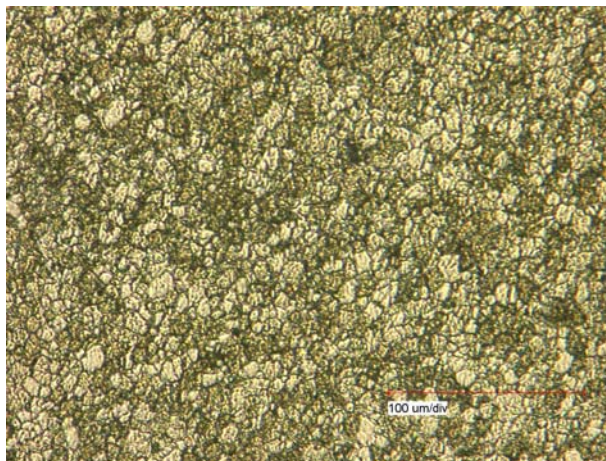


Figure 7: Weld nugget microstructure

A micro-hardness test was also performed on a cross section perpendicular to the welding direction using a 300g for 3 seconds. The results of the test are illustrated in Figure 8. The figure shows a softened region corresponding to the weld nugget. The variations in hardness can be correlated to the microstructure developed after the welding process.

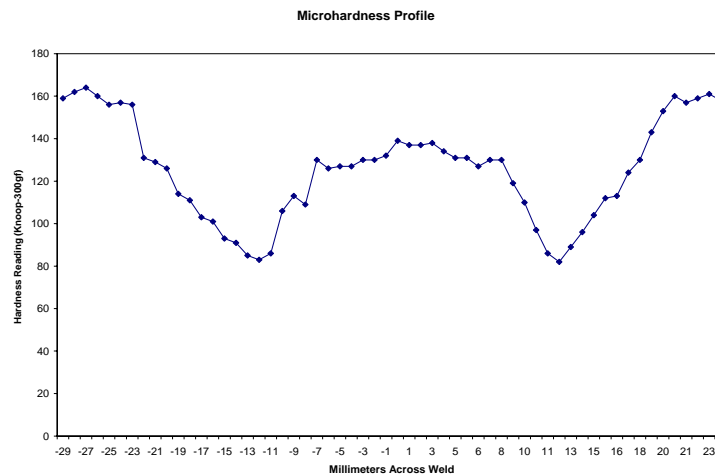


Figure 8 Micro-hardness test across the weld of FSW 7075-T7351

3.2 Surface Roughness

The surface roughness resulting from the different laser, shot peening is illustrated in Figures 9, 10, and 11 below.

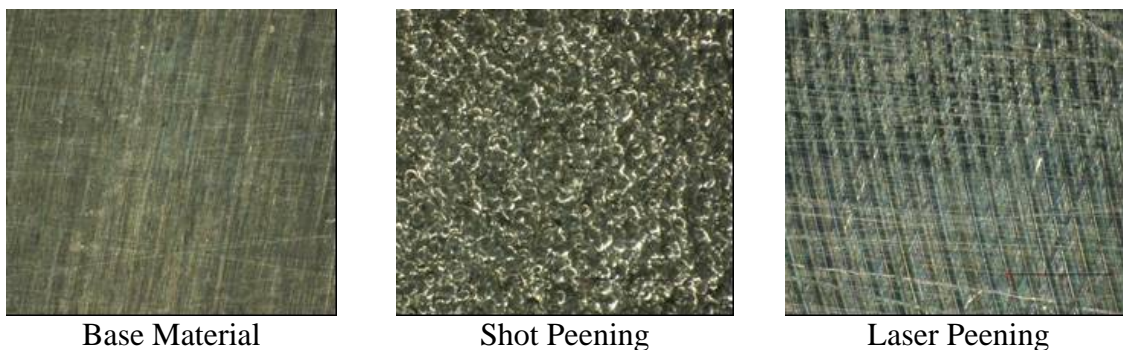


Figure 9: Different surface roughness resulting from different peening techniques

The shot peening technique resulted in significant surface roughness compared to the base material, while specimen processed with laser peening had very smooth surface that could be compared to the base material. Surface roughness can have a big impact of the fatigue life. It is possible the some of the gains from shot peening can be reduced by the adverse surface roughness on the specimen surface.



Figure 10: A 3d rendering of the surface roughness resulting from different peening techniques

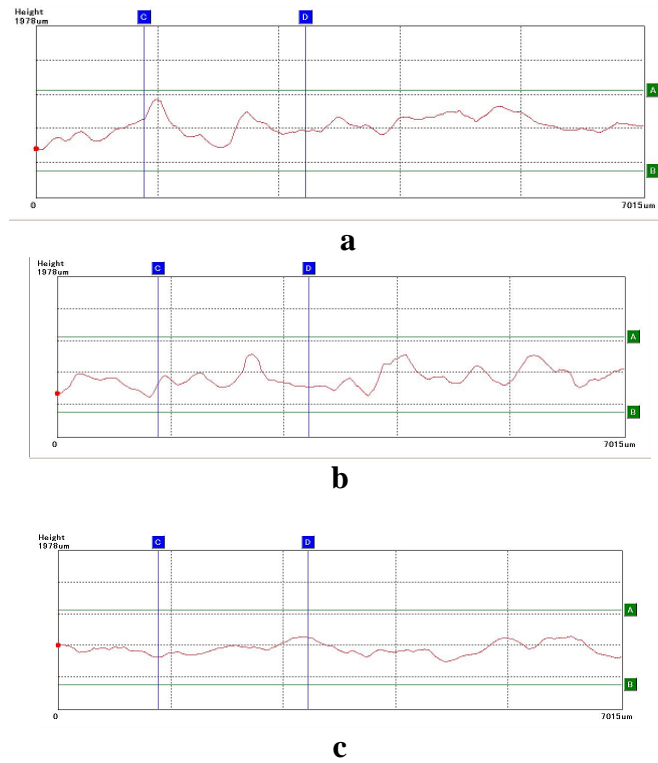


Figure 11: Profilometry results for the different peening technique. (a) base material, (b) shot peening, and (c) laser peening

3.3 Fatigue life

Fatigue life changes as a result of peening are shown in Figure 12. The specimens processed with shot peening indicated around 10% increase in fatigue life when compared to the base material. On the other hand, specimens processed with laser peening had an increase about 60% over the base material. This can be attributed to the high compressive residual stresses and relatively smooth surface introduced by the laser peening. All the crack initiation sites during the fatigue test took place at the corners, due to the high stress concentration exhibited at that particular location. Shot peened specimens also exhibited multiple smaller crack initiations on the surface as a result of the high surface roughness, but were small compared to the dominant flaw at the corner.

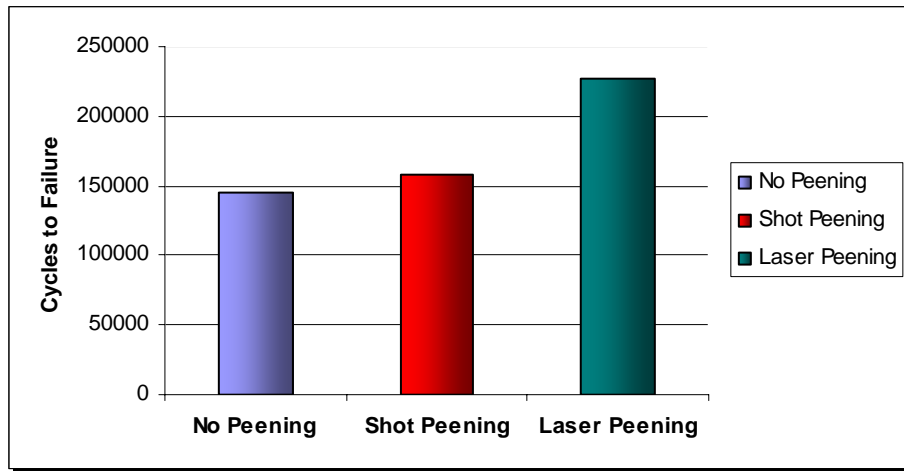


Figure 12: Average fatigue life results for the three different configurations investigated

3.4 Fractography

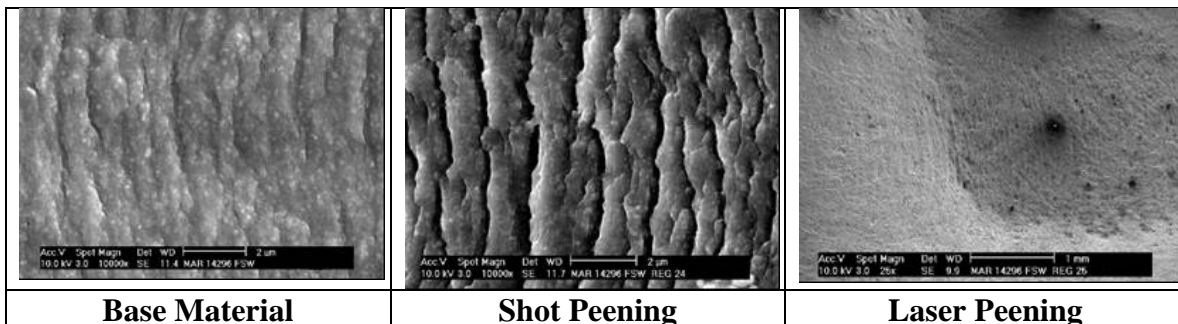


Figure 13: Fractographic analysis for the three different configurations investigated

Add discussion on fractography.....

4. SUMMARY & CONCLUSION

In this investigation, the effects of laser, and shot peening on the fatigue life of Friction Stir Welds AA 7075-T7351 were investigated. The fatigue samples used in the test were conventional dog bone specimen in accordance to ASTM 466. The loading during the fatigue life testing was applied in a direction perpendicular to the weld direction. The surface roughness of shot peening was significantly higher compared to the base material, while specimens processed with laser peening were relatively smooth. The fatigue testing results indicated an increase of about 10% in fatigue life from shot peening, and an increase of 60% from the laser peening. It should be mentioned that the laser peening parameters used in this investigation are preliminary and still under development. New modified laser peening parameters at the corners are currently being developed, and are expected to significantly increase the fatigue life in FSW fatigue specimen. Special care is needed at the specimens' corners when machining the fatigue specimen, since corner sharpness can significantly increase the scatter in the fatigue results. Furthermore, it is recommended to investigate the effects of combining shot and laser peening on the fatigue life of the FSW specimen to gain more insight on improving fatigue life. It would also be beneficial to investigate the effects of additional laser peening layers on the fatigue life performance.

5. ACKNOWLEDGMENT

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