Evaluation the Mechanical Properties of Shot Peened TIG Welded Aluminum Sheets

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ABSTRACT

A tungsten inert gas (TIG) welding is one of the most popular kinds of welding used to join metals mainly for aluminum alloys. However, many challenges may be met with this kind of joining process; these challenges arise from decay of mechanical properties of welded materials. In the present study, an attempt was made to enhancing the mechanical properties of TIG weld joint of 6061-T6 aluminum alloy by hardening the surfaces using shoot peening technique. To optimize the shoot peening process three times of exposure (5, 10, and 15) min. was used. All peened and unpeened, and welded and unwelded samples were characterized by metallographic test to indicate the phase transformation and modification in microstructure occurring during welding process. Tensile test and Vickers micro-hardness measurements were performed for all samples to investigate the effect of shoot peening on mechanical properties of welded aluminum. The results indicated a significant improvement in properties for peened welded and unwelded samples compared with those unpeened one. Also, the results showed that the tensile and micro-hardness properties were increased with increasing the time of exposure to 15 min. due to generation of compressive residual stresses at surface.

Key words: shot peening, TIG welding, aluminum alloy 6061 -T6.

تقييم الخواص الميكانيكية لصفائح الالمنيوم الملحومة بطريقة قطب التنكستن المحمي بالغاز الخامل والمعاملة بطريقة القذف بالكرات

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الخلاصة

تعتبر عملية اللحام بقطب التنكستن المحمي بالغاز الخامل (TIG) من اكثر انواع اللحام انتشارا والمستخدمة لربط المعادن وخصوصا سبائك الالمنيوم. رغم هذا فهناك العديد من التحديات والتي ممكن مواجهتها عند استخدام هذا النوع من عمليات

الربط. هذه التحديات ناشئة من انخفاض الخواص الميكانيكية للمواد الملحومة. في الدراسة الحالية تم عمل محاولة لتحسين الخواص الميكانيكية لوصلة من سبائك الالمنيوم (6061-T6) ملحومة بطريقة اللحام بقطب التنكستن المحمي بالغاز الخامل (TIG) من خلال تصليد السطح باستخدام تقنية القذف بالكرات. وللوصول الى الاسلوب الامثل في عملية القذف بالكرات تم استخدام ثلاث ازمان للتعرض (5,10,15) دقيقة. تم توصيف جميع العينات المعاملة بالقذف بالكرات وغير المعاملة، الملحومة وغير الملحومة من خلال فحص سطح المعدن لبيان التحولات الطورية والتغيرات الحاصلة خلال عملية اللحام. تم اجراء فحص الشد وقياس صلادة فيكرز المجهرية لجميع العينات لدراسة تاثير القذف بالكرات على الخواص الميكانيكية لملحومات الالمنيوم. بينت النتائج تحسن ملموس في خواص العينات المعاملة بالقذف بالكرات الملحومة وغير الملحومة مقارنة بالعينات الغير معاملة. بينت النتائج ايضا ان خواص الشد والصلادة المجهرية قد ازدادت مع زيادة زمن التعرض الى 15 دقيقة نتيجة لتوليد مستويات اعلى من اجهادات الضغط المتبقية عند السطح.

1. INTRODUCTION

Aluminum alloys (Al6061) are preferred engineering material for many application in fields of construction (building and high way construction), automobile, aerospace, and various high performing components owing to their lower weight, excellent corrosion resistance, and high thermal conductivity **Kaufman, 1999, Narsimhachary, 2014**. But when joining these materials, there are many difficulties raised. These difficulties are associated with the high thermal conductivity and high coefficient of thermal expansion of aluminum, the existence of tenacious oxide layers, shrinkage, and high solubility of hydrogen in molten state **Narsimhachary, 2014**, **Nandan, 2010**. In addition to, problems associated with phase transformation and softening of the alloys due to heating during welding operation which results in reducing the mechanical properties of alloys **Kumar, et al., 2013**. The welded joints are involved in wide range of components and being used in critical load bearing structures. Therefore, it is important to study techniques or methods that can alleviate these negative effects of welding process and enhance the mechanical properties of welded components. One of these techniques is hardening the surface by shot peening method. Shot peening is a metal working process in which small spherical balls with velocities of 20-120 m/s are fired toward the surface of a part. Shot peening is usually used to produce a continuous layer of compressive stress at the surface of parts **Salman, et al., 2015**. The compressive stress produced by shot peening depends upon several factors; material properties being shot peened, prior processing, and the specific peening parameters (velocity, time exposure, ball diameter) **Mehmood,** and **Hammouda, 2007**.

Many papers were published in this field. The effects of surface hardening by shot peening on fatigue properties for low carbon steel (1020 AISI) were studied by **Abbass, 2008**. She found a significant improvement in the fatigue strength of shot peened welded parts. Similarly, **Salman, et al., 2015** investigated the mechanical properties for welded joint of aluminum alloy 6061 and influence of shot peening of welded parts. Also, the modifying the surface of friction stir welded 7075 aluminum alloy samples by using laser peening and shot peening was analyzed by **Hatamleh, et al., 2007**.

A TIG welding was used in present work to weld 6061 aluminum alloy specimens. TIG welding is one of the most popular methods used to join metals mainly for aluminum alloys. With this method the electric arc, created between a continuously fed filler wire electrode and the metal, provides thermal energy to melt the work piece as well as the filler material **Weman, 2003**.

In this work, shot peening was used to introduce compressive residual stresses into TIG AA-6061-T6. An attempt was involved in this study to optimize the shot peening parameters in order to get the best enhancement of mechanical properties of welded Al6061 specimens. Hence, varying time exposure (5, 10, and 15) was used for shot peening process. The mechanical properties (yield strength and elongation) of unpeened and shot peened TIG welded specimens were investigated also in this work and compared to the base unpeened material.

2. EXPERIMENTAL WORK

2.1 Sample Preparation

The samples used for welding process were rectangular plates (100mm×50mm with a thickness of 3mm) of aluminum alloy (Al6061-T6) and wire type ER4043 used as a filler, their chemical compositions are shown in Table 1. The sample surface was peroxided by stainless steel brush and whipped with acetone solution to remove scale, rust and dirt. **Table 2** illustrates different categories of used samples.

2.2 TIG Welding Process

Cleaned and brushed samples with dimension (100 x 50 x 3) mm were joined by using TIG welding to yield butt joints TIG welding using ER4043 as filler metal and argon as shielding gas. The other parameters were as follows: current 133A, flow rate 33 cfh, gap 1mm, filler diameter 3mm, voltage 20V. The welded samples were then inspected visually by using dye penetrating and magnetic inspections. The inspections revealed there were no defects in welded samples.

2.3 Shot Peening Treatment

All specimens (welded and as received (unwelded samples)) were shot peened with steel ball (1.25 mm mean diameter) for varying time (5, 10, and 15) min. The angle of nozzle inclination was shifted by 10^{o} with respect to vertical axis to avoid medium collision. A constant distance about 120 mm was maintained between specimen and nozzle.

2.4 Tests and Inspection

2.4.1 Metallographic Practice

Metallographic samples with dimensions (30mm x 20mm x 3mm) were cut from the welded sheets in perpendicular to the welding direction. The as-received and welded samples were prepared by mounting, grinding, polishing and then etched to analyze the microstructure, and observe the change in grain structure. Wet grinding was performed by emery paper of SiC with particle size sequentially (320, 500, 800, 1000, and 1200) and water was used as a coolant and lubricant to facilitate hand grinding. Polishing stage was carried out by using special polishing cloth and diamond paste to obtain mirror polished surface. Finally, etching was performed by immersing the prepared specimen in Keller's Reagent (15 ml HF, 45 ml HCl, 15ml HNO_3 and 25 ml H_2O) for (15-20 sec) and washing by water, then the samples were dried by exposing to stream of warm air. Optical microscope was used to perform this test.

2.4.2 Micro-hardness Measurement

The micro-hardness of the samples was measured with a Vickers micro-hardometer model (HVS-1000). The micro-hardness test was taken using an indentation load of 500 g for 15 seconds at different regions across the surface of the weld. In order to obtain a reliable statistical data, the micro-hardness was evaluated by taking two indentations on each point and averaging of these values.

2.4.3 Tensile Test
The tensile properties for all samples were characterized by using Instron tensile testing machine 3710-016 according to ASTM 638. The orientation of the samples was with the weld in the center of the sample and the load was applied perpendicular to the weld direction. A cross head speed of 10 mm/min was used and all tests were performed at room temperature.

3. RESULTS AND DESCUSSION

3.1 Metallographic
Different regions of the weld were shown in **Fig. 1,** where **1-a** illustrates the microstructure of base metal. While, **Fig. 1-b&c** illustrate the microstructure of weld and the transition area for base metal and weld zone. It is clear from **Fig. 1** that the base metal consists of uniformly distributed and equi-axed grains which are significantly coarser as compared with those of weld zone. Also, it can be noticed that there are some precipitates, represented by dark particles, that are spread uniformly in base metal and their amount are larger than those in weld zone. This may explain the higher strength of base metal. Moreover, it can be shown the dendritic structure in weld zone that may be attributed to the fast heating in welding process of base metal and fast cooling for molten metal as it gets lesser time for solidification.

3.2 Micro-Hardness
Fig. 2 and **Table 3** illustrate the micro-hardness measurement at different locations across the weld zone. There are three areas in which micro-hardness values show significant change, the weld zone; fusion boundary and heat affected zone (HAZ). The largest value of micro-hardness was at base metal 90 HV. The lowest value was recorded at HAZ and weld center. As it moves from the HAZ the micro-hardness values increase at fusion boundary and then return to decrease at near and at weld line due to softening effects. Micro-hardness value varies at a range of 90 HV to 56 HV from base metal to weld center. The variations in micro-hardness values may be correlated to the microstructure developed after the welding process. The low level in micro-hardness at base metal can be explained by coarsening grain size structure which reduces the effect of precipitation elements. The higher value of micro-hardness at fusion boundary may be attributed to recrystallization process occurring at this region due to high temperature during the thermal cycle of the TIG welding which yielded fine grain size. Moreover, it may be due to precipitation of intermetallic phase and thermal cycles. The same findings were observed by **Kumar, et al., 2013, and Abbass, at el., 2013**. They reported that this variation in micro-hardness values is due to phase transformation induced by fusion weld metal effect of heat input.

3.3 Tensile Properties
Fig. 3 and Table 4 summarize the results of tensile test for all samples. These results indicate that the highest tensile properties was for unwelded samples (as received or peening treated sample) as compared with other TIG weld samples in all cases. These are revealing that the effects of softening occurred due to high temperature involved in welding process. The microstructure test shows the phase transformation was taking place in weld zone. It is also observed that the location of fracture was at or near the weld line. As reported previously **Suzuki,** and **Hasegawa, 2007**, there is relation between surface hardness and tensile properties, and it was clarified that

the surface hardness is one of the main factors for determining the tensile, tensile, and fatigue strength. **Fig. 2** shows that the HAZ region and weld center have the lowest micro hardness area because the recrystallization process occurs in this region due to high temperature and the decreasing in participates particles left in the material. **Hatamleh, et al., 2007**, found the similar results and reported in his article the effect of laser and shot peening on fatigue life that "this area of the weld will be relatively ineffective in inhibiting dislocation motion and the strain localization in the softened area of the weld will result in a degradation of the mechanical properties".

On the other hand, an improvement in tensile strength and elongation was recognized with shot peening treated samples in all conditions. Moreover, it is noticed that there is significant effect of shot peening time on magnitude of this improvement in tensile and elongation properties. The improving properties were increased with shot peening time 5 and 15 min. while decreased for 10 min. This variation may be caused by the quantity of residual compressive stress generated at the surface and its values and distribution. Compared to tensile strength of unpeened samples of about (300) MPa, the tensile strength of shot peened samples for 5, and 15 min was about (334 and 332) MPa respectively. The increase of about 11% was recognized. The same trend was observed with TIG weld samples, where the tensile properties of shot peened TIG weld samples exhibited higher values than unpeened TIG weld samples in all cases. The specimens processed with shot peening indicated around 11.2% increase on average in tensile strength when compared to the unpeened TIG weld samples. In the same manner, it is noticed also from the results that the properties were changed as a result of changing the shot peening exposer time. The tensile properties were enhanced in about 5.5 % with shot peening 15 min as compared with (5 and 10) min.

4. CONCLUSIONS

It can be concluded from the results above the following points:

- Properties of weld zone are greatly affected by microstructure and softening effects.
- Shot peening is effective way to improve the properties of welded structures. It improved the yield strength in about 11.2%.
- The effect of shot peening on the improvement of time exposure properties is apparent and more obviously at time of 15 min and in lesser level at time 5 min.

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Table 1. Chemical Analysis of the used materials 6061 - T6 and Filer wire ER 4043.

Element	Cr	Cu	Fe	Mg	Mn	Si	Ti	Al
Measured Value	0.04-0.35	0.15-0.4	Max 0.7	0.8-1.2	Max 0.15	0.4-0.8	Max 0.15	balanced
Standard Value	0.25	0.35	0.55	1	0.15	0.4	0.12	balanced
Filer Metal	0.15	0.3	0.45	0.9	0.15	0.45	0.12	balanced

Table 2. Test samples classification

No.	Symbol	Conditions
1	$A_{\circ}$	As received (unwelded samples)
2	A_1	As received + shot peening 5 min.
3	A_2	As received + shot peening 10 min
4	A_3	As received + shot peening 15 min
5	$B_{\circ}$	TIG Weld Process
6	B_1	TIG Weld + shot peening 5 min
7	B_2	TIG Weld + shot peening 10 min
8	B_3	TIG Weld + shot peening 15 min

Table 3. Micro-hardness values across the TIG weld A6061-T6 sample**.**

Distance	-12	-11	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0 Weld line
Micro-hardness Value	90	88	73	66	57	56	61	59	78	80	63	57	56
Distance	1	2	3	4	5	6	7	8	9	10	11	12	....
Micro-hardness Value	66	75	74	56	58	61	65	68	76	79	88	89	.....

Table 4. Tensile test results of all samples

Sample	Yield Strength MPa	Elongation %
$A_{\circ}$	300	17
A_1	334	21.7
A_2	304	21.9
A_3	332	21.7
$B_{\circ}$	140	7.2
B_1	151	9.7
B_2	150	9.3
B_3	158	12

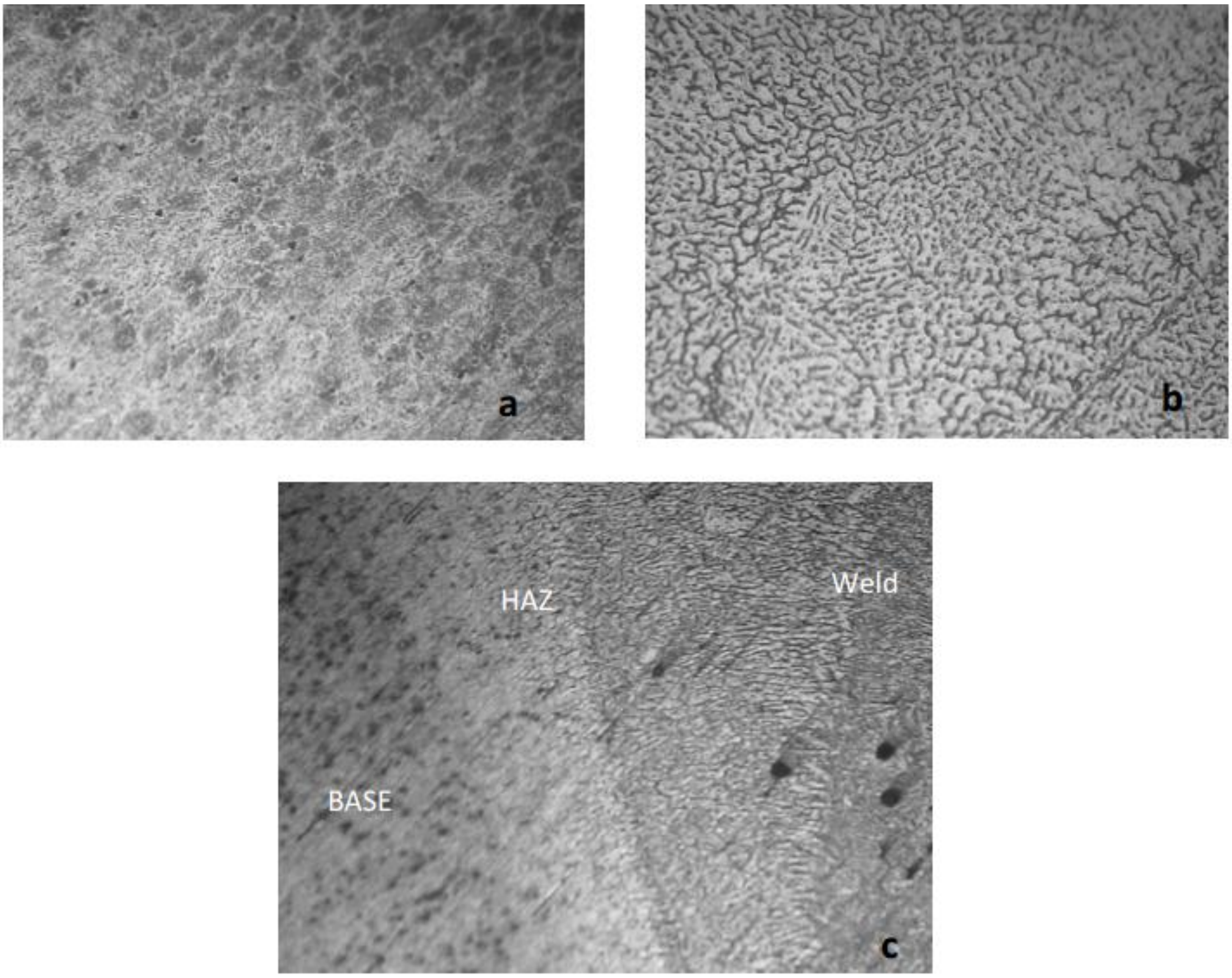

Figure 1. Microstructure of samples a- base metal, b- weld zone, c- base metal, HAZ, and weld zone interface. (20X).

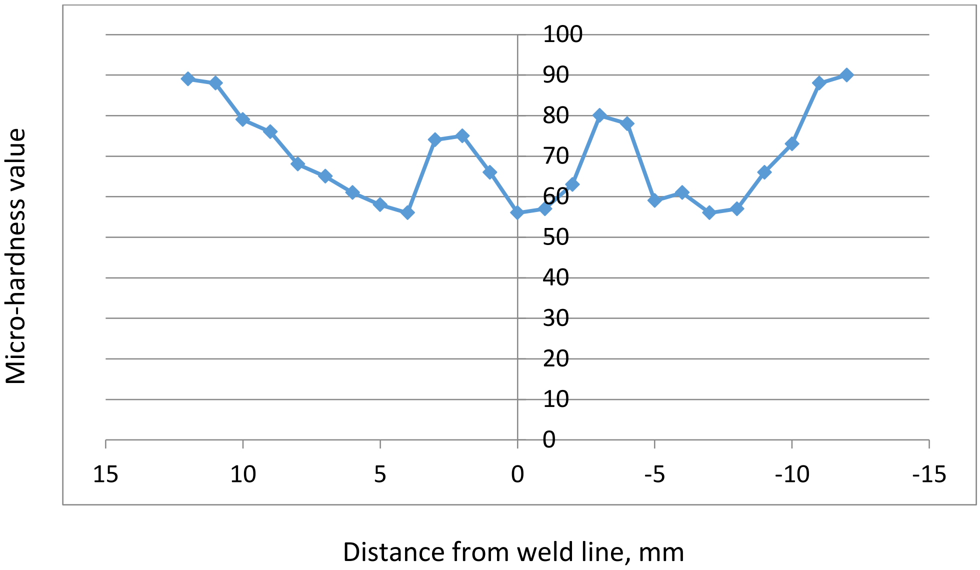

Figure 2. Micro-hardness distribution across the TIG weld A6061-T6 sample

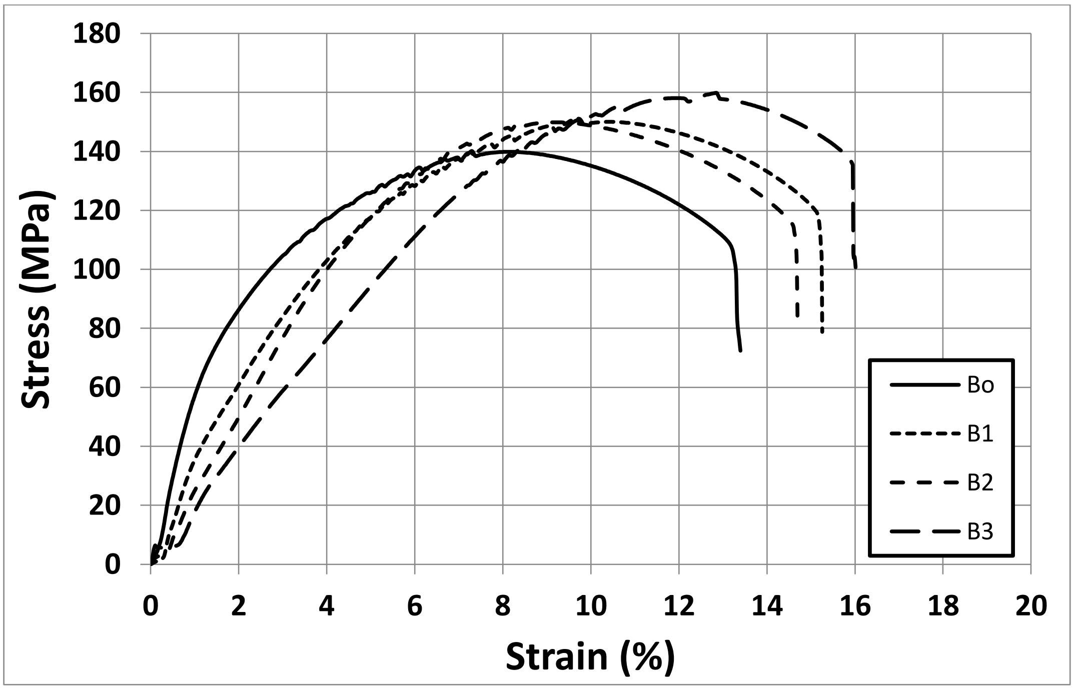

Figure 3. Stress-strain curves of all samples