AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2

ISSN: 1998-4456

EFFECT OF ULTRASONIC PEENING TECHNIQUE ON FATIGUE LIFE OF 6061-T6 ALUMINUM ALLOY

Shaker S. Hassan,

Mechanical Engineering Dept., University of Technology, Baghdad. Iraq.

Email: shaker_sakran1952_1@yahoo.com

Mohsin N. Hamzah,

Mechanical Engineering Dept., University of Technology, Baghdad. Iraq.

Email: 20066@uotechnology.edu.iq

Raad M. Abed,

Ministry of Higher Education and Scientific Research, Baghdad. Iraq.

Email: raad1232002@yahoo.com

Received on 23 January 2017 *Accepted on 13 March 2017*

Abstract: *The ultrasonic peening technique (UP) is one of the innovative and hopeful methods for fatigue life enhancement and upgrading of welded structures and components. The fatigue testing of sheet specimens for 6061-T6 aluminum alloy, demonstrated that the UP is an effective change treatment to mechanical properties as judged against unpeened specimens. S-N curve and the fatigue fracture mechanism were scrutinized in detail. The most important results revealed the fatigue life of specimens improved due to the surface hardening. Residual compressive stresses were created by UP and increased the fatigue life and strength. This paper scrutinized the potential use of ultrasonic waves on the surface of 6061-T6 aluminum alloy. This can be exhibited as a factor of safety due to ultrasonic, reach to 1.42 when estimate the number of cycles fatigue based on amount of applied stress at 0.3 σu.*

Keywords: ultrasonic peening technique, fatigue test, 6061-T6 aluminum alloy

1. INTRODUCTION

Over the past decade, there has been a developing enthusiasm for quickening the advancement and employment of novel substances in vital railroads, cars, and pipelines frameworks. A vital branch of this exertion includes significant expansion of fatigue life forecast capacities. One of the hopeful processing by means of the high power ultrasonic for manufacturing applications is the ultrasonic peening technique (UP) of elements and welded sections. In most industrial appliances, the UP is known as Ultrasonic Impact Technique (UIP). The ultrasonic peening generates a sum of valuable effects in alloys and substances. Most an important along with these effects is escalating the resistance of substances to failures, such as fatigue life span, wear and stress corrosion cracking.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2
ISSN: 1998-4456

In common, the essential UP components, as shown in Figure (1), could be utilized for handling of weld toe and bigger outside regions if needed (Yuri and Jacob 1). numerous investigational researches on the cause of UP on the fatigue strength have been carried out in the condition that UP was done under no load and lower stresses (Kazeno and Sekiguchi, Tominaga et. al., 2, 3). This method was primary discovered in the

1950s and the early effort through 1980 was assessed by (Le 4).

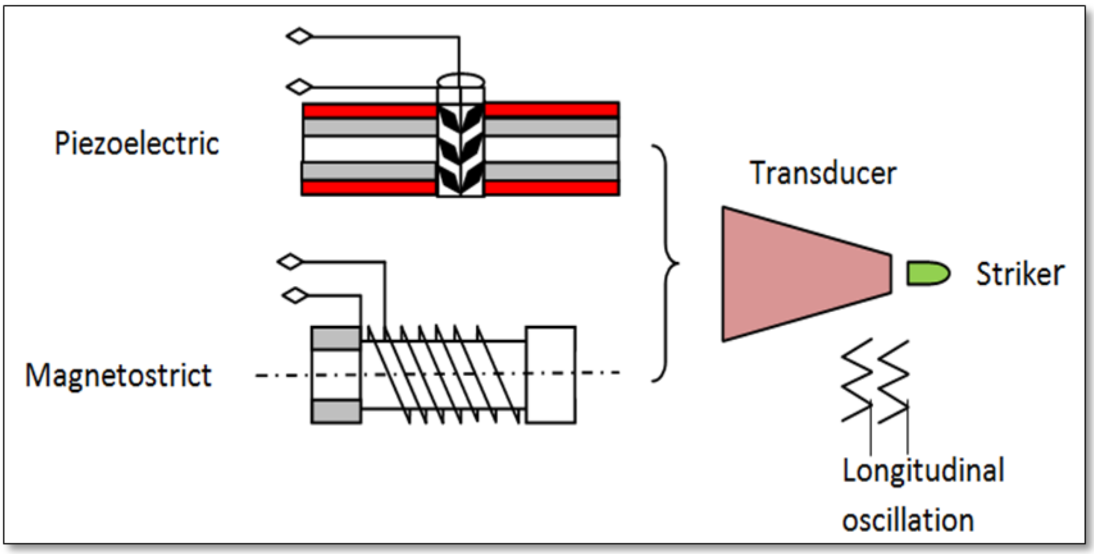


Figure 1. Graphic sight of transducer designed for ultrasonic Peened samples.

More recently, (Herwig 5) has put forward a comprehensive survey of enhancements in the mid ten years back, particularly with respect to the utilization of ultrasonic fatigue for fatigue crack growth threshold studies. However in latest years, study endeavor has been focused mainly in Japan and Europe, where the method is benefit from substantial utilize there as a instrument for very extended fatigue life forecast (Stefanie and Herwig, Stefanie 6, 7). Various studies have been carried out viewing that the fatigue behavior of many important structural materials systems, comprising aluminum, nickel titanium and based alloys can be determined efficiently by ultrasonic fatigue technique.

A weld toe pattern could be treated by means of ultrasonic peening which it is in fact affected to plane surface of the forged spring or gear of the manufactured components. It has been verified that eliminating tensile residual stress from weld toes without doubt improved the fatigue strength (Mehmet 8). In scientific literatures, apparatus are identified with numerous given names: ultrasonic impact treatment, ultrasonic .peening, ultrasonic peening treatment (Lets global, Zhao 9, 10) , high-frequency .impact treatment (Sonats 11), pneumatic impact treatment (Pitec 12), and ultrasonic needle peening (Sonats, Bousseau and Millot, 13, 14). In this research, the aim of the study described is to check up the prospective utilization of ultrasonic waves on the surface of 6061-T6 aluminum alloy.

The ultrasonic transducers which can be utilized for UP, consist of two general sorts: magnetostrictive and piezoelectric. Together achieve a similar errand of changing over varying electrical energy to vibratory mechanical energy yet do it in a dissimilar manner (Figure 1). In magnetostrictive transducer the substituting electrical energy from the ultrasonic generator is initially changed over into an alternating magnetic field using a wire coil. At the ultrasonic frequency in magnetostrictive substance, the alternating magnetic field could be utilized to initiate mechanical vibrations .For the most part, the magnetostrictive transducers are less proficient than the piezoelectric ones. This is expected essentially to the way that the magnetostrictive transducer needs a double energy change from electrical to magnetic also, after from magnetic to mechanical. This lead to missing a several effectiveness in every transformation. Magnetic hysteresis impacts likewise reduce the proficiency of the magnetostrictive transducer. Also, the magnetostrictive transducer for UP necessities required water-cooling. The apparatus for this situation is moderately substantial and costly.

Piezoelectric transducers change over the alternating electrical energy straightforwardly toward mechanical energy throughout the piezoelectric impact. A piezoelectric transducers physically powerful incorporated in the recent years, more effective and exceedingly steady ceramic piezoelectric substances, which be able to work under the temperature and stress situation. Piezoelectric transducers are dependable today and can lessen the energy.costs for function by as much as.60%.

Because of the elevated energy effectiveness of piezoelectric transducers, .the outcome in fatigue life enhancement is virtually the identical by utilizing of the magnetostrictive transducer through power utilization of 1000 Watts and enhanced piezoceramic transducers by power utilization of just 250 to 500 Watts. So, the device which used in this work is piezoelectric transducer.

2. EXPERIMENTAL WORK

The ultrasonic treatment was completed according to the manufacturer's principle. The ultrasonic producer was 20 kHz at the utilization. The ultrasonic peening device has a trade name: HC, and made in china with numeral model: HC-S-1. For typical states of application, the indenters consist of four 3 mm diameter pin, fitted in a solitary holder as shown in figure (2).

Figure2. Ultrasonic peening device type HC-S-1

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2
ISSN: 1998-4456

Short passes was used for the treatment. One passes over one surface of specimen with instrument velocity of 0.25 m/min were completed at an exacting place to make sure a smooth consistent contour contact. The concentration power of the handling was controlled via setting the intensity of output power variety on regular box with 500W maximum power. Appropriate process of the apparatus was ensured through the electronic screen on the regular box, which demonstrated the working amplitude of the indenters, and was kept up at 30-35 μm. The sufficiency of the treatment was guaranteed by adopting the working systems consistently and via visual examination of the treated surface. Perfect treated specimen showed a glossy regular groove on surface figure (3). Indications of extreme cold working and plastic deformation with creation of material flake were obvious.

Figure 3. Treated specimen by ultrasonic peening at the narrow area.

The geometry of fatigue workpiece and the dimensions are shown in Figure 4, and the chemical composition and mechanical properties of Al- alloy 6061-T6 are given in table (1) and (2), respectively. The tests were performed at the SIER- Baghdad (State Company for Inspection and Engineering Rehabilitation).

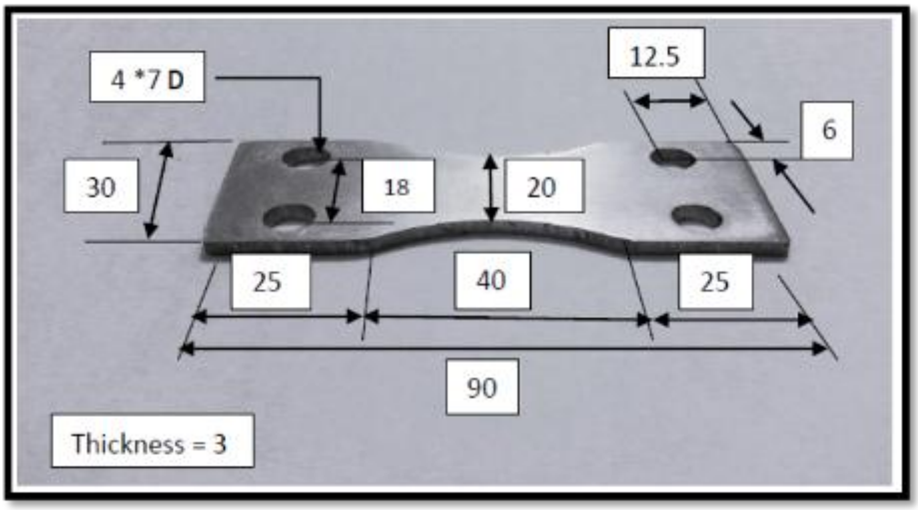


Figure 4. Geometry of fatigue specimen (dimensions are in millimeter) [ASTM].

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2
ISSN: 1998-4456

Table (1). Chemical composition of Al- alloy 6061-T6, wt %, [ASTM].

	% Zinc	%Titanium	%Silicon	%Manganese
Standard	≤ 0.25	≤ 0.15	0.4-0.8	≤ 0.15
Measured	0.16	0.024	0.55	0.07
	% Iron	% Copper	% Chromium	% Magnesium
Standard	≤ 0.7	0.15–0.4	0.04 - 0.35	0.8 – 1.2
Measured	0.35	0.23	0.065	1.12

Table (2). Mechanical properties of the specimens of Al - alloy 6061-T6.

Property	Experimental	Standard
Ultimate stress strength	348 MPa	340 MPa
Yield stress strength	306 MPa	296 MPa
Fatigue strength	100 MPa	95 MPa
Modulus of elasticity	71 GPa	69 GPa
Elongations %	11.9	11

VICKERS HARDNESS TEST

The Vickers hardness examination approach comprises of indenting the check material with a diamond indenter, as a correct pyramid with a quadrangle base with an edge of 136 degrees between opposite confronts subjected to a load of 30 kgf. The applied load is typically connected for 10 to.15 seconds. The double diagonals of the breach left in the surface of the material subsequent to expulsion of the load are calculated utilizing a microscope and their normal computed. The zone of the inclining surface of the space is determined. The Vickers hardness is the remainder obtained by separating the kgf load by the square area of space. And the result come from the Vickers hardness test for ultrasonic peening and unpeened specimens was 95.89HV30 and 93.78HV30, respectively.

MECHANICAL TESTING

The fatigue tests device which is utilized in this study shown in Figure 5. The experiments were carried out at constant amplitude fatigue loading in bending. The utilized frequency was 23.33 Hz at the experiments with changeable loads. The tests were carried out by using AVERY 7305 bending machine manufactured in England.

All experiments were controlled and checked by strain gages fixed on the external face of the specimens. The specimens were from time to time reviewed for fatigue cracks, visually with the aid of a amplifying glass. Tests were ceased when a fatigue crack propagate throughout the surface of the specimens.

Figure 5. Fatigue bending machine type (AVERY 7305)

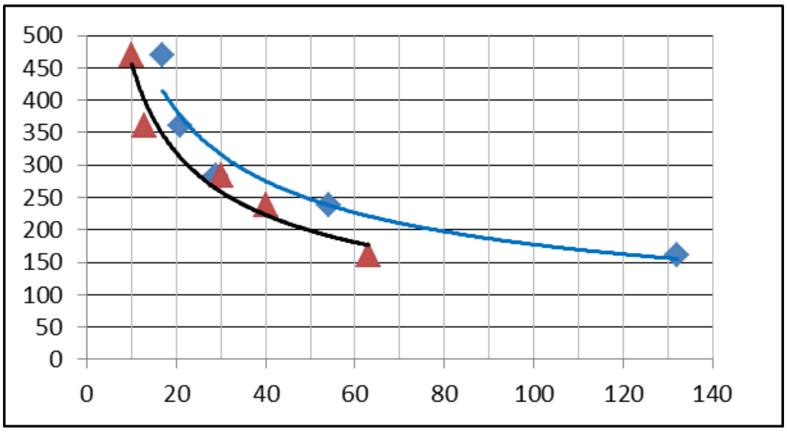
3. RESULTS AND DISCUSSION

S-N SCHEMES

Fatigue life against the average documented nominal stress variety data for the handled specimens and unpeened specimens are schemed to obtain as S-N curve. These curves consist of five level of stress with three recordings for each level. Experiments outcome reveal that the treated specimen via UP obtained considerable improvement in life and strength.

The fatigue results of 15 specimens for five level of stresses, each level examined 3 specimen, the results were obtained at room temperature (RT) and stress ratio (R= -1) for two cases, so the total is 30 specimens. The first case comprised specimens examined as received alloy, while in the second case, the specimens were tested under fatigue ultrasonic peening interaction, as illustrated in Figure (6). It is apparent that the ultrasonic peening improved the fatigue life of alloy and extend the high cycle fatigue life (HCF).

Stress at failure, бƒ (MPa)



Nƒ (Number of cycles to failure x10^3)

Figure 6. S-N curves at constant load for unpeened and ultrasonic peened samples.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2
ISSN: 1998-4456

In circumstance of S – N curve fatigue properties, high cycle fatigue region are remarkably affected by the ultrasonic peening due to power influence on the surface. Because the dominant factor at LCF region is the applied load and there is no enough time for the fatigue cracks to propagate while at HCF region, the dominant factor is the compressive residual stress generated due to the ultrasonic.

The ultrasonic takes apart in a main factor in increasing the pressure which increases the hardening of the surface and initiating a compressive residual stresses at the treated surface as well as subsurface. The energy absorption created main shock waves on the material. And these waves work to generate a high compressive residual stress. The obtained data of S – N curves for ultrasonic and as unpeened alloy can be formulated by the equations:

$$б_f = 788.2*N_f^{-0.155} \quad , \quad б_f = 841.6*N_f^{-0.166} \text{, respectively………………… (1)}$$

Referring to Figure (3), the ultrasonic peened specimens showed considerable plastic deformation zones. This deformation is depended on the collective effects of superior frequency impacts of particular identical strikers and ultrasonic fluctuations in handled peening pieces. The advantages of this method in addition of possible increase in fatigue life of workpieces, least amount cost, labor and power utilization. It can be concluded from Figure (3) that the macrograph method is a very good tool for the comparison, because of a noticed plastic deformation.

It was observed that all ultrasonic specimens' lives increased in a range of 1.01-1.42 as given in Table (3), it is common to estimate the number of cycles as some fraction of ultimate tensile strength (σ_u) that is specific to a material type, depending on the stress level. This percentage gives a factor of safety due to ultrasonic peening from 1.42 to 1.01, based on stress level.

This result is in a good agreement with what was found when 2017-T3 aluminum alloy under one, two, and three line of ultrasonic peening with rotating bending fatigue, a researcher found that the fatigue lives and strength of this alloy are significantly improved due to one line ultrasonic peening for constant and cumulative fatigue testing (Ali 15).

Table (3). Fatigue lives improvement due to ultrasonic peening.

Applied load MPa	0.3 σu	0.5 σu	0.7 σu	0.9 σu	σu
Ultrasonic lives (cycles)	51072	2308	305	67	35
Unpeened lives (cycles)	72587	2629	300	59	30
Safety factor due to ultrasonic peening	1.42	1.13	1.01	1.13	1.16

Table (4) gives the fatigue strength for given number of cycles starting from 103 to 107. And the improvement percentage (IP) (Mehmet 16) :

$$(IP) = ((б\, up - б\, unpeened)/б\, unpeened) \times 100. \text{ ……………… (2)}$$

It is observed that the specimens treated with ultrasonic have more resistant against the dynamic loading fatigue than that unpeened due to generated a hardened surface and a compressive residual stresses on the surface in addition to subsurface.

AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10 , No. 2
ISSN: 1998-4456

Table (4). Comparison between the unpeened and ultrasonic peening in term of fatigue strength.

Fatigue life cycles	103	104	105	106	107
Ultrasonic	270.16	189.07	132.32	92.6	64.4
Unpeened	267.17	182.43	124.39	84.938	57.95
Improvement percentage	1.1	3.63	6.37	9.02	11.1

4. CONCLUSIONS

1. The UP technique is a practicable and alternative choice compared to conventional treatment method. It was found to substantially improve the fatigue life.
2. The UP initiated hardening surface and commenced a beneficial compressive residual stress to the order of yield stress of the material at the treated surface. Cumulatively these improvements enhanced fatigue strength of the treated alloy by increasing the fatigue crack initiation life.
3. The enhancement of the fatigue lifetime is exceptionally influenced by the ultrasonic peening of the low cycle fatigue and particularly at high cycle fatigue. This can be symbolized as a factor of safety due to ultrasonic peening get in touch with to 1.42 based on stress level.

REFERENCES

1. **Ali Y.** , "*Analysis of Ultrasonic peening mechanical properties and fatigue damage of 2017-T3 Aluminum Alloy*", Sudan University of Science and Technology, PhD thesis, (2016).
2. **Bousseau M. and Millot T**., "*Fatigue life improvement of welded structures by UNP compared to TIG dressing*". International Institute of Welding, Paris, Document XIII-2125-06, (2006).
3. **Herwig M.**, "*Fatigue crack growth and threshold measurements at very high frequencies*", Int. Mat. Rev., 44, pp. 1-36. (1999).
4. **Iwamura Y.**, *Proposal of Ultrasonic Peening (UP) system*. In: The March 2005 issue of welding technology, Sanpo Publications, Inc, Tokyo, pp. 128–133, (2005).
5. **Kazeno H., Sekiguchi T., Sakaue S., Katayama Y., Fujikawa N. and Satou H**.: "*Jacket technology of D-runway of Tokyo International Airport*" , The World's first airport that consists of Jacket type pier, Nippon Steel Engineering Co., Ltd. Technical Review, Vol. 1, pp. 6-14,(2010).
6. **Le W.,** "*Ultrasonic fatigue*", Int. Met. Rev., 25, pp. 65-78, (1980).
7. **Lets global**. In: http://www.lets-global.com/.
8. **Mehmet A**., "*Elastic buckling of steel columns under axial compression*", American Journal of Civil Engineering, 2(3), 102- 108, (2014).
9. **Pfeifer.** In: http://www.pfeifer.de/.
10. **Pitec**. In: http://www.pitec-gmbh.com/.
11. **Sonats**. In: http://www.sonats-et.com/.
12. **Stefanie E.** , "*Ultrasonic Fatigue*", in Fatigue, 96: Sixth International Fatigue Congress, Elsevier Science Inc., 1887-1898. (1996).
13. **Stefanie E. and Herwig M, Eds**., *Proceedings of the International Conference on Fatigue in the Very High Cycle Regime*, Institute of Meteorology and Physics, Vienna, (2001).
14. **Tominaga T., Matsuoka, K. and Satoh Y**., "*Fatigue Improvement Method for Weld Repaired Crane Runway Girder, Steel Construction Engineering*", Vol. 14, No. 55, pp. 47-58, 2007.

15. **Yuri F. and Jacob K**., "*Increasing Fatigue Strength of Welded Elements and Structures by Ultrasonic Impact Treatment*", International Institute of Welding. IIW Document XIII-2318-10. (2010).
16. **Zhao X,Wang D, Huo L** "*Analysis of the S–N curves of welded joints enhanced by ultrasonic peening treatment*". Mater Des 32:pp.88–96, (2011).

