IMPROVEMENT OF FATIGUE LIFE OF AA 7075 USING LASER SHOCK PEENING (LSP) SURFACE TREATMENT TECHNIQUE [+]

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Abstract :

In general, laser shock peening (LSP) technique is a surface treatment to increase the resistance of metals and alloys to fatigue failure. The aim of the present work is to study the improvement of fatigue life of AA-7075 at constant and variable load by using laser shock peening (LSP) technique with two energies, 250mj and 500mj, on the surface to be treated. The results show that the fatigue life has increased in different percentages at different constant stress amplitude loading. The average improvement in life factor was approximately (1.534) and (1.157) at constant amplitude stress in the range (0.3-0.8σ_u) for specimens treated with laser shock peening (LSP) technique with 500mj and 250mj respectively. The experimental results of cumulative fatigue damage under variable amplitude stress tests which have been conducted into two-steps program: Low-High stress (156–312MPa) and High-Low stress (312–156MPa) have also showed improvements in life factor of 1.61 and 1.54 respectively for specimens treated with 500mj laser shock peening (LSP) compared with that of untreated specimens.

Key words: **Improvement in fatigue life, laser shock peening, aluminum 7075 alloy.**

تحسين عمر الكلال لسبيكة الالمنيوم 7075 باستخدام تقنية معاملة السطوح بضربات الليزر

عبد الجبار حسين علي

المستخلص:

بشكل عام ، استخدام تقنية الليزر (LSP) يحسن من مقاومة المعادن والسبائك لفشل الكلال. ان الهدف من البحث الحالي هو دراسة تحسين عمر الكلال لسبيكة الألومنيوم 7075 تحت تأثير الحمل الديناميكي الثابت و المتغير باستخدام تقنية معاملة السطوح بالليزر (LSP) وبطاقة على نوعين (250 ملي جول) و (500 ملي جول). أظهرت النتائج أن عمر الكلال في ازدياد وبنسب مختلفة عند الاحمال المختلفة. حيث كان معدل معامل تحسين عمر الكلال (1.543) و (1.157) تحت تأثير الاحمال ذات السعة الثابتة ضمن حدود (0.3 الى 0.8) من الاجهاد الاقصى لسبيكة الالمنيوم 7075 باستخدام تقنية معاملة السطوح بالليزر بطاقة (500) ملي جول و (250) ملي جول على التوالي. كما أظهرت النتائج العملية لفحص الكلال التراكمي تحت تأثير الاحمال ذات السعة المتغيرة التي أجريت بنسق برنامج ذي خطوتين واطئ – عالي (156– 312) ميكا باسكال و عالي – واطئ (312–156) ميكا باسكال ان معامل تحسين عمر الكلال (1.61) و (1.54) على التوالي للنماذج التي عوملت سطوحها باستخدام تقنية الليزر بطاقة قدرها (500) ملي جول مقارنة بتلك النماذج غير المعاملة بتقنية الليزر.

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Introduction:

Only few machine parts are subjected to static loading and the majority of machine parts are subjected to variable loads. Experimentally, when a material is subjected to dynamic loads, it fails at a stress below the yield point; such type of failure is known as fatigue. Fatigue may occur under constant or variable loads. Constant fatigue loading is defined as fatigue under cyclic loading with constant amplitude and a constant mean stress or load. But in service, the structures or components are subjected to variable amplitude loading, which can be a rather complex load time history [1].Variable loading or cumulative damage is usually investigated by testing specimens with a definite number of cycles at one stress level, and then to continue the test at other stress level until failure. In these various stress level tests, the stresses either may be in an increasing or decreasing order or mixed together [2].
Laser shock peening (LSP) technique is a surface treatment that is used to improve material performance. Like other similar surface treatments, laser shock peening (LSP) produces a layer of compressive residual stress on the surface of a part, which results in fatigue life enhancement. In order to favorably affect performance, the residual stress produced by LSP should be compressive near critical locations where failure is likely to occur [1, 2]. It is concluded that residual stress fields from LSP are larger and extend to a greater depth in the components than is found with traditional mechanical shot peening [3]. In laser shock peening (LSP) treatment, the sample is subjected to short duration pulses from a laser, which produces a layer of compressive residual stress on the surface of a part. Over the past decade, there have been many published investigations to measure the residual stress fields produced after laser peening, and to document the improvements, particularly in fatigue behavior. Fatigue performance with laser shock peening (LSP) has been measured in aluminum alloys [4-10] and broadly, similar conclusions are found for each. The laser shock peening treatment is widely recognized as an effective technique for extending fatigue life, fatigue strength as measured by S-N curves is significantly improved, and Fatigue Crack Growth (FCG) rates are reduced. The decrement of FCG is depends on the laser shock peening technique [11].

Experimental Work:

The current work is based on an experimental program which included 72 fatigue specimens, 60 specimens were tested under constant amplitude loading to establish the S-N curves for three conditions; untreated, treated with laser shock peening (LSP) 250mj and 500mj, 12 specimens were tested under variable amplitude stress loading; Low-High and High-Low stress loading for both untreated and with 500mj laser shock peening treatment.
The chemical composition of the material used in this work, Al-7075, is presented in Table (1), while the experimental mechanical properties with the standard values are listed in Table (2).

Table (1): Chemical composition of 7075 Al-alloy in wt. %

Element	Cu	Si	F e	Mg	Mn	Zn	Ti	Cr	Al
Experimental	1.64	0.063	0.253	2.16	0.230	5.43	0.016	0.208	Balance
Standard	1.2-2.0	0.4	0..5	2.0-2.9	0.3	5.1-6.1	0.2	0.18-0.28	Balance

Table (2): Mechanical properties of 7075 Al-alloy

Mechanical properties	Yield strength σ_y MPa	Ultimate strength σ_u MPa	Elastic modulus GPa
Experimental	310	513	72
Standard	355-460	420-530	74

Fatigue Specimen Preparation:

The **72** specimens were prepared according to DIN 50113 as shown in Figure (1). The specimens are manufactured using programmable CNC lathing machine to get the profile at 20mm gauge length.

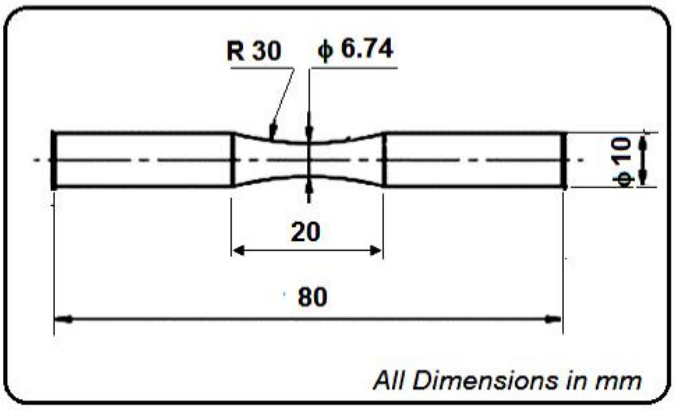


Figure (1): Standard Fatigue Specimen Geometry According to DIN 50113

The Nd:YAG laser system was used for laser shock peening surface treatment technique of different targets. The output pulse duration is 10 nanoseconds, having a wavelength of 1.064 µm with maximum energy per pulse of one Joule. Two types of laser shock peening (LSP) with 0.4mm spot diameter was used for critical section surface treatment of **46** specimens, **20** specimens with 250mj energy and **26** specimens with 500mj energy at room temperature which was 45^{o}C.

Constant Amplitude Test:

All fatigue tests were carried out in the laboratories of electromechanical engineering department, University of Technology using fatigue testing machine type PUNN rotating bending. The experiments were conducted under constant amplitude stress at room temperature and at stress ratio R=-1(mean stress=0).

Variable Amplitude Test:

The cumulative fatigue damage tests have been conducted under variable amplitude stress for two-steps program: Low-High stress (156-312 MPa) and High-Low stress (312-156 MPa). The number of cycles for each step is 1000 cycles under constant loading for each step and so on up to the specimen failure.

Results and Discussion:

The experimental results of fatigue tests under constant stress amplitude which has been conducted at (0.8, 0.75, 0.7, 0.65, 0.6, 0.55, 0.5, 0.45, 0.4, 0.35 and 0.3 σ_u) for specimens of untreated AA 7075 alloy and for specimens treated with laser shock peening (LSP) of 250mj and 500mj showed approximately average improvement in fatigue life by a factor of (1.157) and (1.534) respectively, based on the fatigue life of untreated specimens as shown in Figure (2).

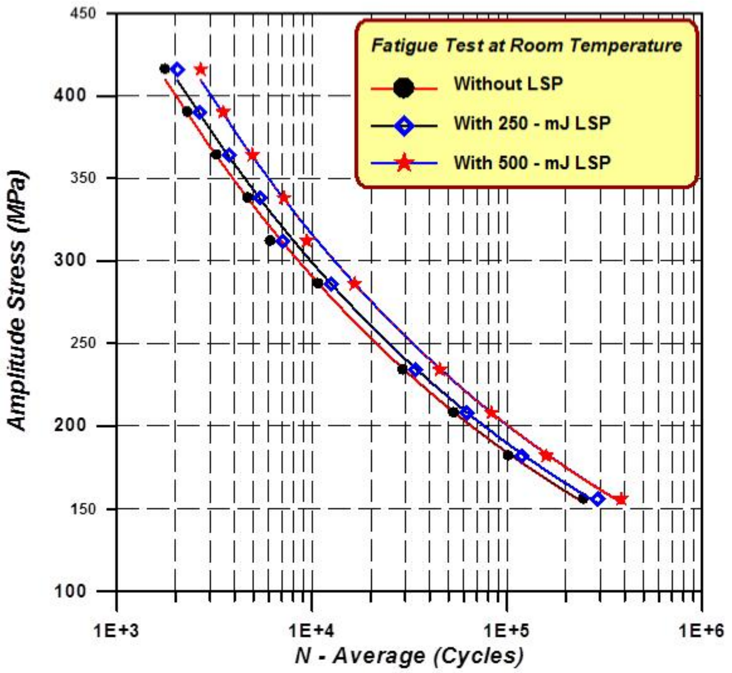


Figure (2): Effect of LSP on S-N Curves at Room Temperature

The power law regression can be summarized in Table (3) for the fatigue life power law given by:

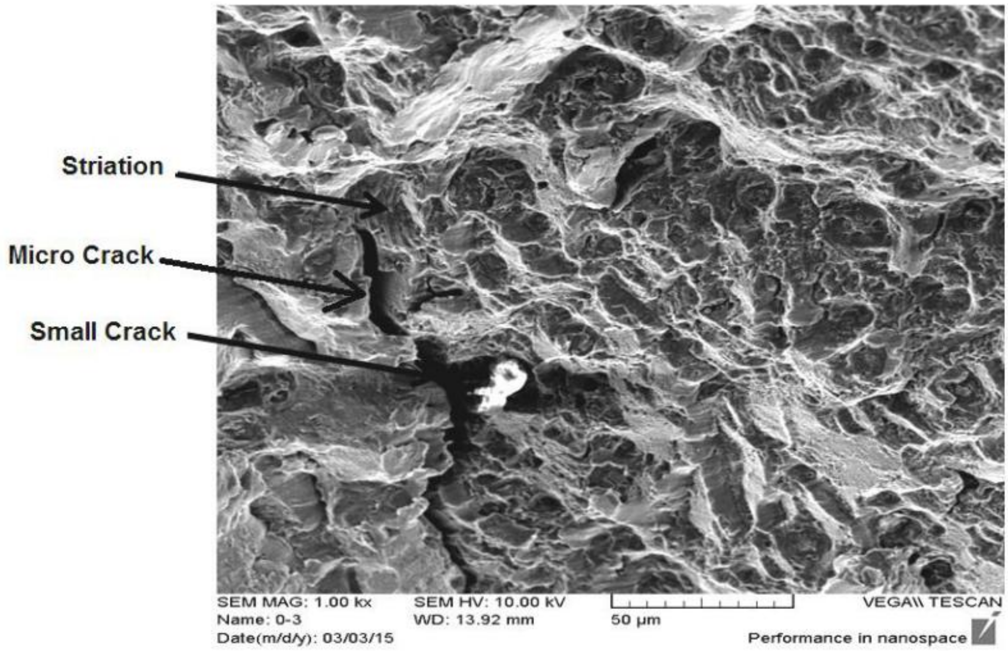
$$\boldsymbol{\sigma = aN^b} \qquad (1)$$

Where, $(\boldsymbol{\sigma})$ is the applied stress, $\boldsymbol{N}$ is the number of cycles to failure and $(\boldsymbol{a})$,$(\boldsymbol{b})$ are the fitting parameters. The regression constants represent the fatigue trends from the model and the fatigue strength at $\mathbf{10^8}$ cycles are given in Table (3).

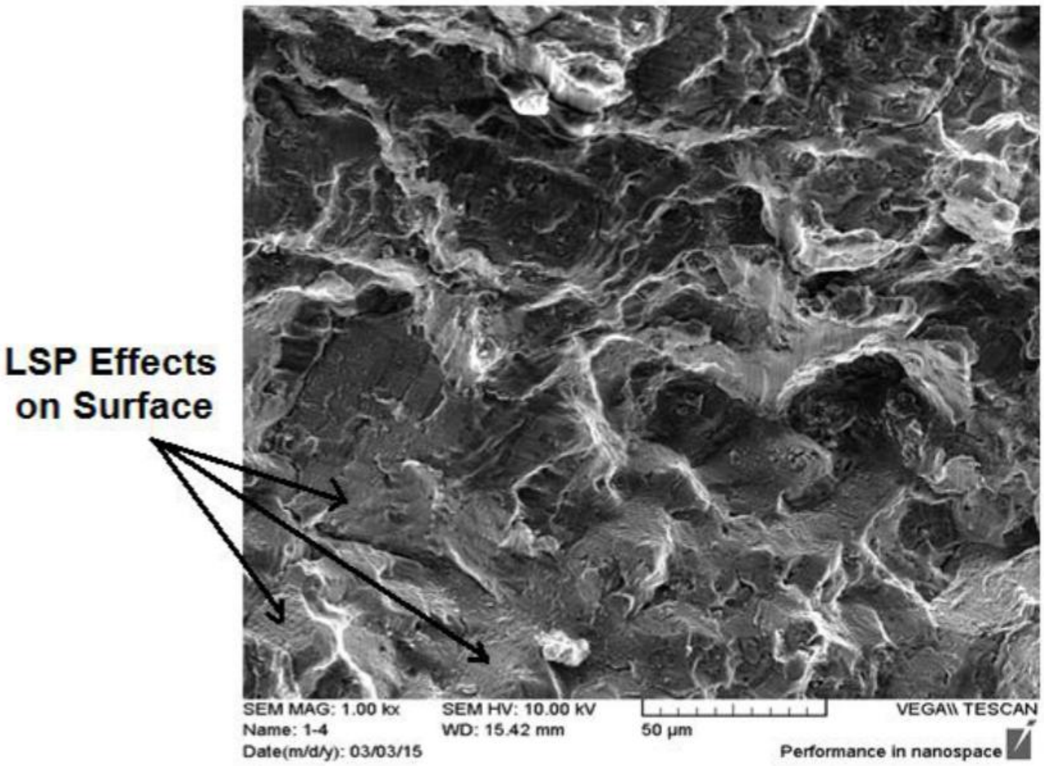
Table (3): Fatigue S-N Curve Parameters and Fatigue Strength of AA 7075

Description	a	b	Fatigue strength at 10^8 Cycles (MPa)	Increasing of Fatigue Strength (%)
Without LSP	1805.4	– 0.19833	46.7	-----
Treated with LSP 250mj	1846.1	– 0.19765	48.4	3.54
Treated with LSP 500mj	1943.8	– 0.19723	52.7	12.85

Scanning Electron micrograph (SEM) has also have been used in order to observe the damage in the material used at the Center of Nano technology and advanced materials at the University of Technology. The increase in fatigue strength and fatigue life is proportional to the effect of LSP energy. As the LSP energy increases more strain hardening at the surface takes place as shown in the fractograph of the fracture surface by SEM of untreated and LSP 500-mJ in Figures (3 and 4) respectively.

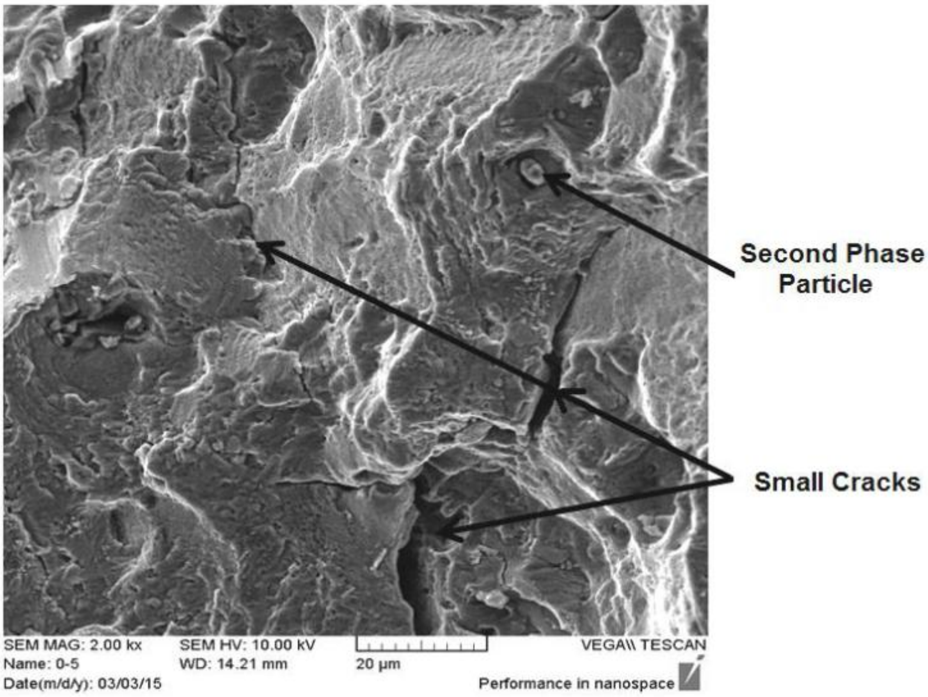


(a) Untreated

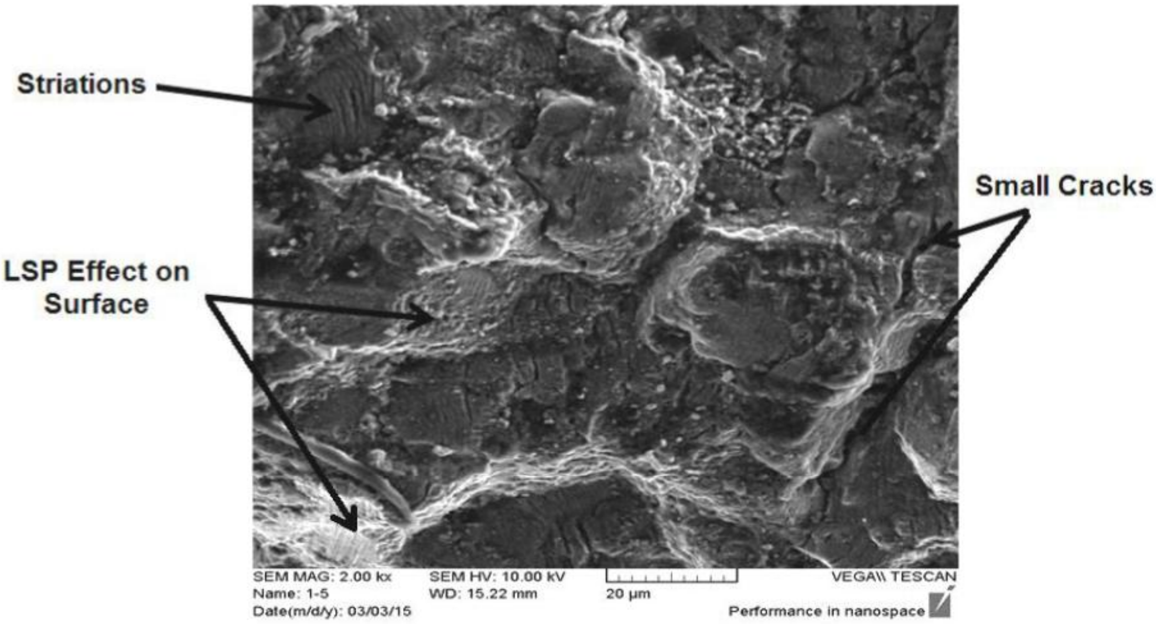


(b) LSP 500 mJ

Figure (3): SEM image at the fracture surface at 1000× for Untreated and LSP 500mJ



(a) Untreated – 2000× Magnification



(b) LSP - 2000× Magnification

Figure (4): SEM image at the fracture surface at 2000× for Untreated and LSP 500mJ

The results of experimental cumulative fatigue damage under variable amplitude stress tests for untreated specimens and treated specimens with 500mj laser shock peening which has been conducted for two-steps program; Low-High stress (156−312MPa), and High-Low stress (312−156MPa) with1000 cycles for each step showed improvement in fatigue life factor of 1.61 and 1.54 respectively based on the fatigue life of untreated specimens as shown in Table (4). The results showed that the improvement in fatigue life factor for Low-High loading program test was higher than that factor for High-Low loading program tests based on that program tests for untreated specimens. The improvement in fatigue life factor was in the range

(1.53–1.55) under constant amplitude stress test at the same LSP energy 500mj. This result is in agreement with sequence effects observed and reported previously in many cases which highlight the limitation of the application of the Miner rule [12].

Table (4): Experimental cumulative fatigue damage results

Description	Loading program	Amplitude stress (MPa)	N(Cycles) average	Improvement Life factor
untreated	Low-High	156-312	11300	---
LSP-500mj	Low-High	156-312	18200	1.61
untreated	High-Low	312-156	7050	---
LSP-500mj	High-Low	312-156	10900	1.54

Conclusions:

The effects of laser shock peening (LSP) surface treatment technique with two different energies on fatigue life of AA-7075 were investigated; some important conclusions have been made as follows:

1- The fatigue life was improved for treated specimens with laser shock peening (LSP) with 500mj and 250mj under constant amplitude stress tests in the range (0.3- $0.8\sigma_u$) by an average factor of (1.534) and (1.157) respectively.

2- The experimental cumulative fatigue damage results under variable amplitude stress tests for treated specimens with 500mj laser shock peening showed that the fatigue life was improved by a factor of 1.61 for low-high stress loading and 1.54 for high-low stress loading respectively compared with the untreated condition.

3- The fatigue strength increased 12.85% and 3.54% for laser shock peening (LSP) with 500mj and 250mj respectively compared with that for untreated specimens.

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