Constant Fatigue Life Under Laser Shot Peening Using Different Surface Coatings

Dr. Alakawi H.J.M
Electromechanical Engineering Department, University of Technology
Email : Alalkawi2012@yahoo.com
Dr. Bashar A. Bedaiwi
Engineering College, University of Al-Mustansirya/ Baghdad
Email: phdbashar@yahoo.com
Adel A. Mahmood
Engineering College, University of A-lMustansirya/Baghdad
Email: adelakram88@yahoo.com

Received on:18/9/2014 & Accepted on:9/7/2015

ABSTRACT

Laser peening (LP) is a surface treatment technology for metallic materials. LP has shown a great improvement in the fatigue strength and life. A study of fatigue under constant rotating bending stress programs has been conducted on 7049 AL alloy at a stress ratio (R=-1) and room temperature using laser peening technique .Four groups of tests have been designed. The first group (15 specimens) tested under unpeened condition. The second group (15 specimens) tested under air laser peening (ALP) while the third group (15 specimens) tested under water laser peening (WLP). The last group was designed to examine the fatigue behavior under black paint laser peening (BPLP). All the above groups were designed to establish the S-N curve. The results show no effect of laser peening LP at higher stresses (above 300 MPa), while this effect appears clearly at low stresses (200 and 250 MPa). The results also indicated that the WLP is more effective than the ALP. The fatigue life improvement factor (FLIF%) was 39, 18.9 and 4.65 under WLP for 200 MPa, 250 MPa and 300 MPa stress levels respectively. while a clear effect was observed for black paint laser peening (BPLP),it was found that the FLIF % was 93.25 at 300 MPa , 103.24 at 250 MPa and 116 at 200 MPa compared to unpeened data .
Keywords: Fatigue, laser peening, aluminum alloy 7049

INTRODUCTION

Laser shock peening(LSP) is a surface treatment, capable of imparting compressive residual stress and thereby improving the resistance of component to fatigue failure.
In aluminum (LSP) may also leave an improved surface, which would reduce the

https://doi.org/10.30684/etj.34.7A.2
2412-0758/University of Technology-Iraq, Baghdad, Iraq

occurrences of surface lapping, folds and other undesirable features that occur with shot peening(SP) [1,2]

It is known that when LSP conditions are optimal for the material and specimen configuration, a three to four times increase in fatigue life over the as-machined specimens can be achieved, however, if the process parameters are not optimal, the fatigue lives of LSP treated specimens may not reach such an improvement [3].

In this study, laser shock peening(LSP) was used to introduce compressive residual stresses. The influence of various surface coating i-e air laser peening (ALP), water laser peening(WLP) and black paint laser peening (BPLP) was characterized and assessed using 7049 Al. alloy.

The effects of laser waves on the mechanical properties and fatigue life of metals and alloys has been the subject of numerous investigations. These shock waves can develop significant plastic strains in the metal. Investigations have been done on the effects of shock treatments, on strength and hardness, fracture toughness ,stress corrosion cracking and other properties.[4,5]

The effect of high amplitude stress waves on the properties of metals and alloys have been investigated by Clauer and Fair [6]. They examined 2024_T351 and 7075_73 aluminum alloy under tensile tests it was found that the yield strength was increased for both alloy but the ultimate strength

was increased in 7075_T73 only under the effect of laser shocking . Thompson [7] studied the effect of laser peening on fatigue behavior of thin sections on F101_GE 102 aircraft gas turbine engine fan blades. In this study, the effect of shot penning and laser penning surface treatment to increase the resistance of the airfoils damage were compared. The results indicated that a significant increase in fatigue life of engine fan blades due to laser penning treatment.

Fatigue crack growth tests under the effect of shot peening and laser penning have been carried out on 4340 steel and 2024-T3 aluminum alloy ,the results indicated that after peening the fatigue life was improved by a factor of 2-4 times greater than unpeened results under shot peening. However, for laser peening this factor was approximately 1.8 compared with the results of unpeened lives [8]

Various studies on AL alloy showed the benefits effect of laser shock peening(LSP) on fatigue creak growth and fatigue life. Luong and Hill [9] studied high cycle fatigue performance of 7050-T7451 aluminum alloy for untreated as-machined, laser peened, and shot peened conditions. Results show that laser peening induces a layer of compressive residual stress more than three times deeper than for shot peening. At a moderate level of stress, penned specimens outlast as-machined specimens, by a factor of 7.9 for laser peening and 2.9 for shot peening. At higher stress, life improvements are lower, a factor of 3.3 for laser peening and 2.1 for shot peening. At a 100,000-cycle lifetime, fatigue strength of laser-peened specimens is 41% higherthan as-machined specimens and the fatigue strength of shot peened specimens 30% higher than as machined.

Rubio et al [10] studied fatigue crack growth in 2205 duplex stainless steel with LSP and they observed no effect of LSP on the microstructure and micro hardness and then fatigue behavior.

Alalkawi et al [11] tested 7049 aluminum alloy under rotating bending using black paint laser peening (BPLP) and it was found that the fatigue life improvement factor (FLIF%) due to

(BPLP) was from 1.319 to 3.625 compared to unpeened data .also the fatigue strength was increased by 58% at 10^7 cycles due to black paint surface coating.

Experimental details

The material of the tested specimens is 7049aluminum alloy of 7049 type. The shape and dimensions of the specimens are shown in figure (1)

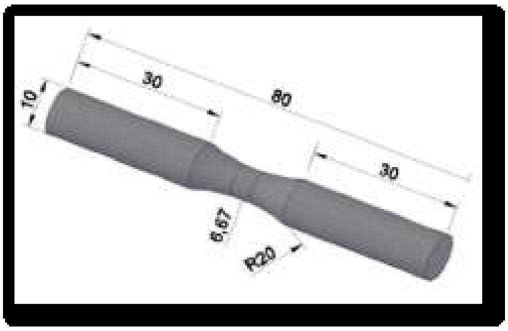

Figure (1): Geometry of Fatigue Specimens; Dimensions, in Millimeter according to (DIN 50113) Standard Specification

The average of three mechanical properties reading are tabulated in table (1)

Table (1) mechanical properties of 7049 aluminum alloy

Property	*Magnitude (unit)*	
	Experimental	**Standard**
Ultimate stress σu	515 Mpa	520 Mpa
Yield stressσy	312 Mpa	317 Mpa
Fatigue strength	287 Mpa	290 MPa
Shear modulus	27Gpa	27 Gpa
Shear strength	277 Mpa	280 Mpa
Modulus of Elasticity	74 Gpa	74 Gpa
Posions ratio	0.32	0.32
Elongation %	19	20

Table (2) chemical composition of 7049 Al-alloy wt %

	Zinc	Titanium	Silicon	Manganese	Iron	Copper	Chromium	Magnesium	Al.
Standard	7.2-8.2	0.1 max	0.25 max	0.2 max	0.35 max	1.2-1.9	0.1-0.2	2-2.9	Bal.
Experimental	7.6	0.08	0.15	0.18	0.25	1.5	0.16	2	Bal.

Four series of test are planned to study the S-N fatigue behavior under unpeened condition, air laser (AL), water laser (WL) and finally black paint laser peening (Bplp) to show the effect of different conditions of surface coating on the fatigue life and strength.

Fatigue Testing Machine:

Fatigue testing machine type (SCHENCK) PUNN Rotating bending is used to execute all fatigue tests, with constant and variableamplitude, Rotating bending fatigue tests were conducted at Room Temperature (25C) under stress ratio R=-1 The test rig has a property of automatic cut-off when specimens fails ,the value of load (p) is measured by (N) applied to thespecimen for a known value of stress (σ) measured by (N/mm2) and extracted from applying the relation below:

$\sigma(N/mm^2)= (32 \times 125.7\ P(N))/(\pi \times d^3)$

Where, (P) is force, the force arm is equal to 125.7mm and d (mm) isthe minimum diameter of t he specimen.

Laser peening treatment device

Typical laser system was used in this work (Qswitched neodymiumYAG laser) for laser peenin g has the following parameters :

1-Laser wavelength is about 1.065 µm .

2- Pulse duration 7 nano seconds .

3- Pulse energy (1000)mJ .

4- The laser spot is typically (8) in diameter .

5 The deep water to the area that treated is typically (5-10)mm .

Results and discussion

Figure (2) illustrates the experimental constant fatigue results of 60 specimens tested at room temperature (RT) and stress ratio R= -1 for four conditions of testing i-e the first group without laser (blue line) and the other three groups with laser peening at different surface coatings. One group with air laser peening (ALP) (red line), the other two groups with water laser peening (WLP) (green line) and black paint laser peening (Bplp)(Yellow line).The basquin equation for the four conditions of testing can be seen in table (3)

Table (3) the Basquin equation at different fatigue – laser interaction conditions

Conditions	Basquin equation
Unpeened	$\sigma_f = 1006 N_f^{-0.137}$
(ALP)	$\sigma_f = 1008 N_f^{-0.140}$
(WLP)	$\sigma_f = 910 N_f^{-0.125}$
(bPLP)	$\sigma_f = 1050 N_f^{-0.132}$

The experimental constant S-N results for the above test conditions are given in table (4)

Table (4) experimental results for constant fatigue tests for different conditions of testing

Specimens no.	N_f (cycles)	σ_f (MPa)	N_f average	Condition of testing
1,2,3,4,5	7000,9000,8000, 6000, 6000	300	7200	**unpeened**
6,7,8,9, 10	24000,46000, 15000, 20000,25000	250	26000	
11,12,13,14,15	127000,134000 ,93000, 80000,110000	200	108800	
16,17,18,19,20	5000,6600, 7000,8200, 5900	300	6540	**ALP**
21,22,23,24,25	17000,22000, 19000,27000, 25000	250	22000	
26,27,28,29,30	81000,94000, 73000,88000, 95000	200	86200	
31,32,33,34,35	6000,7000,7000,5000, 8000	300	6600	**WLP**
36,37,38,39,40	27000,31000,40000, 42000,35000	250	35000	
41,42,43,44,45	111000,150000,172000, 166000,174000	200	154000	
46,47,48,49,50	9000, 10000, 12000,11000, 9000	300	10200	**bPLP**
51,52,53,54,55	70000,74000, 77000,75000, 72000	250	73600	
56,57,5859,60	334000,339000, 342000, 337000,340000	200	338400	

These S-N curve results are plotted in figure (2)

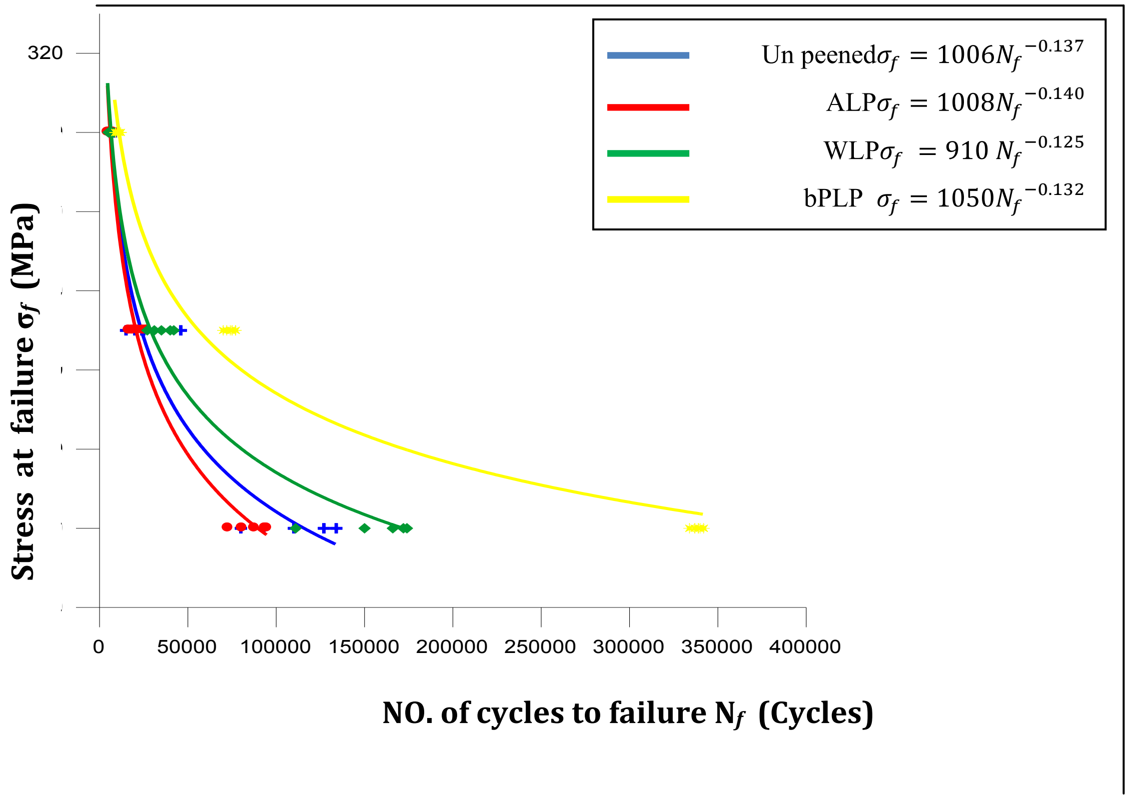

Figure.(2) shows the fatigue results at constant load for four condition of laser penning .

It is clear that the WLP increased the resistance of material and improved the high cycle fatigue (HCF) life. The ALP and WLP did not improve the life of low cycle fatigue (LCF) (fatigue life < 10^4), but reduced these lives compared with unpeened fatigue lives [12]. The water laser peening (WLP) used water over the surface, which was not to cool the surface but serves the key function of confining the plasma generated when the laser beam interacts with the opaque overlay surface [13]. For BPLP the results clearly indicated that the fatigue life of 7049 aluminum alloy increased compared to the unpeened data for both high cycle fatigues (HCF) and low cycle fatigue (LCF). This finding is a well agreement with the conclusion of Ref [11].

Fatigue life improvement factor FLIF% :

The FLIF% at different stress levels can be defined as:[14]

$$\text{FLIF\%} = \frac{\text{Nf} - \text{Nf unpeened}}{\text{Nf unpeened}} * 100$$

The factor for three stress level (constant load) are given in table (5)

Table (5) give this factor for three stress level (constant load)

Stress level (MPa)	FLIF %	treatment
300	-10.6 4.65 93.25	Air laser Water laser Black paint
250	-12.36 18.91 103.24	Air laser Water laser Black paint
200	-14.39 39 116	Air laser Water laser Black paint

It is clear that the values of FLIF% at ALP are negative, see Fig. (3). this means that the fatigue properties are reduced due to laser peening whether using ALP or WLP. However, the effectiveness improvement appears in using WLP and Bplp. Figure (3) shows the relation between FLIF% against stress levels

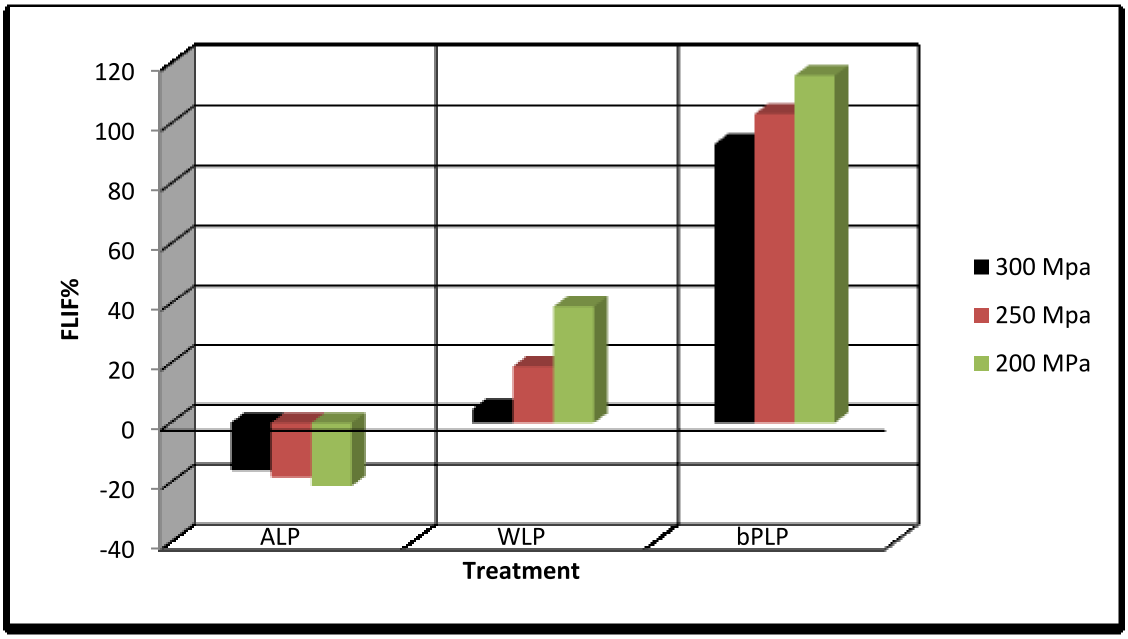

Figure (3) shows FLIF% against stress levels for ALP ,WLP and Bplp .

Figure (3) gives significant improvement in fatigue life due to BPLP and WLP. This improvement may be coming from generally deep compressive stresses and then increases the fatigue life. It can be said that, laser peening with black paint coating significantly improve the fatigue properties of the 7049 aluminum alloy. This results in good agreement with that found by Alalkawi [11]. The compressive residual stress level appears to be somewhat higher in the case of BPLP than the other coating surface. Arvi [15] explained this improvement in fatigue properties to the following parameters:

1- Avoid red position of debris
2- Cool the material
3- Increase plasma pressure
The reason for the above fatigue life improvement is that probably because the bPLP work to heavily deformed the surface of the specimens, and this will stop fatigue cracks to initiate . The results is closer to that of Ameur [16] .

Fatigue strength

Fatigue strength of the metal is shown in table (6) for different laser coating treatments.

Table (6) fatigue strength of 7049 aluminum alloy for different laser coating treatment

Condition of treatment	Fatigue strength at 10^7 cycles (MPa)
Unpeened	111
ALP	106
WLP	121
BPLP	125

Experimental results showed that BPLP has superior effectiveness to increase the fatigue life and strength. The fatigue strength after treatment by WLP and BPLP increased to 121 MPa (about 9% improvement) and 125 MPa (about 12.6% increase in fatigue strength) respectively. These findings are in good agreement with the results of given by [13].

CONCLUSIONS

For this work on laser shot peening under different surface coatings of 7049 aluminum alloy, The followings are concluded.

1. It has been demonstrated that the BPLP is more effective surface treatment than the WLP and ALP .
2. The fatigue life of BPLP specimens were greatly increased compared to unpeened specimens and the value of FLIF% are 93.25 , 103.24 , and 116 for 300 , 250 and 200 MPa stress levels respectively .
3. The FLIF% for specimens treated by WLP were 4.65 ,18.9 and 39 for 300 , 250 and 200 MPa stress levels respectively .
4. It was observed that, the ALP gives reduction in fatigue life under constant loads.
5. The fatigue strength at 10^7 cycles improved by 9% due to WLP and 12.6% due to BPLP treatment .

REFERENCES

[1] Jon E. rankin ,Michael R. Hill, Lloyd A. Hackel ((the effects of process variations on residual stress in laser peened 7049 T73 aluminum alloy)) Materials science and Engineering A349, 379-391 (2003).

[2] Alalkawi H. J., Mohammed Q. K., Al-Nuami W. S. ((The effect of shot peening and residual stresses on cumulative fatigue damage)), Eng.And Tech. J. vol. 28, No. 15 (2010).

[3] Chunhui yang , petterdamianhodgson , Qianchuliu , lin ye((Geometrical effect on residual stresses in 7050-T7451 aluminum alloy rods subject to laser shock peening))Journal of materials processing technology 201 , 303-309 (2008)

[4] D. Voss , T.M.F. Ronald ((microstructure and mechanical property modification of plastic wave TMT 7075 Aluminum)) ALME spring meeting 1973.

[5] Mairb R. Abdul Hassan ((Microstructure and hardness effects on behavior of copper alloy under creep-fatigue interaction)), Eng.And Tech. J. vol. 29, No. 9 (2011).

[6] A .H .clauer and B.P. Fairand ((interaction of laser – induced stress waves with metals)) Application of laser in material processing , ASM international , Materials park , OH 44073-0002 1979.

[7] S.Thompson , D.See C. Iykins , P. Sampson ((surface performance of titanium)) Ed. J. Gregory,H.Rack and D. Eylon .the materials , Metals and materials society ,pp.239-251 (1997).

[8] R. A. Everett ,W.T Matthews ,R. Prabhakarn ,J.C Newman , M. J. Dubberly((the effects of shot and laser peening on crack growth and fatigue life in 2024 AL. alloy and 4340 steel)) NASA ITM -2001-210843 ARL –TR -2363 (2001).

[9] Harold Luong , Michael R. Hill " The effects of laser peening and shot peening on high cycle fatigue in 7050-T7451aluminumalloy"Materials Science and Engineering , Volume 527, Issue 3, 15 January 2010, Pages 699–707 .

[10] C. Rubio-Gonzalez, G. Gomez-Rosas, J.L. Ocana, C. Molpeceres, A. Banderas, J. Porro, M. Morales, Appl. Surf. Sci. Vol. 252, (2006),PP. 6201–6205

[11] AlalkawiH.J.M , sadkhanB.A , Noor N.Abed "laser peening on aluminum alloy 7049 using black paint surface coating " , al-khwarizmi engineering journal (2015) .

[12] D. See, D. Lahrman ,R.Tenaglia ,Affordable laser peening , proceedings of the 8th national turbine engine high cycle fatigue conference , monterey (2003).

[13] Richard D. Tenaglin , David E. Labrman ((preventing fatigue failures with laser peening)). The AMPJIAC Quarterly , Vol.7 No.2 (2003).

[14]Abdul JabarH.A((fatigue of composite materials at elevated temperatures))PhD thesis , university of Technology (2012)

[15] Arvikruusing ((under water and water-assisted laser processing)) part I Available online 7 January 2013.

[16] Mohamed FaycalAmeur ((shot peening effect in particular air craft aluminum alloys)) Msc thesis , university of technology (2002).