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Laser Peening on Aluminum Alloy 7049 Using Black Paint Surface Coating

Alalkawi H. J. M.* **Basim A. Sadkhan**[**] **Noor N. Abed**[***]

**Departement of Electromechanical Engineering/ University of Technology.*
***, *** College of Engineering/ University of Almustansiriyah.*
*Email: Alalkawi2012@yahoo.com
**Email: drbasimajel@yahoo.com
***Email: nawara_najm@yahoo.com

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Abstract

Black paint laser peening (bPLP) technique is currently applied for many engineering materials , especially for aluminum alloys due to high improvement in fatigue life and strength . Constant and variable bending fatigue tests have been performed at RT and stress ratio R= -1 . The results of the present work observed that the significance of the surface work hardening which generated high negative residual stresses in bPLP specimens .The fatigue life improvement factor (FLIF) for bPLP constant fatigue behavior was from 2.543 to 3.3 compared to untreated fatigue and the increase in fatigue strength at 10^7 cycle was 21% . The bPLP cumulative fatigue life behavior was improved by 1.786 at L-H and 1.55 at H-L due to black paint coating .

Keywords: *Constant and variable fatigue behavior , Black paint laser peening , 7049 Al- alloy .*

1. Introduction

The failure of metalic material structure especially the light structures (Aluminum alloys) is totally difficult to control , experimentally when the qpplied loads behaver in variable manner[1]. The estimation of the fatigue lifetime of companents subjected to random loading (cumulative amplitude conditions) is a complex subject [2]. However, in practice many structural or components are subjected to combined or complex fatigue loading which is happened due to changing in the applied stress amplitude. In the field of variable amplitude loading, it is an important to assess the fatigue damage occurred due to variable amplitude loading conditions [3]. Damage increases when cyclic stresses increase in a cumulative way which may lead to fracture. Fatigue damage analysis in variable loading plays very important factor in the fatigue life evaluation of structures and components[4].

Laser peening (LP) is a surface treatment which works to create compressive residual stresses at the surface and to extend below the metal surface [5]. LP has been known to be very effective in improving the mechanical and fatigue properties of many metals and alloys [6] .The combination of laser and shot peening treatment was investigated in 7075 AA gave an optimum residual stress profile at the surface resulting in the improvement in fatigue life and strength of 7075 AA[7]. Everett et al [8] examined4340 steel and 2024-T3 AA under fatigue and crack growth tests using shot peening and laser peening treatments.The experimental results showed that after peening the fatigue life and crack growth rates were noticeably improved and the fatigue life was increase by a factor of 2-4 times greater than the results of the average un peened results .Comparision between laser peening (LP) and shot peening (SP) residual stresses of 7049-T3 AA was made by Rankin et al [9] .They observed that residual stress 0.1 mm from the surface due to LP was far greater than for SP. AA type LY2 was tested under LP in two ways and they compared .The results show that the LP improved the fatigue life by 131.4 % compared to untreated condition [10]. Laser peening treatment without protective coating (LPwC) was carried out by Yasuo Ochi et al[11] to improve fatigue strength ,the result showed the LPwC treatment was effective for the fatigue strength improvement in fatigue lives regime before $2{\sim}3\times10^6$ cycles, but the treatment reduced the strength after the cycles at the both stress ratios conditions. Duplex stainless steel alloy used to study the effect of laser treatment on fatigue charistrestice . The condaded remarks were increasing pulse density reducing the growth of the cracks which resulting in increasing the fatigue life[12]. Different laser peening were used to study the laser effect on lifetime of (3003-H18) AA using different (LP). The results observed that the fatigue lifetime increment over the life of samples without (LSP) in range (12%) for 1-spot LSP, 18%for 2-spots LSP and 77%for 3-spots LSP[13]. Al-6061-T6 surface topography was studied using energy Nd: YAG laser with 300mJ. They concluded that laser peening without coating (LPWC) can significantly improve the surface topography i-e compressive stress , and microhardness but the surface roughness showed an increase. The compressive residual stress was improved by 27% and the hardness was increased by 10 HV [14].45 specimens of 7049 AA were examined under constant rotating fatigue at R= -1 using 7049 AA to establish the S-N curve for three types of surface coatings .15 specimens for air without peening ,15 specimens for air laser peening (ALP) and the third group 15specimens was tested under water laser peening (WLP). The results indicated that no effect of laser peening at low cycle fatigue (LCF) above 300 MPa . But this effect appeared clearly at (HCF). Also it was concluded that the fatigue life improvement factor is 32.6 and 8.97 under WLP for 200MPa and 250 MPa respectively[15].

Date in the literture observed the benficial effects on fatigue life , an increase in fatigue life by as much as a factor of 10 at a given stress level for aluminum alloys[16] .

2. Experimental Details

2.1. Material and Testing

The material used was 7049 AA supplied as a round bar of 10mm diameter with chemical composition in weight percentage as given in table (1).

The mechanical properties of the material were obtained using an instron machine . The average results of three tests are presented in table (2).

Table1,
Chemical composition in wt% of 7049 AA.

Element	Si%	Fe %	Cu%	Mn %	Mg%	Cr%	Zn%	Ti%	Al%
Standard	Max. 0.25	Max. 0.35	1.2-1.9	Max. 0.2	2-2.9	0.1-0.22	7.2-8.2	Max. 0.1	Bal.
Experimental	0.21	0.29	1.52	0.14	2.5	0.18	7.8	0.08	Bal.

Table 2,
Mechanical properties of 7049 AA.

Property	Yield Stress, σ_y (MPa)	Ultimate Stress, σ_u (MPa)	Elongation%	Modulus of elasticity, E (GPa)	μ	HB
Experimental	312	515	19	74	0.32	131
Standard	317	520	20	74	0.33	135

2.2. Fatigue Specimen

Fatigue specimen , shown in figure(1) , was employed to carryout all the fatigue tests under laser peening and without laser treatment .All the fatigue specimens were manufactured using programmable (CNC) turning machine ,the test specimen is:

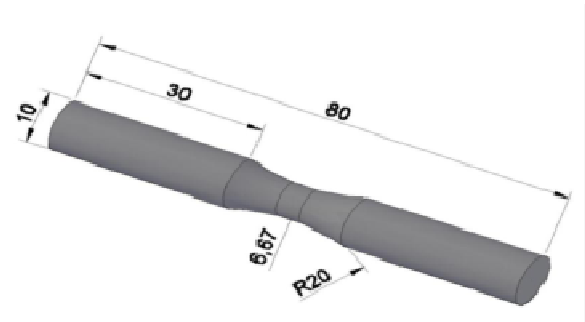

Fig. 1. Fatigue specimen dimensions (DIN 50113) (all dimnsions in mm).

The detailed dimnsions of specimen are shown in fig. (1) . The samples were then numbered and grinded , first , with grades 200,400,600,1000,1200 emery paper. After grinding , one sample was polished firstly using polishing cloth with diamond pastes and alumina with 1/3 micron,for 5 minutes and then etched in Keller solution for a 2-3 minutes .

2.3. Fatigue Test Procedure

Fatigue analysis are normally based on the results obtained from S-N curve then the first step was to established the constant continuous cycling S-N curve .Fifteen specimens were tested under room temperature control stress with zero mean stress .The second step was to find the S-N curve with black paint laser peening (bpLp) in order to do a comparison in life and strength . The third group of testing was 12 specimens , 6 specimens under untreated cumulative fatigue and the other 6 specimens under (bpLp) cumulative fatigue .

2.4. Fatigue Test Rig.

A fatigue test machine of type (SCHENCK) PUNN rotating bending is employed to execute the fatigue test, as illustrated in figure (4):

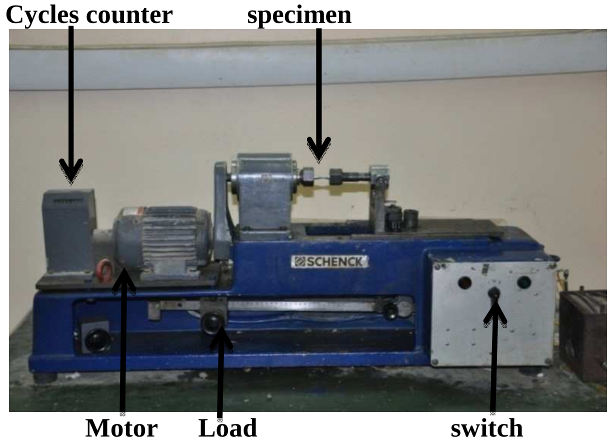

Fig. 2. Fatigue test machine.

2.5. Laser Surface Treatment

The laser system used in this work was (Q-switched Nd–YAG laser) with wavelength is about 1.065 μm ,the energy of pluse (300)mj . (16 ns) shock with black paint for each specimen around the minimum diameter of fatigue specimens were selected.

Figure (2) shows (Q-switched Nd –YAG laser system) used in the present study .

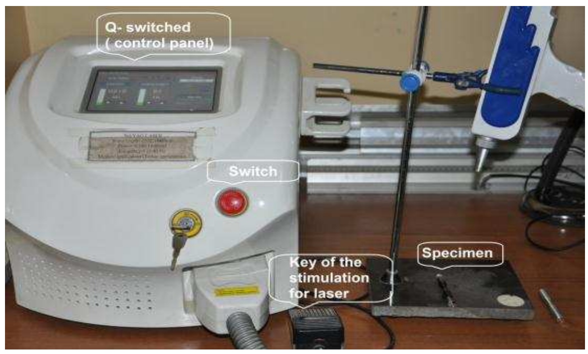

Fig. 3. Nd–YAG laser peening device at university of Technology-Baghdad .

Fig (4) illustrates the laser ring around the minimum diameter.

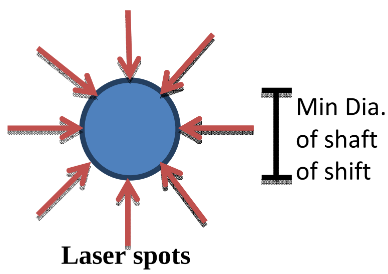

Fig. 4. Laser spots around min. diameter of fatigue specimen.

3. Results and Discussion

Table (3) gives the results of the three groups mentioned above .

Table 3,
Constant and variable fatigue tests with and without (bpLp).

Condition	Specimens No.	Applied stress (σ_f)(MPa)	Cycles to failure N_f (Cycles)	N_f Average
	Dry fatigue S-N curve results			
	1,2,3	400	2000,2200,2500	2233
	4,5,6	300	6000,7000,8000	7000
	7,8,9	250	33000,31800,32600	32467
	10,11,12	200	63000,57500,66000	62167
	13,14,15	150	642000,664300,686600	664300
	bplp fatigue S-N curve results			
	16,17,18	400	4200,5000,3800	4333
	19,20,21	300	9000,11200,10000	10067
	22,23,24	250	119000,130000,110000	119667
	25,26,27	200	205000,198000,180000	194333
	28,29,30	150	2479000,2655000,2303000	2479000
	Dry cumulative fatigue results			
L-H	31,32,33	200-300	12700,16000,11600	13433
H-L	34,35,36	300-200	10800,11600,14000	12133
	bplp cumulative fatigue results			
L-H	37,38,39	200-300	27000,20000,25000	24000
H-L	40,41,42	300-200	21000,18600,17000	18867

3.1. Basic S-N Curve

Fig (5) describes the results obtained from constant stress amplitude tests at room temperature under stress control condition and zero mean stress with and without bpLp .
The bending stress was calculated from the bending moment using the equation :

$$\sigma_b(N/mm^2) = 125.7*32*P(N) / \pi d^3 \qquad ...(1)$$

Where P is the applied load (N) and the arm of the force is equal to (125.7mm) and d is the minimum diameter of the specimen in mm .

Fig. (5) illustrates the effect on the fatigue lifetimes of specimns that have been pened under (bpLP) . As shown by the experimental date , the fatigue life of (bpLP) specimens is improved compared to unpeened specimens and this improvement can be described by table (4) below for different stress levels .

The bPLP creates compressive residual stresses, there by ofering improved resistance to the growth of near- surface , macroscopic crack . This characteristic can , therefore , lead to signficant improvements in the fatigue life of treated specimens , which leads to high FLEF given in the above table . This finding is in good agreement with Ref [11].

Table 4,
Fatigue life improvement factor due to bpLP for different stress levels.

Fatigue life improvement factor (FLIF)				
0.4 σ_u	0.5 σ_u	0.6 σ_u	0.7 σ_u	0.8 σ_u
208 MPa	260 MPa	312 MPa	364 MPa	416 MPa
3.3	3.03	2.833	2.674	2.543

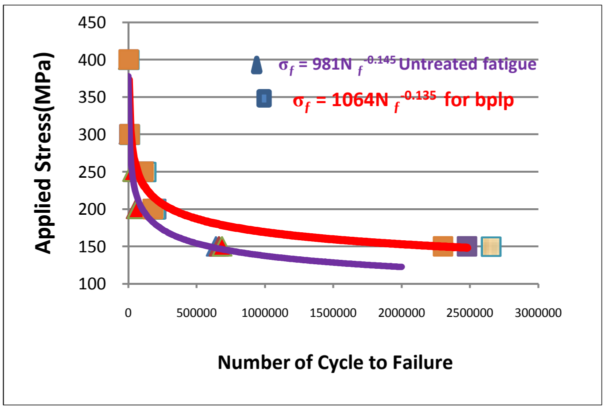

Fig. 5. Convential basic line S-N curve for untreated and bplp fatigue .

The stress amplitude and life (N_f) were estimated from the relation known as the Basques equation , gives the fatigue strength properties and may take the following formula.

$\sigma_f = A(N_f)^{\alpha}$ ...(2)

Where A : is the fatigue strength coefficient.

α : is the fatigue strength exponent.

The value of the parameters in equation (2) are listed in table (5)

Table 5
Fatigue properties of 7049 AA.

Condition	A	α
Untreated fatigue	981	-0.145
bpLP fatigue	1064	-0.135

The bending fatigue properties of 7049 AA that has received bplp and untreated , respectively are compared in fig (5) .

The bpLP gave a 21% rise in endurance fatigue limit, compared with the untreated specimens .

Peyre et al [14] have found that an increase of 22% in fatigue strength of 7075-T7351 AA after treating by LSP (3.8 G W/cm^2) compared to the unpeened specimens .

The constant fatigue life of 7049 AA are improved, as illustrated in table (4), based on stress level applied . This improvement treated due to greater plastiaty affected depth in the matrials as well as the preservation of surface roughness .

Clauer etal [17]concluded that the constant fatigue life of 2024 –T3 specimens with solid laser spot has a fatigue life about 40 times longer than the annular laser spot and a life about three times greater than the as-recived ones .

Referring to table (3). It can be obtained a cumulative fatigue life improvement factor (CFLIF) for cumulative fatigue results in table (6).

Table 6,
Cumulative constant fatigue life improvement factor .

Stress sequences MPa	Cumulative fatigue life improvement factor (CFLIF)
200-300	1.786
300-200	1.555

It can be seen that :

The Cumulative fatigue life was increased by a factor of 1.786 at low –high stress sequences while this factor reduced to 1.555 at high –low stress sequences . The fatigue life of 7049 was extended by bpLP due to greating compressive stress at the surface. This finding is in good agreement with Peyre etal [14] .

4. Conclusions

The bending fatigue behaviour of 7049 Al-alloy were stuided , the following remarks are drawn from the work described here in :

1- The fatigue strength at 10^7 cycles was improved by a 21% increase due to bpLP .
2- The fatigue life improvement factor (FLIF) was obtained to be from 2.543 to 3.3 due to bpLP based on stress level applied .
3- The lives of sequence loading (L-H) were higher than lives of sequence loading (H-L) either with bpLP or without .
4- The fatigue lives were improved by afactor of 1.786 at (L-H) , while this factor was 1.555 at (H-L) due to bpLp .

Notation

AA	Aluminum alloy
Bplp	Black paint laser peening
CFLIF	Cumulative fatigue life improvement factor
FLIF	Fatigue life improvement factor
HCF	High cycle fatigue
H-L	High-Low Stresses
LCF	Low cycle fatigue
L-H	Low-High Stresses
LPWC	Laser Peening Without Coating
LP	Laser peening
R	Stress ratio
SP	Shot peening

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الصفع الليزري لسبيكة الالمنيوم ٧٠٤٩ باستخدام الطلاء الاسود للسطوح

حسين جاسم العلكاوي* باسم عاجل سدخان نور نجم عبد*****

** قسم هندسة الكهروميكانيك / الجامعة التكنولوجية*

***، *** قسم هندسة المواد / كلية الهندسة / الجامعة المستنصرية*

*البريد الالكتروني : Alalkawi2012@yahoo.com

**البريد الالكتروني : drbasimajel@yahoo.com

***البريد الالكتروني : nawara_najm@yahoo.com

الخلاصة

ان تقنية التصليد بالليزر مع استخدام الصبغ الاسود تستخدم لكثير من المواد الهندسية ولاسيما سبائك الالمنيوم بسبب انها تعمل على تحسين اعمار ومقاومة الكلال . تم انجاز فحوصات الكلال الانحنائيه ثابتة ومتغيرة السعة عند درجة حرارة الغرفة ونسبة اجهاد (R=-1) . نتائج هذا العمل لوحظ اهمية عمل التصليد السطحي نتيجة الاجهادات الضغطية المتبقية المتولدة من العينات المطلية بالصبغ الاسود . عامل تحسين عمر الكلال ثابت السعة (FLIF) للعينات المطلية بالصبغ الاسود كانت من ٢.٥٤٣ الى ٣.٣ مقارنة مع الكلال غير المعالج وعملية الطلاء بالصبغ الاسود والليزر ادت الى زيادة في مقاومة الكلال عند $١٠^{٧}$ دورة بنسبة ٢١% . اما سلوك اعمار الكلال التراكمي (متغيرة السعة) فان التصليد بالليزر مع الطلاء بالصبغ الاسود ادت الى تحسن في الاعمار بمقدار ١.٧٨٦ عند الاجهادات من واطئة (L) الى عالية (H) و ١.٥٥ من الاجهادات العالية الى الواطئة نتيجة التصليد بالليزر مع الطلاء بالصبغ الاسود .