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Effect of laser shock peening on fatigue life of aluminum-alloy (3003-H18)

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ABSTRACT

The aim of the present work is to study the effect of laser shock peening (LSP) on fatigue life of aluminum alloy (3003-H18) by using different (LSP), single spot, 2-spots with 50% overlap and 3-spots 100% full overlap on the surface to be treated. The effect of laser shock peening (LSP) on the fatigue life were investigated with constant amplitude stress at stress ratio R=-1 at room temperature. The results showed that the fatigue life increment over the life of samples without (LSP) in range (12%) for 1-spot LSP, (18%) for 2-spors LSP and (77%) for 3-spots LSP for aluminum alloy 3003-H18 at 100MPa amplitude stress. Also the results show that the highest fatigue strength was for samples with 3-spots LSP.

Introduction

Laser peening is a comparatively recently-developed technique for surface treatment of metal components and structures. In laser peening 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 durability and strength, that can be produced. It is concluded that residual stress fields from laser peening are larger and extend to a greater depth in the components than is found with traditional mechanical shot peening, and that the fatigue strength and durability of samples subjected to laser treatment are superior to those produced by mechanical peening [1].

Residual stresses and fatigue performance produced by laser peening have been measured in steels [2, 3, and 4], titanium alloys [5, 6, 7, and 8], aluminum alloys [9, 10, 11, 12, and 13] and copper alloys [14] and broadly similar conclusions are found for each. Fatigue performance is invariably enhanced by the laser peening treatment: fatigue endurance as measured by S-N curves is significantly improved, and fatigue crack growth rates are reduced.

Experimental work:

The aluminum alloy is widely used in the aging aircraft due to its high strength to density ratio. However the chemical composition of this Aluminum (3003-H18) alloy is presented in Table (2-1) while the experimental mechanical properties with the standard values are listed in Table (2-2).

Table (2-1): Chemical composition of Aluminum (3003-H18) alloy in wt%

Elements	Si	Fe	Cu	Mn	Zn	Rem.
Standard Values (ASM) weight%	0.60	0.70	0.05-0.20	1.0-1.5	0.10	Al
experimental	0.167	0.483	0.0601	0.645	0.310	Al

Table (2-2): Mechanical properties of Aluminum (3003-H18) alloy.

Property	Tensile strength (MPa)	Yield Strength (MPa)	Elongation %	Modulus of elasticity (GPa)
Standard (ASM)	200	186	4	69
Experimental	205	196	5	72

Fatigue Test Specimens Preparation:

The specimens were prepared according to ASTMD3479/D3479M–96, standard test method for fatigue of Aluminum (3003-H18) alloy. Fatigue specimens were cut in suitable dimensions to satisfy the machine test section that suited for flat plate specimens. Figure (2-1) shows the fatigue test specimens and its configuration.

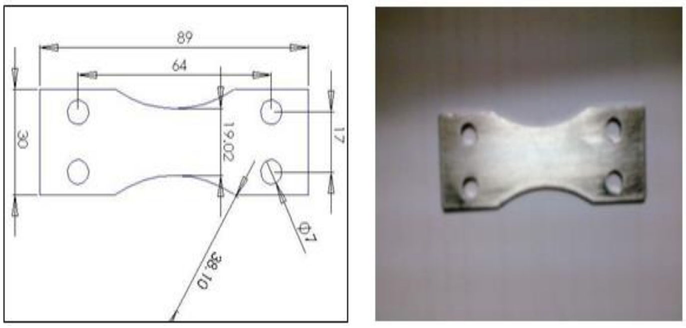

Figure (2-1) the fatigue test specimens (all dimensions in mm).

Fatigue Tests Procedure:

All fatigue tests were carried out in the laboratories of electromechanical engineering department, University of Technology using AVERY fatigue testingmachineType-7305.The experiments were conducted at room temperature and at stress ratios R=-1. Figure (2-2) shows the fatigue test machine.

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Figure (2-2) AVERY Fatigue Testing Machine Type *7305*

Laser characteristics:

Nd:YAG laser system was used for ablation of different targets. Figure (2-3) show the laser system, the output pulse duration is 6nanosecond having a wavelength of 1.064 µm with the maximum energy per pulse of 1Joule.

Three type laser shock peening (LSP) 4mm spot diameter was used for surface specimens treatment carried out in the laboratories of Baghdad science collage; single spot LSP, two spots LSP with 50% overlap and three spots LSP 100% full overlap. The 50 pulses were used for each spot having 0.532µmwith pulse energy 20mJ.

Figure (2-3) ND: YAG laser system

Results and discussion:

Specimens without laser shock peening and with 1-spot LSP, 2-spotsLSP with 50% overlap and 3-spots LSP 100% full overlap were tested at constant stress amplitude with (-1) stress ratio at room temperature to find fatigue life formula for aluminum alloy used. The experimental results are given in Tables (3-3, 4, 5 and 6) The S-N curve was obtained from these results as shown in figure (3-1). The equation of power law regression is given by [17]:

$$\sigma = aN^b \quad \text{….. (3-1)}$$

where (σ) is the applied stress, and (***a***),(***b***) are the fitting parameters. The regression constants representative of the fatigue trends, from the model, and the fatigue endurance limit at 10^7 cycles are given in Table (3-7).

Table (3-3): fatigue results for aluminum alloy without LSP

Specimen No.	Applied stress (MPa)	Number of cycles to failure	*Nf*(Cycles) Average
1, 2, 3	204	9200, 9500, 9800	9500
4, 5, 6	163	29500, 32000, 30000	30500
7, 8, 9	132	82000, 90000, 83000	85000
10, 11, 12	100	480000, 510000, 50500	500000

Table (3-4): fatigue results for aluminum alloy with 1-spot LSP

Specimen No.	Applied stress (MPa)	Number of cycles to failure	*Nf* (Cycles) Average
1, 2, 3	204	13400, 14100, 14500	14000
4, 5, 6	163	32000, 33500, 37500	35000
7, 8, 9	132	115000, 130000, 136000	127000
10, 11, 12	100	540000, 575000, 535000	550000

Table (3-5): fatigue results for aluminum alloy with 2-spots LSP 50% overlap

Specimen No.	Applied stress (MPa)	Number of cycles to failure	*Nf* (Cycles) Average
1, 2, 3	204	16000, 14100, 14900	15000
4, 5, 6	163	47000, 50600, 52400	50000
7, 8, 9	132	160000, 180000, 176000	172000
10, 11, 12	100	570000, 620000, 580000	590000

Table (3-6): fatigue results for aluminum alloy with 3-spots LSP 100% full overlap.

Specimen No.	Applied stress (MPa	Number of cycles to failure	*Nf* (Cycles) Average
1, 2, 3	204	20000, 16500, 17500	18000
4, 5, 6	163	66000, 68000, 78000	70000
7, 8, 9	132	190000, 200000, 213000	201000
10, 11, 12	100	850000, 880000, 925000	885500

Table (3-7) Fatigue parameters and fatigue strength for Al-alloy used

description	A	B	Fatigue strength at 10^7 cycles (MPa)	incremental strength %
without LSP	1052.09314	-0.18050	57.35	-
with 1-spot LSP	1225.13165	- 0.189939	58.00	1.133
with 2-spots LSP 50% overlap	1300.200	- 0.191819	59.00	2.877
with 3-spots LSP 100%full overlap	1253.6156	- 0.184281	64.297	12.113

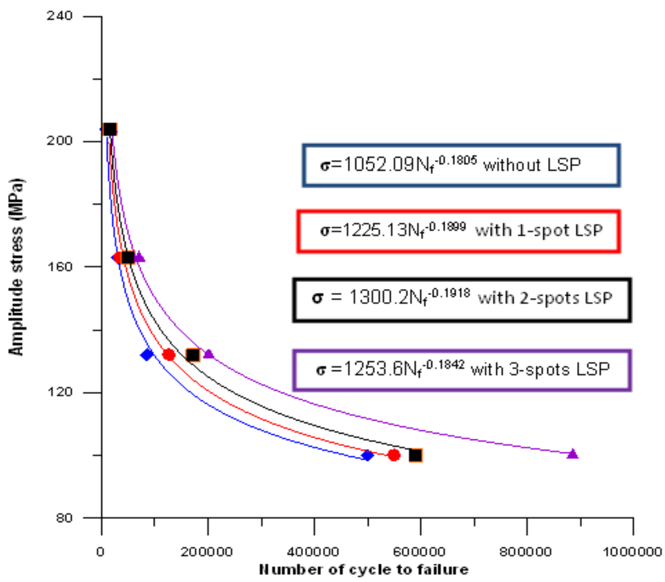

Figure (3-1) S-N curve for Al-alloy 3003-H18 with different LSP.

Figure (3-2) shows examples of some specimens after fatigue test failure. The failure occurred in the middle gage section as expected for specimens without LSP (Laser Shock Peening). But for specimens with 2-spots (LSP) 50%overlap and, with 3-spots (LSP) 100% overlap, the failure occurs outer LSP-spots reign. While for 1-spot LSP the failure occur in middle gage section through the spot LSP reign. Therefore it can be observed that the increasing of number of pulses of laser shock peening has significant affect on fatigue failure.

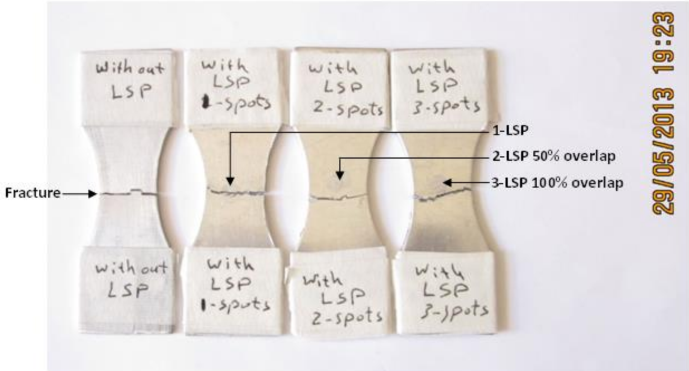

Figure (3-2) Fatigue failure for different LSP Specimens

The result shows that the fatigue life of the samples that have been used treatment surface by laser shock peening (LSP) has increased extrusive with the number of pulses used and by the fact that along the fissure that the wire was longer than route of incision in the natural state, before surface treatment by laser as was evident in the figure (3-2) where the area of fracture outside the affected area by laser shock peening specially for 2-spots with 50% overlap and 3-spots 100% full overlap. The fatigue life increment over the life of samples without LSP in range (12%) for 1-spot LSP, (18%) for 2-spots LSP, and (77%) for 3-spot LSP for aluminum alloy 3003-H18.Also the results show the highest fatigue strength improvement was (12.113%) for samples with 3-spots LSP.

It can be observed that the improvement of fatigue life was due to the residual compressive stress product by laser shock peening, which can be predict it by X-ray diffraction method [15]. The results of x-ray diffraction shows that the lattice spacing for the samples with 3-spots laser peening was the smallest than that the other samples used, in a corresponding shift in the diffraction angle 2theta. Then it can observe that the compressive residual stress was higher for 3-spots LSP samples. The x-ray diffraction measurement was carried out in the laboratories of the Ministry of Science and Technology.

Conclusions:

1-It was found that the fatigue life improvement for aluminum alloy 3003-H18 varying with the different pulse intensity used 1-spot, 2-spots and 3-spots LSP, depending on compressive residual stress produced by laser shock peening on treatment surface.

2-The fatigue strength for aluminum alloy 3003-H18 with 3-spots LSP was higher than the other with 1-spot LSP and 2-spots LSP used in the present work.

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