Influence of Laser and Shot Peening Treatments on Fatigue Properties of 2017 Aluminum alloy.

تاثير معاملات الليزر والقذف بالكريات على خصائص الكلال لسبيكة الالمنيوم2017

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Abstract

Laser peening (LP) is an emerging surface treatment capable of imparting compressive surface residual stresses and thereby improving the surface resistance of structure to dynamic loading. While the general mechanical concept is similar to conventional shot peening(SP). The present work presents an attempt to illustrate the influence of laser and shot peening on the behavior of fatigue of 2017 aluminum alloy under room temperature and stress ratio (R= -1). The objective of the current work is to evaluate the effect of (LP) and (SP) on the constant fatigue behavior of 2017 aluminum alloy. Also the evaluating of residual stresses at the surface has been conducted. The concluded remarks from this study can be summarized as: At high stresses the (SP) treatment improved the fatigue life by a factor of (35%) while at low stresses this factor becomes (%44%). No improvement effect of (LP) on fatigue life and the lives were reduced by (40%) compared with dry fatigue.

Keywords: Laser surface treatment, shot peening, residual stress, Aluminum alloy, fatigue properties.

الخلاصة

تظهر المعاملات السطحية بالليزر تفاوتا في الاجهادات الانضغاطية المتبقية عند استخدامها لتحسين مقاومة السطوح للأحمال الديناميكيه المعرضة لها،في حين ان المعايير الميكانيكيه العامه تظهر بانها مشابهه لعملية القذف بالكرات الصلدة.البحث الحالي يهدف الى دراسة تاثير المعاملة بالليزر وعملية القذف بكريات الصلب المقساة على خصائص الكلال بدرجة حرارة الغرفة وبنسبة إجهاد(R= -1) وبتحميل معاكس على سبيكة الالمنيوم 2017، ويهدف البحث أيضا إلى دراسة الاجهادات السطحية المتبقية.إن الاستنتاجات المستخلصة من البحث يمكن اجمالها بالاتي:عند الاجهادات العاليه فان القذف بالكرات الصلدة قد زاد من عمر الكلال بمقدار(35%) أما بالاجهادات الواطئة كان(44%) في حين ان استخدام الليزر قد خفض عمر الكلال بمقدار(40%) بالمقارنة مع العينات غير المصلده.

Nomenclature

σ_f	Applied stress at failure	(N/mm^2)
N_f	Number of cycles at failure due to the applied stress(σ_f)	
N_i	Number of cycles reading (i=1,2,3,…….)	
σ_R	Residual stress	(N/mm^2)
L_p	Laser peening	
L_P	Shot peening	

Introduction

Mechanical components are regularly subjected to dynamic loads, which make them prone to fatigue failure. It is a well known fact that almost all fatigue cracks form at the surface due to a variety of surface stress concentration failures. [1]

Improvement in fatigue life of 2024 AL alloy is due to the formation of hard layer on which compressive residual stresses exist. [2]

Laser processing covers a range of operations in industrial material processing, the result shows that when the laser energy is increased the hardness is increased in (Al-Si-Mg)while a decrease in hardness for(Al-Cu-Si)alloys. [3]

Laser surface hardening is a relatively new and promising process for the thermal hardening of steel. Laser hardening of ferrous materials is an established process widely used to enhance the mechanical properties of highly stressed machine parts such as gears and bearing. [4,5]

Residual stress forms in the laser–treated surfaces because of rapid thermal heating and constrained cooling due to clamping of the work pieces. The nature and magnitude of these stresses of the surface formed during laser processing depend on the type of processing,temperature gradients, and phase-change kinetics.This in turn may or may not give rise to cracking tendency after processing depending on the level of stress, distribution and nature of the type of stress distribution,and the mechanical strength of the phases present in the laser- treated microstructures. [6]

Various techniques of laser surface hardening for various kinds of structural and tool steel showed different properties and residual stresses of hardened path of layer. [7]

The effect of shot peened (SP), and laser peend coupons Ti- 6AL -4V coupons in fretting fatigue show that the subsurface tensile residual stress was significantly greater in (LP) coupons than in (SP) coupons, the level of fatigue stress above which lead cracks were initiated by fretting was higher for (LP) than for (SP). [8]

The effect of different shot peening time on the rotating bending fatigue behavior of austenitic stainless steel TP321 shows that the life improvement factor was increased by a factor ranging between (1.72 to 5.3). [9]

The effect of shot peening and laser peening on crack growth of fatigue tests shows that shot peening increase the time to failure from a factor of (2-4), while the laser peening was increased by approximately (1.8). [10]

The different lasers processes can be controlled by varying the power density and the interaction time. In case of transformation hardening the resulting surface properties as hardness, hardening depth, residual stress and fatigue strength depend on these two independent process parameters. [11]

Fatigue life of 1100 and 5052 Al alloys is reduced because shot peening causes high surface roughness consequently high local stresses.[12]

The aim of this study is to evaluate the influence of laser and shot peening treatments on fatigue properties of 2017 aluminum alloy and to make comparison between laser and shot peening residual stresses against fatigue life.

Experimental Work

2-1 Metal used:

The nominal and actual composition of Aluminum alloy 2017 are shown in Table (1).The average grain size is 55µm in the longitudinal direction, while the mechanical properties of this alloy is given in Table (1).

Table (1): Experimental chemical composition of 2017 aluminum alloy, (wt %)

Material	Chemical composition								
	Cu	Mg	Mn	Zn	Si	Fe	Ti	Cr	Al
Nominal	3.5-4.5	0.4-0.8	0.4-1	Max. 0.25	0.2-0.8	max. 0.7	Max. 0.15	Max. 0.1	Rem
Actual	4.1	0.7	0.62	0.25	0.21	0.61	-------	0.04	

Table (2): Mechanical properties of 2017 aluminum alloy

Property	Yield stress (σ_y) (MPa)	Ultimate stress (σ_u) (MPa)	Elongation (RA%)	Modulus of elasticty (E) (GPa)	Modulus of rigidity (G) (GPa)	Poisson ratio (v)
Nominal	69	179	22	72	28	0.3
Actual	72	185	20	73	28	0.3

2-2 **Laser Treatment**

Laser treatment was performed using Cw Nd: YAG laser at (1.06 µm) wave length and full capacity of laser system (5) watt. Low laser power
(2.7) watt was used in this work. Pulse duration (7) nano seconds.

2-3 **Shot Peening**

The specimens are treated with shot peening using device of type shot tumblast control panel model (STB-OB).Spherical steel ball of size (1mm) having Rockwell hardness of (50 HRC) used. The peening pressure (12 bars) and the number of balls was kept constant at the whole operation time. The ball velocity is (40 m/s).

2-4 Fatigue –testing machine and its specimen:

A fatigue – testing machine of type PUNN rotating bending was used to execute all fatigue tests, with constant and variable amplitude. Specimen was subjected to an applied load from the right side of the perpendicular to the axis of specimen, developing a bending moment; therefore the surface of the specimen is under tension and compression stress when it rotates. Cylindrical specimens with minimum diameter of (6.74) mm were used according to (DIN 5013) standard specification. fig(1).

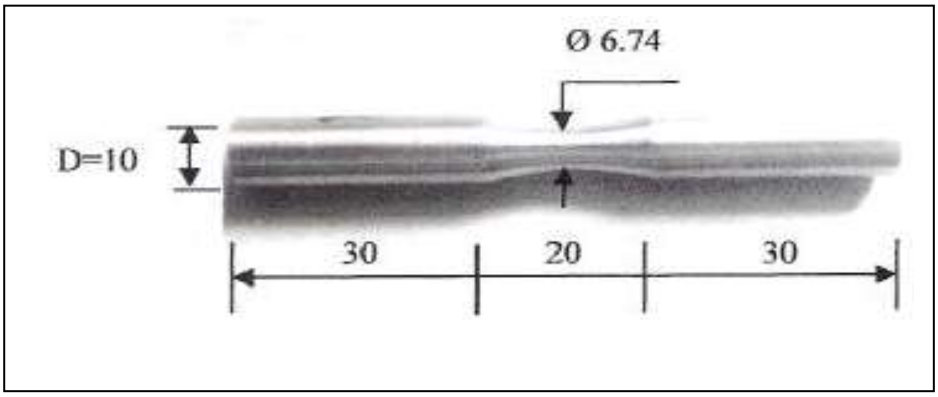

Fig.(1). Geometry of fatigue specimens dimensions in millimeter according to (DIN 50113) used standard specification.

2-5 Results and Discussion:

(45) Specimens were investigated in this work and classified in (3) series, Dry fatigue, Laser treatment, Shot peening treatment.

Dry fatigue

(15) specimens were used to establish the (S.N) curve; the results of this series are illustrated in Table (3).

Table (3) Basic data for dry S-N curve

Applied Stress(MPa)	Specimens number			Number of cycles(N_i)			$N_{f\ average}$
100	A_1	A_1*	A_1**	18200	14600	19900	17566
75	A_2	A_2*	A_2**	66900	81200	77600	75233
60	A_3	A_3*	A_3**	133000	142600	139600	138400
50	A_4	A_4*	A_4**	416000	522000	686000	541333
40	A_5	A_5*	A_5**	1.2×10^6	1.7×10^6	2.1×10^6	1.6×10^6

Laser fatigue

This group was selected in order to investigate the fatigue using laser surface hardening; the results are given in Table (4).

Table (4) S-N curve data under laser treatment

Applied Stress(MPa)	Specimens number			Number of cycles(N_i)			$N_{f\ average}$
100	B_1	B_1*	B_1**	6800	9600	8700	8366
75	B_2	B_2*	B_2**	41600	50800	39800	44066
60	B_3	B_3*	B_3**	101200	92800	96000	96666
50	B_4	B_4*	B_4**	291000	310600	312000	304533
40	B_5	B_5*	B_5**	866000	907860	1.07×10^6	947953

Shot peening

This group was selected to observe the effect of shot peening surface treatment on the number of cycles (fatigue life), the results are given in Table (5).

Table (5) S-N curve data under shot peening treatment

Applied Stress(MPa)	Specimens number			Number of cycles(N_i)			$N_{f\ average}$
100	C_1	C_1*	C_1**	37000	41800	48000	42266
75	C_2	C_2*	C_2**	90600	102000	111200	101266
60	C_3	C_3*	C_3**	225000	232000	242000	233000
50	C_4	C_4*	C_4**	968000	1025250	1125200	1039483
40	C_5	C_5*	C_5**	1.9×10^6	2.4×10^6	2.6×10^6	2.3×10^6

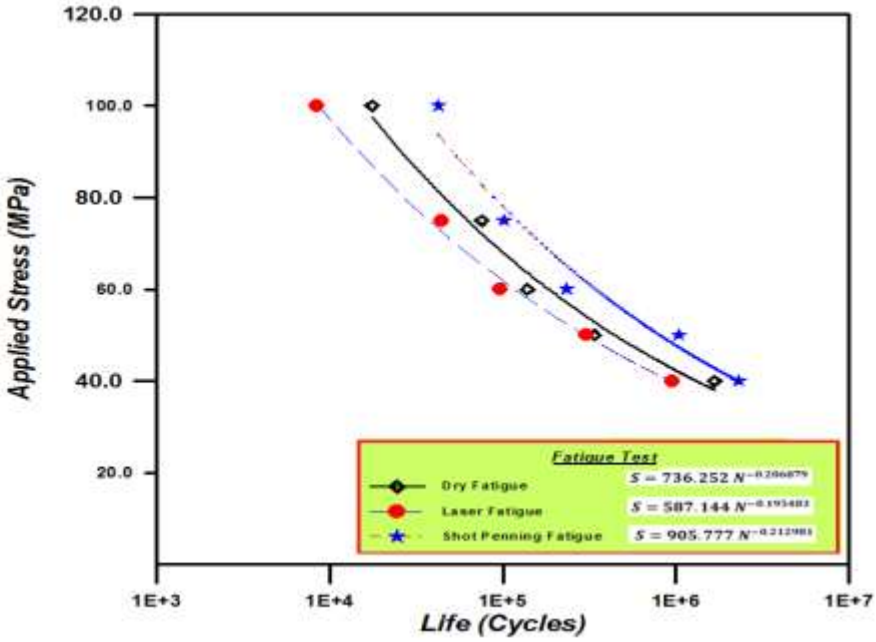

Figure (2) S-N curve behavior for dry 2017 Aluminum alloy in comparison between laser and shot peening treatment.

Comparison between the three series of fatigue S-N curves can now be made as shown in fig.(2), the S-N curves for both laser peening and shot peening is different compared with dry curves, shot peening increase the fatigue life of 2017 aluminum alloy by creating residual compressive stress in the surface which reducing the effective tensile stress, since the maximum tensile stress due to an applied load normally occurs at the specimen surface the residual compressive stress reduces this stress and increase the fatigue life by reduce the possibility of prosperities fatigue crack.

Experimental surface residual stresses can be seen in table (6) and the equation which may describes the residual stresses at a givens fatigue live can be taken the form of bansqun formula as ($\sigma = AN_f^{\ \alpha}$).

Table (6) Residual stresses for different surface treatments

Fatigue life **(N_f)**	Residual stress (laser)	Residual stress (Shot peening)	Bansqun equations
10^3	24	-32	$\sigma = 905N^{-0.212}$ (Shot peening)
10^4	13	-18	
10^5	6	-10	$\sigma=587N^{-0.195}$ (laser)
10^6	3	-6	
10^7	1	-3	

Fig.(3). Shows the behavior of compressive residual stresses against fatigue life for 2017 aluminum alloy. It is clear that the maximum compressive residual stress occurred at 10^3 cycle due to shot peening and the tensile stress occurred at the same life due to laser peening.

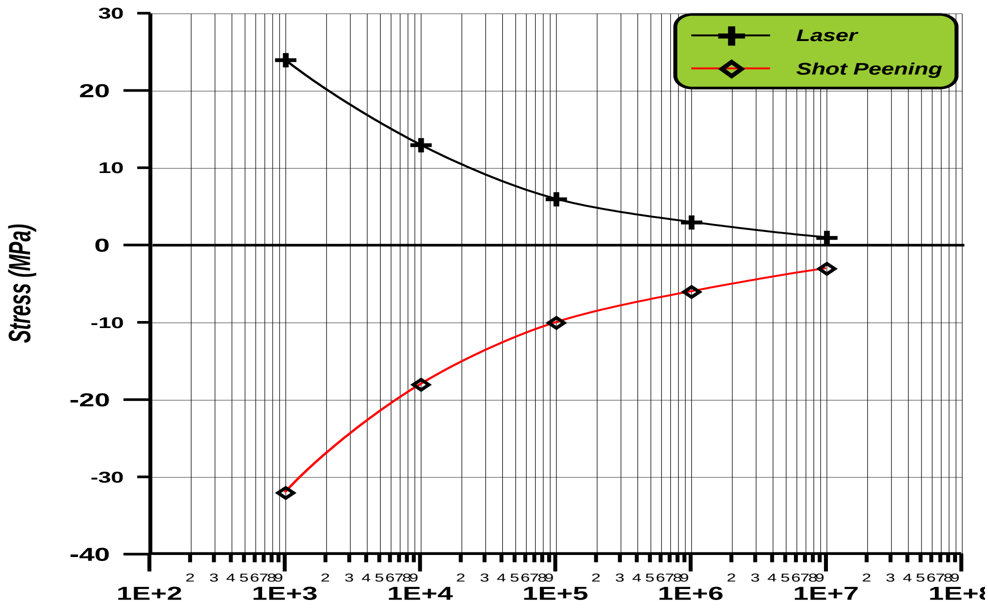

Figure (3) comparison between laser and shot peening residual stresses against fatigue life for 2017 Al alloy.

The fatigue behavior of all test groups (dry fatigue, shot peening and laser peening) treatment can be seen in (fig. 2). The comparison shown that the best fatigue characteristic was achieved by shot peening for induced compressive residual stresses in the surfaces which reduce the possibility of properties fatigue crack ,while residual tensile stress was induced in the laser treated see table(6).

Conclusions

1- The shot peening increased the constant fatigue life compared with dry fatigue by factor of (35%) at high stress while at low stress becomes(44%).

2- Constant fatigue life of 2017 aluminum alloy was signifiently reduced due to laser peening.

3- The shot peening creates compressive residual stress while laser peening creates tensile residual stress.

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