FATIGUE LIFE ENHANCEMENT OF AL-ALLOY 7075 UNDER COMBINED LASER AND HYDROFLUORIC ACID INTERACTION

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ABSTRACT

Laser shock peening (LSP) is a technical method for generation the compressive residual stress. LSP has been shown to greatly improve fatigue strength and lifetime. A study of fatigue under a constant repeating bending stress has been conducted on AL-alloy 7075 alloy at a stress ratio (R= -1) and room temperature using laser peening technique with overlay hydrofluoric acid (HF) as a confinement acid layer and as a media to increase the penetration of laser pulses. Two groups of test have been considered. The first group (15 specimens) was examined under unpeened situation. The second group (15 specimens) was examined under acid laser peening (ACLP). All mentioned groups were tested to generate the S - N curve. hydrofluoric acid (HF) coating was used as a new technique to improve the properties of the AL-alloy 7075. The experimental data showed that the use of (HF) acid, as a coating material, largely increased the compressive residual stress at the surface. The results provided a substantial improvement in fatigue life improvement factor reaching to 80% for this new coating.

KEYWORDS : Hydrofluoric acid (HF) surface coating , aluminum alloy 7075 , Laser- fatigue interaction.

تحسين عمر الكلال لسبيكة الالمنيوم 7075تحت تأثير تفاعل مشترك لليزر وحامض الهيدروفلوريك

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الخلاصة :

الصعق باستخدام الليزر تعتبر من الطرق الحديثة لتوليد جهد متبقي ولتحسين مقاومة الكلال والعمر التشغيلي . تمت الدراسة في ظروف حمل مستمر ترددي وبدرجة حرارة الغرفة مع استخدام تغطية سطح السبيكة بحامض فلوريد الهيدروجين بعد عزله عن السبيكة لزيادة نفوذية نبضات الليزر. وقد استعملت مجموعتين ، كل مجموعة تتكون من 15 قطعة وفحصت الاولى بدون تاثير الليزر والثانية تحت تاثير الليزر وبوجود الحامض يغطي السبيكة .الغاية هو لغرض عمل مخطط الاجهاد مع عدد الدورات.يعتبر استخدام الحامض فلوريد الهيدروجين تقنية جديدة لتحسين خواص سبيكة الالمنيوم 7075 . وأظهرت النتائج باستخدام هذه الطريقة زيادة كبيرة في الاجهاد الانضغاطي المتبقي على سطح المعدن وكذلك تحسن في معامل تحسن خواص الكلال بنسبة تصل الى 80 % لطبقة الطلاء الجديدة .

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INTRODUCTION :-

Laser shock peening (LSP) is a cold working process, able to initiate compressive residual stress and thus increase the resistance of component to process fatigue. The focal endings obtained from this work were enhances in hardness, tensile strength and fatigue life due to LSP. The increases in fatigue life are a result of considerable residual surface stresses created due to shock process and to extend under metal surface. Hu and Yao [2006]. Research concluded that the Al- alloy 6061-T6 by means of low energy Nd : YAG laser with coating, laser peening can extensively get better surface compressive stress and micro-hardness with a little increase in surface roughness. This compressive stress leads to a rising in fatigue life and wear resistance of metal. G. Gomez et al [2005]. Lawrence Livermore National Laboratory, carried out experiments shown that laser peeing can eliminate the occurrence of stress corrosion cracking in metal during an accelerated stress-corrosion cracking experiment in an aqueous solution of $MgCl_2$ at high temperature. Sathyajith et al [2013]. The outcome of laser shock peening on fatigue life of aluminum alloy 2024using Q switched Nd: glass laser with high-power used for LSP. The finding showed that the fatigue lives of aluminum alloy are enlarged seriously after LSP. The mean fatigue life of AL-alloy 2024T62 after the LSP is 4.5-9.8 times that of the un-shocked ones. Zhaxg et al [1997]. A comparison was done for the residual stresses produced by laser peening of AL- alloy 6061-T651 between the residual stress before and after laser peening and it was set up that the compressive residual stresses at the surface was about (350 MPa) which is close to the yield stress. The outcome noticeably gives an idea about that LSP is a successful surface treatment method for getting better fatigue performance of aluminum alloys. Ren et al [2006]. Study for AL-alloy 2024-T351 and 7075-T73 under tensile tests it was found that the yield strength increased for both alloys but the ultimate strength increased in AL- alloy 7075-T73 only under the effect of laser shocking. Sathyajith et al [2013]. In this work, laser shock peening (LSP) was used to establish compressive residual stresses. The influence of acid laser peening (ACLP) was characterized and assessed using AL-alloy 7075. The current work aims to assess the influence of HF acid, as a coating surface of laser on the fatigue properties using AL- alloy 7075.

EXPERIMENTAL WORK :-

The substance of the test is an aluminum alloy of 7075, this alloy has good strength properties and low specific gravity allowing one to extensively use this alloy in various fields of industry, e.g. aircraft and instrument production. The profile and dimensions of the specimens according to (DIN 50133) standard specification are shown in figure (1). The chemical composition and static properties of AL- alloy 7075 are given table (1) and (2), respectively. Five stress levels were selected, and three specimens for each level to build the S – N curves for unpeened and peened fatigue behavior, covered with black tape was used and nylon as isolated layer to prevent the effect of acid on the surface of the specimens.

Fatigue Test

A fatigue testing machine of type (Avery) was used to perform all fatigue tests at a constant amplitude, and the bending fatigue tests were conducted at room temperature 25˚C under stress ratio (R = -1).The test rig is provided with a mechanical counter used to count the number of cycle of stress. Figure (2) shows the fatigue testing machine.

Acid Surface Coating Technique

There are different manners to increasing the absorption of the power of the laser which is focused on the surface of the alloy, the black tape on the surface of the specimens

is best way to increase this power with water as confinement layer. In this study hydrofluoric acid (HF) used as a new technique to increase the power of the laser that applied on the 7075 alloy, and to prevent reaction between alloy and the acid, a very thin 100 µm layer from nylon cover the surface of the specimens, then pour HF acid with 1-2 mm in depth above the specimens, exactly on the narrow area of the specimen. As shown in figure (3).Which it shows the specimen with black tape and thin layer of acid.
Prior to the laser treatment, the specimen surface softened with 200 emery paper to give Ra(average roughness) about o.6 µm. LO et al [2003] used Nd : YAG laser using AISI 440 c stainless steel and they obtained an increase in microhardness form 300 HV to 600 HV and 800 HV. In this study the use of black tape and very thin layer of nylon with HF acid to increase the energy absorption of laser.

Laser Peening Treatment Device

Because of wide availability of Nd : YAG laser have been used to produce hardened surface on metals. Lima et al [2007]. Laser device was used in this work (Q-switched neodymium YAG laser) for laser peening has the following properties:

1- Pluse duration is 7 nano seconds
2- Laser wavelength is about 1.065 µm
3- Pulse energy is 300 mJ.
4- The laser spot is typically (5) mm in diameter.

RESULTS AND DISCUSSION :-

The fatigue results of 30 specimens were investigated at room temperature and stress ratio (R= -1) for two conditions, the first condition, laser peening with acid and the second condition as received alloy, as depicted in Figure (4). It is clear that the ACLP increased the resistance of alloy and improved the High cycle fatigue life (HCL).
In terms of S – N curve fatigue properties, the high cycle fatigue region is significantly affected by the acid as a coating surface. The acid plays a major factor in increasing the plasma pressure in which intensifying the compressive residual stresses at the surface and subsurface. The energy absorption in the plasma generates dominant shock waves on the material. And these waves work to generate a high compressive residual stress.
The obtained data of S – N curves for shock laser with acid and as received alloy can be formulated by the equations: $\sigma_f = 890 * N_f^{-0.162}$, $\sigma f = 870 * N_f^{-0.159}$, respectively.
The acid laser peening does not improve the life of low cycle fatigue (LCF) but reduces these lives compared with unpeened fatigue lives, because the dominant factor is the applied load and there is no enough time for the fatigue cracks to propagate through the barriers while at HCF region, the dominant factor is the compressive residual stress generated due to the ACLP, thus the cracks may be retarded during their propagation and the life increased compared to the HCF unpeened condition. Acid peening is not used to cool the surface but serves the key function of confining the plasma generated when the laser beam interacts with the opaque overlay surface and is used as a media to penetrate the laser beam through the acid because of the ability of the acid to pass on the laser power which consists of two synchronized waves, electrical wave and magnetic wave, so the acid can carry the wave through it.

Fatigue Life Improvement Factor FLIF%:

The FLIF % at different stress levels can be defined as: Alalkawi and Bashar [2016],[FLIF % = (Nf –Nf unpeened)/(Nf unpeened)*100].The values of the stress level are given in table (3) is clear that the values of FLIF % at low stresses, i.e. 172.7 MPa are positive and with maximum values, this means that the fatigue properties are improved due to laser peening with acid but, the effectiveness improvement appears in using ACLP. Table 3 and Figure (5) show the relation between FLIF% against stress levels.Figure (5) demonstrates positive values at low stresses (high cycle fatigue) using acid laser peening, the enhancement of fatigue properties using ACLP may well be upcoming from the following causes.

1- To cool the material.
2- To increase the plasma pressure.

CONCLUSIONS :-

After the present analysis of the laser peening the following conclusions could be drawn:

1- It was observed, that when ACLP was used, the lower stresses generated higher a fatigue life compared to unpeened fatigue life.
2- It has been demonstrated that the ACLP is influenced surface treatment technique to improve the HCF properties of aluminum alloy 7075.
3- Significant increase in fatigue life was observed at HCF region due to ACLP treatment, FLIF % values were obtained about 80% .

Table (1) . Refers to chemical composition of AL- alloy 7075,wt%.

	% Zinc	%Titanium	%Silicon	%Manganese
Stand.	6.1-5.1	≤ 0.2	≤ 0.4	≤ 0.3
EXP.	5.52	0.028	0.26	0.11
	%Iron	%Copper	%Chromium	%Magnesium
Stand.	≤ 0.5	1.2 – 2	0.18 - 0.28	2.1 - 2.9
EXP.	0.24	1.82	0.183	2.15

Table (2). The average mechanical properties of three specimens of AL- alloy 7075

Property	Experimental	Standard
Ultimate stress	530MPa	502MPa
Yield stress	496 MPa	406 MPa
Fatigue strength	206 MPa	156 MPa
Modulus of elasticity	75.6 GPa	74 GPa
Posions ratio	0.32	0.33
Elongations %	14.6	16

Table 3. Values of stress level and FLIF%

Stress level (MPa)	**172.7**	**255.2**	**304.8**	**387.7**	**504.4**
FLIF %	80	62	-36.6	-15	-27.27

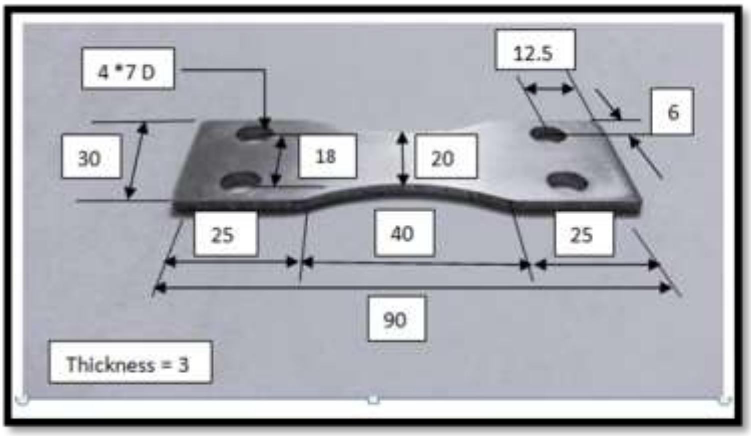

Fig.1, Geometry of fatigue specimens dimensions are in millimeter

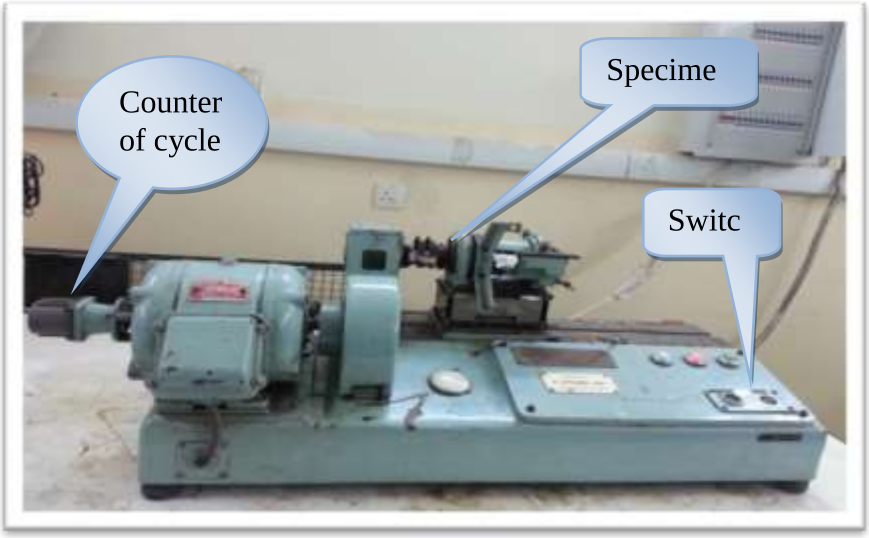

Fig 2. Avery fatigue bending machine

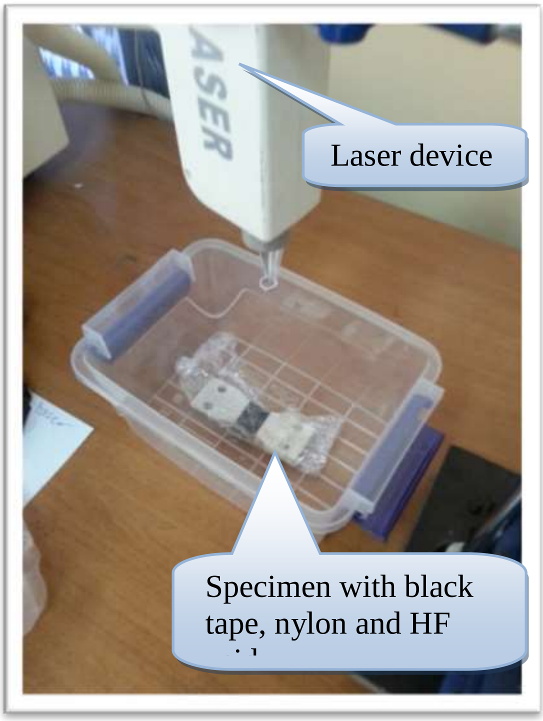

Fig.3 specimen applied under laser power

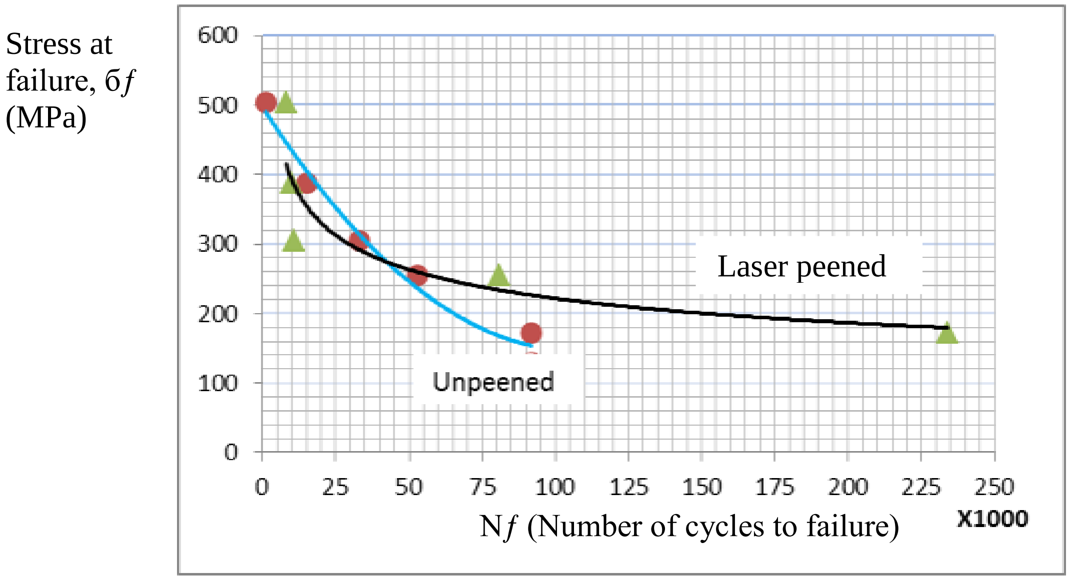

Fig.4: S-N curves at constant load for laser peening

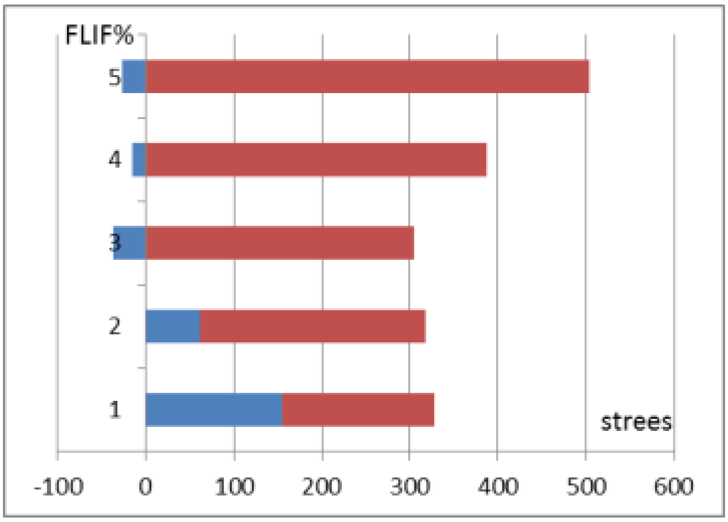

Fig.5: FLIF % versus stress level.

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