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Fatigue of Cu 65400 Alloy under Laser treatment

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Abstract

Fatigue tests were done to determine the S-N curves for Cu 65400 alloy specimens .The effect of laser shotting on the fatigue properties were investigated with stress ratio R=-1 at room temperature. Laser shotting of this alloy increases the life, endurance limits and compressive residual stresses. The largest increase in compressive residual stresses were observed at stress level 350 MPa.

Keywords: Cu65400 alloy, laser fatigue tests, compressive residual stress

تداخل الليزر- الكلال لسبيكة النحاس Cu65400

الخلاصة

تم إجراء فحوصات الكلال لعينات سبيكة نحاس –خار صين Cu65400 المستخدمة في البحث قبل وبعد معاملتها السطحية تحت تأثير ضربات ليزرية عند نسبة الإجهاد R=-1 ودرجة حرارة الغرفة. التصليد بالليزر لهذه السبيكة أدى إلى زيادة العمر وزيادة حدود الكلال والاجهادات الضغطية المتبقية. اكبر زيادة في الاجهادات الضغطية المتبقية تمت ملاحظتها عند مستوى الاجهاد 350 MPa

The Aim of the Present Work

Cu 65400 alloy is most widely used alloy in abroad range of applications .In this investigation the improvement of fatigue properties for this alloy by using laser treatment is the main aim of the current study.

Introduction

Laser surface treatments improve the surface properties of metallic materials and they have been developed for many industrial applications. The observed enhancement of fatigue life is attributed to the development of compressive residual stresses during the laser processing [1-3].

To enable prediction of the fatigue behavior of the laser surface treatment of material, the calculation of the Compressive residual stresses induced by the laser treatment is required.

Modeling of various laser beam processes have been performed in the literature, however most of the models refer to the laser beam forming [4,5].and laser beam welding [6].

Benefits by laser peening are the residual stresses of the effect of compressive stresses and the cold working induced. Compressive stresses are beneficial in increasing resistance to fatigue failures, corrosion, fatigue, stress corrosion cracking, hydrogen assisted, cracking, fritting, galling and erosion caused by cavitation. Benefits obtain due to cold working include work hardening , intergranular corrosion resistance , surface texturing ,closing of porosity and testing the bond of coatings. Both Compressive stresses and cold working effects are also benefits in

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the application of laser peening in forming metal parts [6-8].

Laser heating caused a melting layer to form on the H13 steel ,The modified As by-Eastaring heat transfer equation was used to provide the temperature field for laser hardening in the melt .The main conclusion of this work is ,the larger the grain size , the higher the temperature and the longer the duration required for the steel into austenite [9].

Laser induced shock waves are currently used in industry for harden metal surfaces mechanically in order to increase fatigue strength and wear resistance. It has been found that transparent layers are helpful for the use of laser induced shock wave, since ablation is reduced and the impact of shock waves significantly increased [10-11].

Materials

The Cu65400 copper alloy has a distinctive clear bright yellow normally associated with brass, consists of the face centered alpha phase ,and has the optimum combination of strength and ductility in the copper-zinc series .It is used for heat exchangers, lumping tube and fittings, drain and vent pipes and other applications requiring excellent corrosion resistance in water.

Mechanical tests of the used alloy was effected at the center of quality control. Three specimens have been taken from the received round bar of diameter equal to (Φ=14 mm). The chemical analysis of the material used is given in table (1). While the mechanical properties of the material used is given in table (2).

Fatigue Specimens perpetration

Cu65400 alloy is received from the mechanical manufacturing company in the form of rolled rods. To get perfect dimensions of fatigue specimens and to avoid mistakes, an accurate profile should be attained. All specimens were machined corresponding careful control was taken into consideration to produce a good surface finish and to minimize tensile residual stresses. The test specimen is shown schematically in fig (1).

Fatigue Rotating bending Test

A fatigue –testing machine of type rotating bending was used to execute all fatigue test with constant and variable amplitude .The specimen was subjected to an applied load from the right side. The load axis perpendicular to the axis of specimen, developing a bending moment. Therefore, the surface of the specimen is under tension and compression stresses when it rotates .The value of the load (p) applied on the specimen for a known value of stress ($б_b$) measured by (N/mm^2) is extracted from applying the equation below] 12].

$$б_b = P.L/ \pi d^3 = \frac{P \times 125.7}{\pi d3}$$

$$P=\pi d^3 б_b/125.7 \times 32 \quad \ldots\ldots (1)$$

Where the force arm is equal To 125.7 mm.

Laser characteristics

A pulse 1.06µm Nd:YAG laser system was used for ablation of different targets. In the laser the active medium is an Nd:YAG crystal that operates with Q-switched excitation scheme .The output pulse duration is 1ms and the maximum pulse energy 1J which is measured by a Genetic PS-330 joule meter. A He-Ne laser (λ =632 nm) was used for optical alignment purpose. Table (3) shows the main characteristics of the laser used ,and fig (2) shows the laser shocking on fatigue specimens.

Experimental results and Discussion

Thirty –six (36) specimens were investigated in this series; they were used to estimate the basic S-N curves for rotating bending .Of them nine were virgin as shown in table (4) and the other were shotted by laser with different number of shocks as shown in the below table .The roughness of specimens was found to be equal to Ra= 1µm, and this is the average value from 36 specimens before laser shotting. Deduced relations for Cu 65400 alloy fatigue specimens with and without laser shotting are given in table (5), and the basic S-N curves are shown in fig (3).

The results of table (4) and (5) have brought some comments in the observation of fatigue behavior of Cu65400 alloy under constant loading shown in fig (6) .It was found that laser treatment have improved the fatigue property of the alloy .The improvement is due to compressive residual stresses generated in the surface of the specimen and to the production of a heavily deformed surface layer. It is clear that, the improvement in fatigue strength of 6 shots was increased by 35%, for 8 shoots the improvement was 63%and for 10 shots the increases was 79%.

The effect of laser on fatigue behavior arises the curve level and then increasing the number of laser shots will increases the endurance limit as shown in table (6) .This results are similar to that found by British Aerospace [11] and Ref [13] for aluminum alloys.

In order to evaluate the residual stresses generated due laser shooting, an average life was calculated based on table (3) .The results are given in table (7). Then the above data can be used to find the actual stress applied using the S-N virgin curve which is:

$$\sigma_f = 21899 * N_f^{-0.3312}$$

The result obtained from the above equation gives the applied stress plus the residual stress generated from laser treatment. The residual stresses obtained are given in table (8). Residual stresses calculated from equation above. It is clear that for a given stress level, increasing number of laser shots will increases the residual stress (RS). This result is in good an agreement with what was found by Refs [14, 15]

Conclusions

The constant fatigue properties of Cu65400 copper alloy in different surface conditions (virgin and laser treatment) under rotating bending were investigated .The following conclusions may be drawn from this study.

1. Fatigue life and endurance limit are increased by laser shocks as a result of creation of compressive residual stresses.
2. For the Cu65400 copper alloy, the increasing laser shocks will increase the compressive stresses.
3. The compressive residual stresses higher at lower stress level.

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Table (1); chemical composition of the Cu 65400 alloy

Element	Pb	Sn	Zn	Si	Fe	Mn	Mg	Cu
Standard	0.05	1.2 – 1.9	0.5	2.7-3.4	/	/	/	rem
Measured	0.044	1.4	0.45	2.9	/	/	/	rem

Table (2): Mechanical properties of Cu 65400 alloy specimen in tension

Mechanical properties	Modulus of elasticity GPa	Percentage Elongation %	RA %	Ultimate stress MPa	Yield stress MPa	Poisson 's Ratio	Modulus of rigidity GPa
Measured	118	20	24.7	650	570	0.25	48
standard	117	18	23	657	568	0.26	47

Table (3): shows the main characteristics of Nd :YAG laser.
[university of Technology, laser Eng .Dep.]

laser parameters Nd:YAG	
wavelength	1.06μm
pulse duration	1 ms
energy	1 J
stroke mark area	$0.171 * 10^{-2}$ cm^2
power density	$5.85 * 10^5$ watt $/cm^2$

Table (4): S-N curves data of Cu 65400 copper alloy

No. of specimens	Applied Stress (MPa)	No. of cycles to failure (cycles)	Condition
1,2,3	350	271820 , 267817 , 259824	virgin
1,2,3	360	245000 , 241000 , 234010	virgin
1,2,3	380	212500 , 208504 , 202000	virgin
1,2,3	350	310000 , 300000 , 291000	6 (shocks)
1,2,3	360	274000 , 265009 , 256023	6 (shocks)
1,2,3	380	222500 , 218542 , 215000	6 (shocks)
1,2,3	350	358200 , 354016 , 350000	8 (shocks)
1,2,3	360	310300 , 302005 , 299000	8 (shocks)
1,2,3	380	248100 , 240095 , 235112	8 (shocks)
1,2,3	350	406000 , 400030 , 390000	10 (shocks)
1,2,3	360	330000 , 325000 , 312040	10 (shocks)
1,2,3	380	263102 , 260000 , 250020	10 (shocks)

Table (5): The S-N curve equations

No. of specimen	No. of laser shot	S-N curve equations
9	Virgin	$б_f = 21899 * N_f^{-0.3312}$
9	6	$б_f = 9423 * N_f^{-0.2612}$
9	8	$б_f = 5345 * N_f^{-0.2135}$
9	10	$б_f = 4125 * N_f^{-0.1915}$

Table (6): Endurance fatigue limits under different laser shots .

$б_{E-L}$	Condition	$б_{F-L}$ / $б_{E-L}$
105.2021	Virgin	1
139.8893	6	1.35
171.1683	8	1.63
188.3137	10	1.79

Table (7); Average number of cycles to failure for given stress level and number of shocks.

Applied stress $б_f$ (MPa)	N_f average Laser shot=6	N_f average Laser shot=8	N_f average Laser shot=10
350	300333	354072	398676
360	265010	303768	322346
380	218680	235102	257707

Table (8) :Compressive residual stresses generated from laser treatment RS* residual stresses

No. of shocks / Applied stress (MPa)	6 shot RS*(MPa)	8 shot RS (MPa)	10 shot RS (MPa)
350	-14.07	-41.89	-74.156
360	-9.862	-25.33	-31.85
380	-6.85	-24.489	-26.6

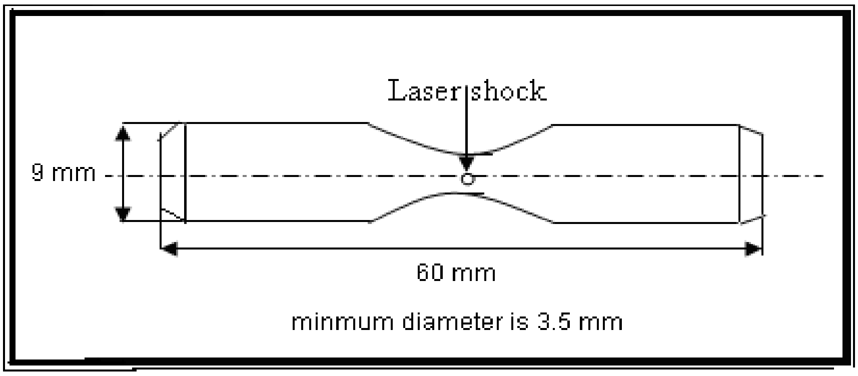

Figure (1): shape and dimensions of fatigue specimens according to German engineering standard DIN (50123).

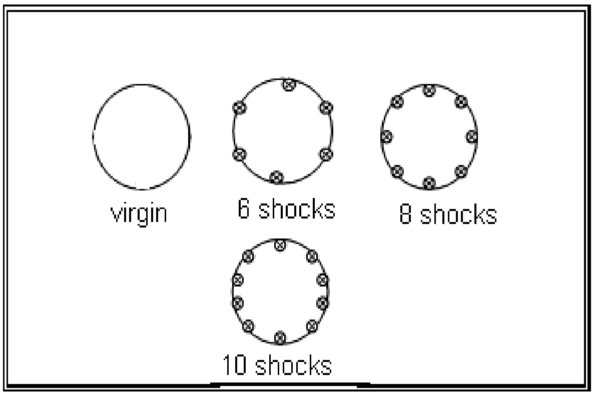

Figure (2): shows Laser shocking on fatigue specimen

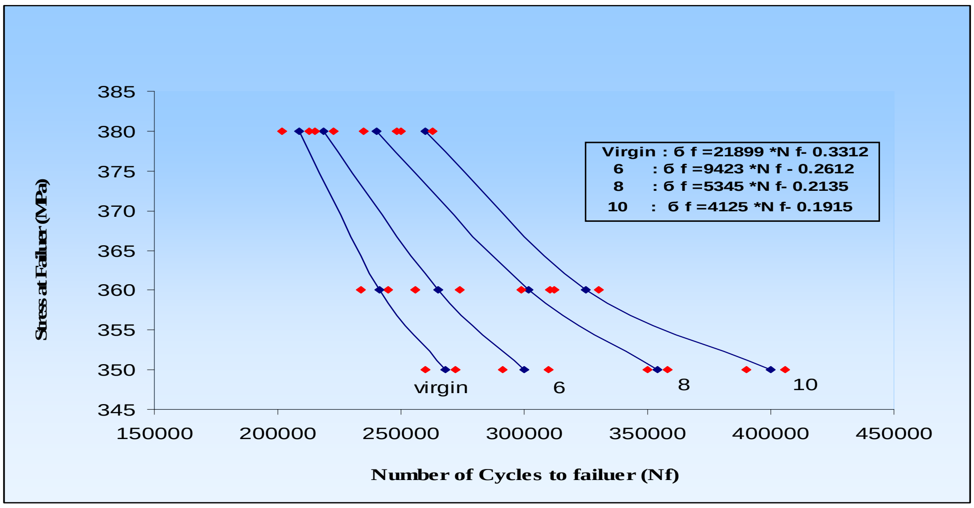

Figure (3) S-N curves for different number of laser shocks