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Wear Resistance Improvement of 41Cr4 Steel Alloy by Laser Surface Hardening

Dhia Ahmed Salal

College of Engineering, University of Diyala

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ABSTRACT - In this paper an overview is given about laser surface modification process, which is developed especially with the aim of wear resistance improvement. Pulsed Laser was applied to 41Cr4 steel alloy specimens using a Nd: glass laser. Laser processing parameters examined in the present study included power density (3*10^5 to 9.5*10^5 W/cm²). The power density and interaction distance were chosen such that the maximum temperature approaches the melting temperature. The importance of sufficiently high temperatures has already been recognized to reduce the wear rate at the highest power density. The 41Cr4 steel alloy samples were examined using optical microscopic inspection, microhardness test to determine the metallurgical phases and pin-on disc machine was used to estimate wear resistance. It was found in this study the microstructure was relatively dependent of laser power density. However, the laser power density had a significant effect on structural and mechanical properties especially wear resistance in a given power density level.

Keywords: laser surface hardening, wear resistance, 41Cr4 steel alloy.

1- INTRODUCTION

The availability of high power lasers in recent years has led to arrange of applications in material processing(1). In fact, lasers because of their wide applications are still a story of success within material and manufacturing(2). The effect of laser hardening on the mechanical properties of steel was considered occasionally in the past. With the help of laser beam which scans the surface of the work piece locally very high temperatures (up to melting) can be obtained. Since this heating is very local, there are very high temperature gradients, so that after the laser beam has passed cooling occurs very quickly. The cooling rate is high enough to guarantee formation of marensite from all austenite formed during heating[3]. The importance of high sufficiently high temperatures has already been recognized by Stäh[4]. This research work focuses on the most important laser application that leads to enhance the mechanical properties of the material which is the laser transformation hardening.

Nd:glass(Nedemuim glass) pulsed laser is found as a significant technique to enhance the mechanical properties especially hardness and wear resistance of 41Cr4 steel alloy. It has resulted in hardness increasing, wear resistance enhancement and favorable microstructure. Similar treatment using Nd:YAG(Nedemuim yittrium) laser on tool steel has produce variation in chemical composition[5].The transformation of austenite phase to martensite is associated with volume change that led to the generation of residual stresses[6]. Residual stresses due to laser pulse are compressive, but when overlapping of those pulses is applied the microstructure in the overlapping region will be tempered and residual stresses become tensile[7].However overlapping of laser pulses results in a more homogeneous microhardness distribution in the heat affected zone (HAZ)[8].

Many research works have been carried out concerning with laser material modification, wear resistance has the interest to be enhanced by many studies, in other hand fatigue behavior of laser treated carbon steel was studied[9,10].

2.EXPERIMENTAL PROCEDURE

In this study samples of circular 41Cr steel alloy were subjected to wear study before and after surface treating by laser. The test specimens were (15mm) in length and (10mm) in diameter. Chemical composition of the alloy is shown in Table (1). Pin on disc sliding machine was used for this study as shown in figure 1. The wear rate was measured by weight loss method using a Mettler AE200 microbalance of (10^-4 gm) sensitivity. The wear rate was calculated according to the following relationship:

$$\text{Wear rate} = \Delta W/SD \quad (gm/cm) \qquad (1)$$

Where: ΔW= Weight loss (gm)

SD=Sliding distance (cm)

$$\Delta W = W1 - W2 \qquad (2)$$

Where: W1= Initial weight of the test specimen (gm)

W2= Finial weight of the test specimen (gm)

The applied normal load was (30) N and three linear sliding speeds (0.7, 0.99 & 1.49) m/sec. The hardness of the disc was 385 HV. The duration of each test was 30 minute and the test was carried out at room temperature and normal atmospheric conditions. Surface roughness estimated of samples before and after laser surface hardening by A Parthen – Perthometer type: 56 P_ISO.The hardness of samples was measured by using Lietz – GMBHD6330 Wetzlar_ Hardness tester with load of 3kg for 30 second. The Vickers hardness Hv number is calculated by:

$$HV = 1.8544 * P/ dav \quad Kgf/mm2 \qquad (3)$$

where:-

P: Applied load (Kgf.)

dav: Average of indentation diameter (mm).

Olympus (Japan) optical microscope was connected to automatic camera. Olympus C-35 AD -2 Japan Serial No.259384and digital controller to adjust exposure time automatically for examination of character and microstructure of samples before and after laser surface hardening.

Three different power densities (3*10^5, 7.75*10^5& 9.5*10^5) W/cm² have been used for different focusing positions (4, 4.2, 4.5 cm) to obtain the best mechanical properties and fineness microstructure. After investigation, the results showed that, there was a significant effect (melting occurring) at the focusing position (4 cm) while the effect has been reduced gradually at the other positions (4.2, 4.5 cm).

3.RESULTS AND DISCUSSION

The base metal microstructure of 41Cr4 steel alloy in Figure (2) consists of the usual pearlite (α + Fe_3C) which is represented by the dark regions while the bright regions is the ferrite (α). This microstructure has an average hardness of 225 HV. The surfaces of a series of samples processed with different power densities and beam interaction times. It can be seen that after investigation the melting is occur for 41Cr4 steel alloy at power density equal or above to 9.5*10^5W/cm² (figure 3) while, the laser surface melting processing doesn't take place below this value and no significant effect has been observed below 3*10^5W/cm². The best and highest hardness was at power density 9.5*10^5W/cm² which is reached ~905 HV after laser surface hardening.

It has been shown that rapid solidification rates of 41Cr4 steel after the laser processing gives rise to a variety of interesting and potentially useful microstructure. Figures (4)& (5) represent the transverse – sections view for the 41Cr4 steel alloy at different positions of the laser pulse and under high microscope magnification. The melted regions and base metal regions were seen clearly inside the material. After laser processing, for all examined specimens the original pearlite colonies appear to have transformed completely to martensite as far as can be observed that by optical microscope.

The effect of the sliding time on the wear rate of 41Cr4 steel alloy before and after laser surface hardening is shown in Figure (6). It is clear that an accumulative wear rate increases with increasing sliding time, this increasing being more pronounced at the beginning of the test. This behavior is explained in terms of the even distribution of the wear debris result in even surface, also the same figure shows that, the results of an accumulative wear rates are changing within the time variation. The increasing ratio in the wear rates reduces gradually after 20 minutes due to the occurring transformation hardening phenomenon of the steel alloy. The effects of laser surface hardening on wear rate of 41Cr4 steel alloy are shown in the same figure. The results include a comparison of the as- received specimen state with laser hardened specimen state. It is obvious from the curves that in all conditions the wear rate has the same trend namely, increasing with sliding time.

Best wear resistance was obtained in hardened specimens. This observation is explained in terms of the fineness microstructures obtained in each case which gives varying hardness from 225Hv before laser treatment to ~905Hv after the laser surface treatment respectively, different amounts of retained austenite estimate from ~ (12-15) % after laser surface treatment [11] and the stress induced phase transformation phenomenon that occur during the test [12,13]. The microstructure studies show that the contributions to the wear resistance come from the acicular matrix of martensite after laser surface hardening figure 7, work hardened structure after laser processing.

Laser surface treatment produces enhancement in hardness from 225HV. up to ~905 Hv. Figure 7 shows the micrographs of some specimens subjected to laser surface treatment in which an acicular microstructure of martensite with some retained austenite are as clear as and contributed to enhancement wear resistance of the martensitic 41 Cr4 steel alloy.

The effect of sliding speed on the wear rate of 41Cr4 steel alloy is shown in Figure (8). The wear -rate increases with increasing sliding speed under effect of the applied normal load. This behavior can be explained by taking the flash temperature into account. The flash temperature increases with increasing sliding speed up to melting point at asperities [14]. The heat dissipation at higher sliding speed is lower than that at low sliding speed, after that the wear rate of steel alloy reaches steady. This causes softening of the asperities and reduces the forces required to shear the welded points so the wear rate will reduce and reaches to the steady state as shown in Figure (8).

4.CONCLUSIONS

Laser surface hardening of 41Cr4 steel alloy by Nd: glass laser has been performed. The effects of processing variables have been optimized. The principal results and conclusions follow:

1. Laser surface melting of 41Cr4 steel alloy occurs at power density equal or above to9.5*10^5W/cm² while, the laser surface melting processing doesn't take place below this value and no significant effect has been observed below 3.5*10^5W/cm².
2. The 41Cr4 steel alloy has the best and highest hardness after Nd:glass laser surface hardening at power density 9.5*10^5W/cm² which reached approximately 905 HV.
3. The accumulative wear rate of 41Cr4 steel alloy increases with the increasing sliding time, this increasing being more pronounced at the beginning of the test , after 20 minutes the increasing ratio of the wear rate is reduced since a work hardening phenomenon is occurred after this time.
4. The Existence of retained austenite in the processed specimen (41 Cr4 steel alloy) have contributed to improve the wear resistance because of the stress induced phase transformation of austenite phase to martensite during the test.
5. The wear rate of 41Cr4 steel alloy increases with increasing sliding speed at applied normal load.

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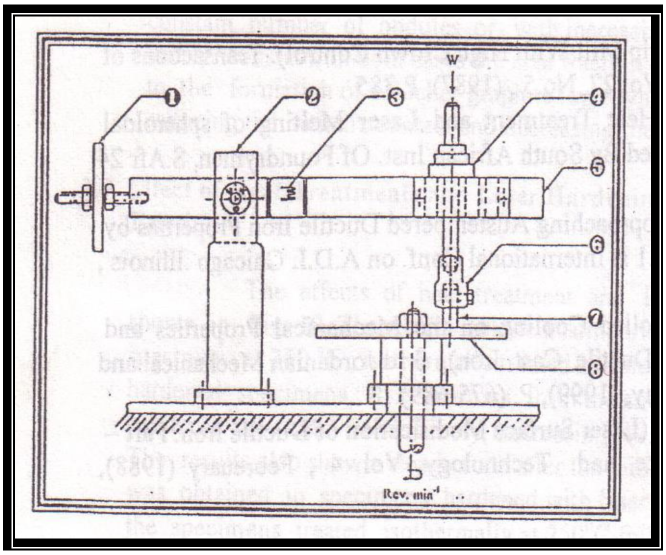
Table 1. The chemical composition of 41Cr4 steel alloy

Composition (%)									
C	Si	S	Cr	Mn	Ni	P	Mo	Al	Cu
0.39	0.21	0.036	0.99	0.66	0.1	0.01	0.04	0.008	0.2



Pin on disc machine			
No.	**Parts name**	**Quan.**	**material**
1	**Balance weight**	**1**	**M.S.**
2	**Fulcrum**	**1**	**C.I.**
3	**Strain gauge**	**2**	**Cu-Ni Alloy**
4	**Loads**	**4**	**M.S.**
5	**Cantilever arm**	**1**	**M.S.**
6	**Holder**	**1**	**S.S.**
7	**Specimen**	**1**	**A.S.G. C.I**
8	**Rotating disc**	**1**	**C.S**

Fig.1. Schematic drawing of the pin on disc sliding machine.

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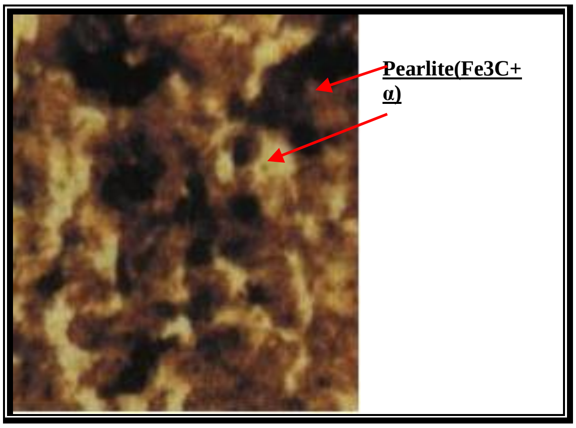

Fig.2. The microstructure of 41Cr4 steel alloy before laser treatment (300X).

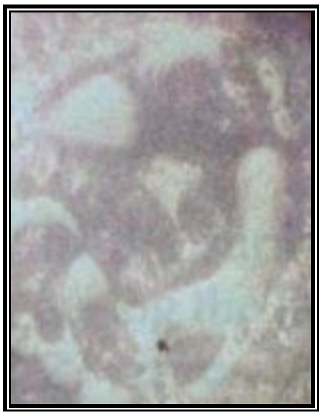

Fig.3. Melted region at laser power density 9.5*10^5(100X)

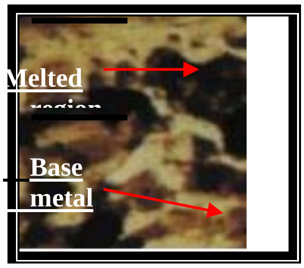

Fig.4. Transverse section for the 41Cr4 steel alloy at magnification power (300X).

Fig.5. Transverse section for the 41Cr4 steel alloy at high magnification power (500X).

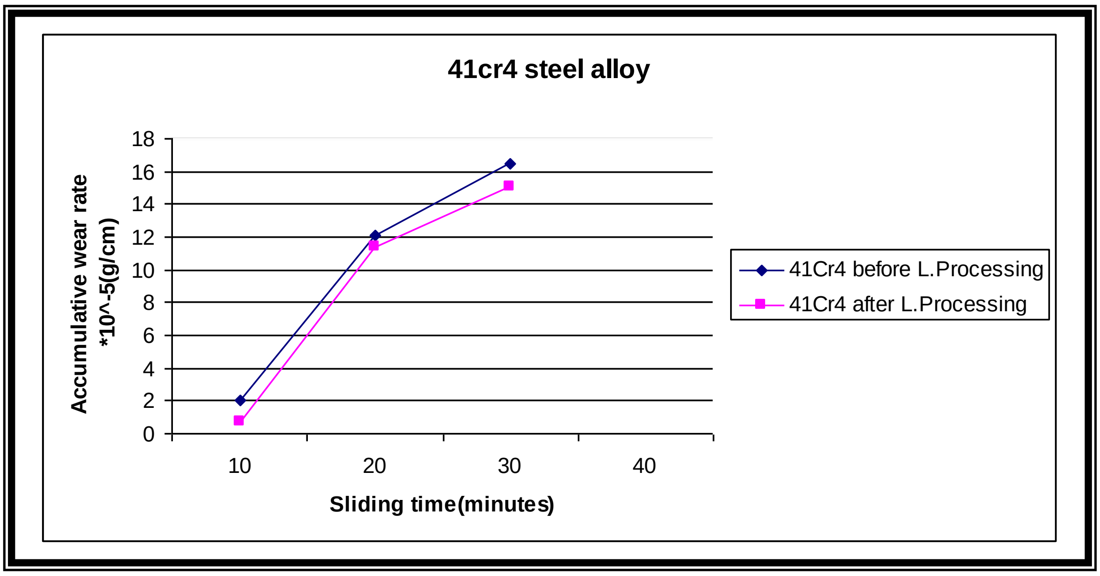

Fig.6. The sliding time versus accumulative wear rate Applied normal load=30N, sliding speed=1.49m/s.

Fig.7. Micrograph of 41Cr4 steel alloy specimen microstructure subjected to laser surface treatment.

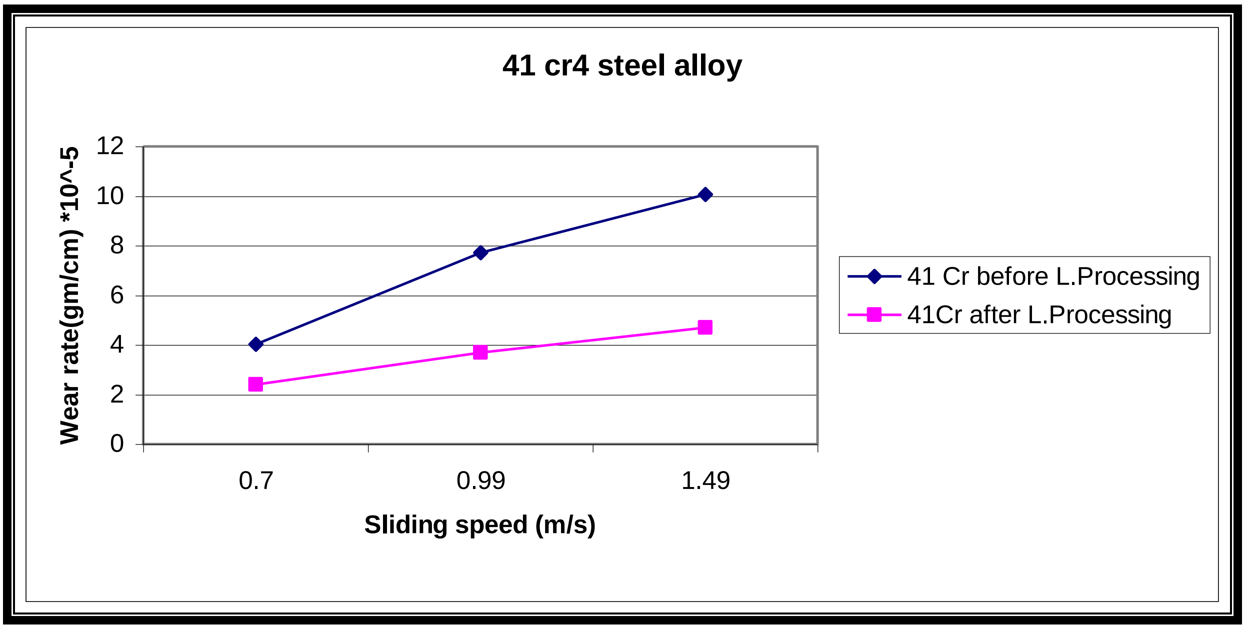

Fig.8. Shows the wear rate versus sliding speedsliding time=10 min ,applied normal load=30N,disc hardness=385HV .

تحسين مقاومة البلى لسبيكة الفولاذ نوع 41Cr4 بواسطة التصليد السطحي بالليزر

ضياء احمد صلال
مدرس مساعد
كلية الهندسة – جامعة ديالى

الخلاصة

يتضمن هذا البحث عرض موجز عن عملية تحسين خصائص السطح بواسطة الليزر وان الهدف الرئيسي لهذه الدراسة هي تحسين مقاومة البلى. تم استخدام الليزر نوع (Nd:glass) في معاملة سبيكة الفولاذ نوع 41Cr4 وان متغيرات المعاملة الحرارية الليزرية المستخدمة في هذه الدراسة تضمنت كثافة قدرة الليزر (3*10^5 – 9.5*10^5) واط/سم٢. كثافة القدرة والمسافة مابين الليزر والعينة تم اختيارها بحيث تعطي المعاملة الحرارية المنجزة درجة حرارة كافية للانصهار واللازمة لحدوث التحول الطوري بالشكل الذي يقلل معدلات البلى بشكل كبير. كذلك تم استخدام عينات من سبيكة الفولاذ نوع 41Cr4 وتم فحصها باستخدام المجهر الضوئي, حيث اجريت عليها اختبارات الصلادة المجهرية الدقيقة لغرض تحديد الاطوار المعدنية للسبيكة بعد المعاملة الحرارية وتم استخدام ماكنة فحص البلى ذات ترتيبة المسمار على القرص لغرض تقييم مقاومة البلى ووجد من خلال هذه الدراسة ان البنية المجهرية تعتمد وبشكل كبير على كثافة قدرة الليزر حيث كانت لها تاثيرات واضحة على البنية المجهرية والخصواص الترايبولوجية للسبيكة وبشكل خاص مقاومة البلى.

*الكلمات الدالة: **التصليد السطحي بالليزر, مقاومة البلى, سبيكة الفلولاذ*** 41 Cr٤