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The Influence of Laser Surface Hardening on Dry Sliding Wear Behaviour of Steel Ck45

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ABSTRACT

This paper describes the effect of laser surface treatment on wearesistance of steel Ck45 .A Pulse Nd:YAG laser with wave length 1064 nm and pulse duration 100 ns was used by applying one pulse ,two pulses with different laser energies (500, 750, 1000 mJ). Pin-on-disc technique was done to define wear rate with different forces (5, 10, 15, 20, 25 N) and different sliding speeds (1.319 ,2.199, 3.078, 3.958 m/s) for constant time (20 min) and constant rotating disc 720 r.p.m with 45HRC .Also defined microhardness which decreases far from the hardened surface , depth of hardening was evaluated through optical microscopy . The results of this work demonstrated that improvement in wear resistance for 1000 mJ laser energy more than the other energies for one pulse and two pulses ,while wear resistance for two pulses more than one pulse for all the energies . X-ray analysis results show that precipitation of another carbides like iron carbides ,chromium carbides ,manganese carbides after the treatment by laser.

تاثير التصليد السطحي بالليزر على سلوك البلى الانزلاقي الجاف للفولاذ Ck45

الخلاصة

يوضح البحث تاثير المعاملة الحرارية السطحية بالليزر على مقاومة البلى للفولاذ Ck45. تـم استخدام ليزر نيد يميوم – ياك النبضي ذو الطول الموجي 1064 نانوميتر وزمن نبضه 100 نـانو ثانيه بتسليط (نبضة واحدة, نبضتين) وبطاقات ليزرية مختلفة (500, 750, 1000 ملي جـول). استخدمت تقنية المسمار -على -القرص لتحديد معدل البلى عند قوى مختلفـة (5, 10, 15, 20, 25 نيوتن) وسرع انزلاق مختلفة (1.319,2.199,3.078, 3.958 متر/ثا) ولفتـرة زمنيـة 20 دقيقة وقرص دوارثابت بسرعة 720 دورة/ دقيقة وصلادة قرص 45 بمقياس روكويل . تم تحديـد الصلادة الدقيقة باستخدام المجهر الضوئي , والتي تقل بالابتعاد عن سطح العينة المصلد بالليزر. اظهرت نتائج هذا البحث تحسن في مقاومة البلى عند طاقة ليزر1000ملي جول اكبر مما هو عليـه للطاقات الاخرى ولنبضة واحدة او نبضتين ,بينما مقاومة البلى عند نبضتين اكبر ممـا هـو عليـه لنبضة واحدة . اما نتائج حيود الاشعة السينية فقد اظهرت حدوث ترسيب كاربيدات اخـرى مثـل كاربيدات الحديد ,كاربيدات الكروم ,كاربيدات المنغنيز بعد المعاملة بالليزر .

INTRODUCTION

Lasers are one of the most influential inventions of the twentieth century because of their extraordinary characteristics of high brightness , high directionality ,high coherence and unique spatial and temporal

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distributions[1,2]. There has been increasing interest in the use of laser and manufacturing applications. The majority of these applications involve surface treatments , in which a surface of metal is modified inorder to improve certain properties [3]. Laser surface engineering techniques involving the subsequent rapid solidification of the molten surface has been used to improve the wear , corrosion ,and erosion resistance of ferrous and non ferrous alloys [4-6].Main advantages of laser surface hardening are ;process selectivity (heating very precise locations); rapid heating of a surface enabling thin layer treatment , and reducing of the thermally affected zones [7,8]. In recent years laser surface hardening using pulse laser sources has become an increasingly established technology in engineering industry and has opened up wider possibilities for application of selective surface hardening [9].

Many previous studies were done to indicate the dry sliding wear behaviour after laser surface hardening of ferrous alloys which exhibited enhancement of wear resistance than conventionally hardening of the specimens. S.P. Gadag and M.N Srinivasan [10], were studied a critical assessment of laser surface treatment of structure sensitive hypereutectic ductile iron by $CWCO_2$ and pulsed Nd:YAG laser .Rakesh Kaul et al [11] ,were made a comparison between the characterization of dry sliding wear resistance of laser surface hardened En 8 steel specimens with those of conventionally hardened .whilst Yu Sirong et al [12],were investigated the microstructural and tribological behaviour of the developed iron- based powder coatings containing nano – Al_2O_3 particles with laser surface hardening by using CO_2 laser. The purpose of this study is to reveal the influence of laser surface treatment on wear resistance of steel Ck45.

EXPERIMENTAL PROCEDURES

Material and microstructure

The material used in this investigation is Ck45 steel .Its chemical composition is shown in table 1 .This type of steel was in the hot-rolled condition .

Optical microscopic examination indicated that the steel contains well-distributed mixture of ferrite and pearlite as shown in figure (1) .Table 2 shows mechanical properties of Ck45 steel [13].

Laser Surface Treatment

Laser surface heat treatment was carried out by using pulse Nd:YAG wave length, while the frequency of laser system is laser with (1064 nm) wave length (1-6)Hz .In this investigation we applied three different laser energies 500, 750, 1000 mJ .These energies were applied by one pulse and two pulses respectively .The same conditions were done for the specimens of microhardness test and the specimens of X-ray examination .

Wear test

Wear test was performed by using pin-on-disc machine to compute the rate of wear of the metal layer before and after laser treatment . This instrument consists of an electrical motor rotating at 720 r.p.m and the rotating disc with 45 HRC. Wear behaviour classified into groupes as follows:

1- Changing the vertical load (5,10,15,20,25 N) with constant time (20min) and constant sliding speed (2.199 m/s).

2- Changing the sliding velocity (1.319, 2.199, 3.078, 3.958 m/s) with constant time (20 min) and constant vertical load (20N).

MEASUREMENT OF WEAR RATE

Wear rate was measured by using weighing method ,each specimen was weighed before and after treatment by laser for each group by digital balance with sensitive 0.0001 gm type (Mettelr AE 160). Wear rate calculated by the following equation:

$$\text{Wear rate} = r\,W/S_D \;\; (gm/cm) \quad ....(1)$$

$$r\,W = W_1 - W_2 \quad .....(2)$$

Where

r W:Changing in weight (gm) W_1,W_2 :weight of specimen before and after test (gm)

$$S_D = 2\pi.r.n.t \quad .....(3)$$

Where

- S_D: sliding distance (cm). r : radius from the centre of the specimen to the centre of the disc (cm). n : no. of rotating disc (r.p.m).
- t: time of test (min).

Microhardness Test

Assessment of surface microhardness was done by using (Hensddt Wetzlar No. 23298), with applied load 500gm . Microhardness calculated according to the following formula :

$$HV = 1.8544\,F/d^2_{(ave)}\,(kgf/mm^2) \quad .... (4)$$

Where;

F: applied load (kgf) .

d: the main diagonal of indentation (mm).

Depth of hardening for the specimens treated by three level of energies with one pulse and two pulses was measured by using hardness method . Figure (2) shows the relation between the hardening number and the depth of hardening for the specimens treated by laser . From this figure its clear that the hardening number decreases with increasing in depth of hardening , that is due to a large gradient of temperature which vary from the melting point to critical point across a layer [14] , thus microhardness for 1000 mJ with two pulses more than for one pulse ,also more than the another energies.

X –ray Diffraction analysis

X-ray diffractometry apparatus was used to qualify the phases of the as-recieved alloy .Also the phases of the treated specimens by laser with one pulse and two pulses with three level of energies were determined . The target of the X-ray tube was copper with wave length CuK_α equal to 0.15405 nm as the following data for the X-ray unit used:

Target: Cu Wave: 1.54060 (A^o) Voltage :40 (kv) Current :30(mA)

Scan range :10-80 (deg) Scan speed :8^o /min

Preset time:0.15 (sec) By using Bragg Law , the value can be determined as follows :

$$n\lambda = 2d \sin \theta \qquad \text{…..(5)}$$

Where n : order of reflection (1,2,3,-----) . λ : wave length of X-ray = 0.15405 nm. d : interplanar distance in A^o, θ: angle of incidence or reflection of X-ray beam. From interplanar distance ,the intensity of the X-ray present ,and by the helyos JCPDS standard files ,the phases can be defined.

RESULTS AND DISCUSSION

A roughness instrument type Talysurf-4 product by English Taylor – Hobson Company **,**was used to measure the average roughness (Ra) for the samples after the treatment by laser. Table (3) shows the reading**s** of the average of surface roughness for the alloy treated by the laser with three level of energies for one pulse and two pulses .

From roughness test its show that when the energy increases the roughness of the surface increases too and for two pulses more than one pulse ,this is attributed to the heating effect of laser pulse on the surface of the metal . Raising in temperature of surface leads to generate a surface tension associated with small melting giving the surface a non-uniform layer having a wave shape [15, 16].

Effect of the applied loads and sliding speeds on wear behaviour

Friction and wear are not intrinsic material properties but are characteristics the engineering system . Any change in load , speed may cause catastrophic changes in the wear rate of one or both of the surfaces in contact [17]. The effect of the loads on the wear rate is shown in figure (3) with one pulse and two pulses for three level of energies. Increasing in load lead to increase in wear rate for all specimens into three distinct regions , mild ,transition and severe wear .As a result , for all loads ,the treatment with laser lead to decreasing in wear rate for one pulse , while the two pulses have wear resistance more than one pulse .It is attributed that very high hardness of the samples makes laser surface treated layer very difficult to be plastically deformed with little adhesive features .Therefore , the laser surface treated sample with 1000 mJ presents a lower wear rate than those of the 500 ,750 mJ .The fluctuation of wear rate caused by material transfer and oxidation occurred in the wear process. These oxide films could act as solid lubricant and avoid direct metallic contact with the coupling counterpart with the advantage of diminishing the wear rate. The friction heat produced during the sliding friction test resulted in the formation of oxide films on the contact surfaces. Furthermore ,higher friction contact temperature may cause larger areas of oxide films formed on the wear surfaces[18]. Wear weight loss and wear track depth of the laser treated samples when compared with the sample as-recieved, the laser treated samples showed a lower wear rate at all loads , because the surface strength and hardness of the samples are significantly enhanced by the laser, also the applied load during the wear test can result in phase transformation and compressive residual stresses[19,20].

The effect of sliding velocities on the wear rate is shown in figure (4) with one pulse and two pulses for three level of powers . we show that the wear rate decreases with increasing sliding speed for all the specimens. This behaviour can be explained by taken the flash temperature into account. The flash temperature increases with increasing sliding speed up to melting point at asperities [18],the heat dissipation at higher speed is lower than at lower speed.This causes softening of the asperities and reduces the forces required to shear the welded points , so the wear rate will be lower[19].

Metallographic analysis

The sample surface was heated by the pulse Nd:YAG laser and subsequent rapid cooling due to self-quenching led to the formation of a hardened surface layer with carbides in a matrix.

The morphology of the surface was studied in order to characterize the changes which take place during the wear before and after laser treatment . This part of the study was conducted by optical microscopy .For the samples treated by laser and before wear test ,It was observed that the area of contact between the laser beam and the metal surface is divided into two major zones ,the irradiated zone (IZ)and the radiation affected zone (RAZ).The typical appearance of these zones is shown in fig (5). The micrograph in this figure also shows concentrated rings (ripples) within the irradiated zone , when the laser energy of the pulse was 1000mJ, the ripples were observed only in RAZ ,as shown in fig (5).Since all this takes place during an extremely short period ,there is no time for the melt to flatten and the whole region freezes with the the ripples [21].

While micrographs of wear tests demonstrated that the laser –hardened surface exhibited good wear resistance .The grooves of the laser –hardened surfaces are relatively shallow due to the higher hardness of the surface and the severity of microploughing is well pronounced on the worn surfaces with 1000 mJ and also we show cracks for some specimens ,perhaps they creat due to residual stresses. Figure (6) shows the topography of the wear surfaces for three level energies.

X-ray diffraction analysis

The results of X-ray diffraction reveal that the the treatment by laser lead to precipitate many carbides (Iron carbides ,chromium carbides, manganease carbides).Table (4) show the phases of the specimens before and after laser surface treatment. Laser surface treatment with one pulse and two pulses lead to precipitate many carbides which increases the microhardness and in turn lead to ncrement of wear resistance of the specimens with two pulses more than one pulse. Figure (7) shows the result of X-ray of the specimens before and after treated with laser (one pulse , two pulses) for the energy 1000 mJ .

CONCLUSIONS

1- Increasing of wear resistance with increasing in energy (for two pulses with 1000 mJ) more than another.
2-Laser treatment lead to form two major zones ,the irradiated zone (IZ) and the radiation affected zone (RAZ).
3-X-ray diffraction analysis show that precipitation of many carbides when compare with the specimen as- received.

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Table (1): The chemical composition of the carbon steel CK45

Element	%C	%Mn	%Si	%Cr	%Ni	%Mo	%S	P%	%Fe
Actual value	0.46	0.65	0.14	0.14	0.14	0.01	0-0.035	0-0.035	remain
Standard value	0.42-0.50	0.5-0.8	0.17-0.37	-----	-------	-----	0.035	0.035	remain

Table (2): The mechanical properties of the Hot –rolled carbon steel CK45[13]

Yield Strength σ_y (Mpa)	Tensile Strength (Mpa)	Poisson's Ratio	Elastic Modulus (Gpa)	Elongation (%)	Hardness (HV) Kg/mm^2
300-450	570	0.27-0.30	190-210	14-30%	180-220

Table (3): Values of the average roughness for three level energies for one pulse and two pulses

Laser energy(mJ)	Average of surface roughness Ra (μ_m)for one pulse	Average of surface roughness Ra (μ_m)for two pulses
500	0.26 0.31 0.38 0.45	0.34 0.40 0.49 0.56
750	0.33 0.41 0.50 0.59	0.41 0.48 0.57 0.66
1000	0.38 0.49 0.58 0.67	0.47 0.56 0.64 0.72

Note: Average roughness for the specimen before laser treatment (0.211 μ_m)

Table (4): X-ray analysis of the specimens

specimens	phases
as-recieved	Fe, Fe_3c, Mn_5C_2, Cr_3C_2
Laser treatment with 1 pulse (1000mJ)	Fe, Fe_5C_2, Mn_7C_3, Cr_7C_3
Laser treatment with 2 pulses (1000mJ)	Fe,Fe_5C_2, Fe_3c, MnC_8,Cr_3C_2

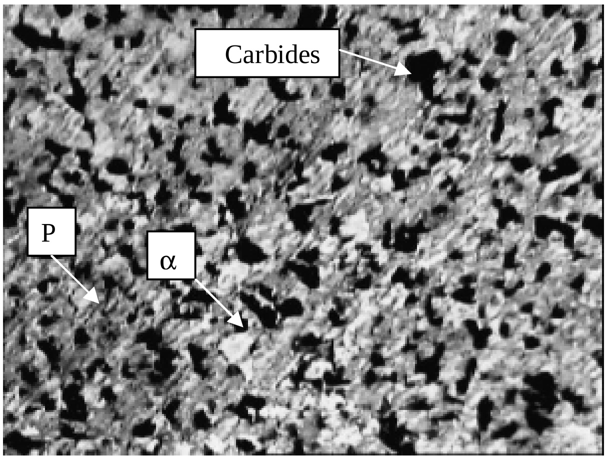
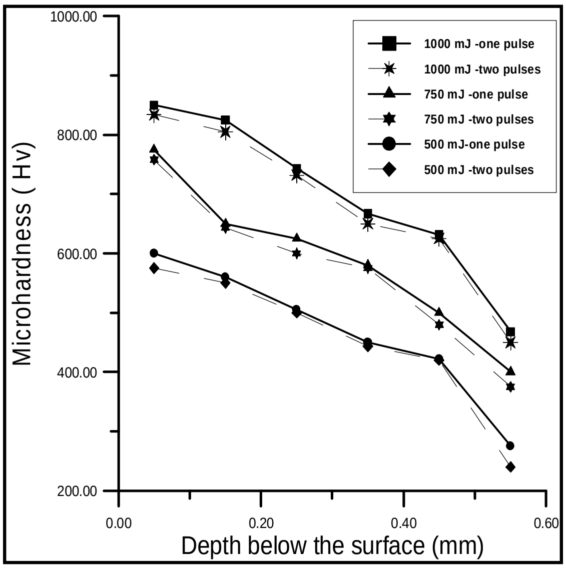


Figure (1): Specimen as-recived



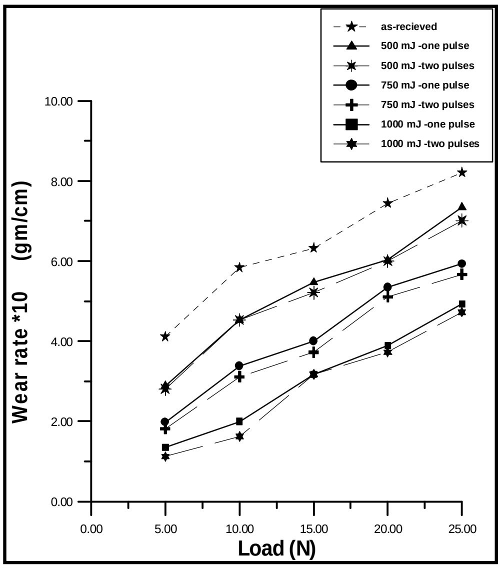


Figure (2): Microhardness distribution curves along hardening depth

Figure (3): Relationship between applied load and wear rate for sliding speed 2.199 m/s

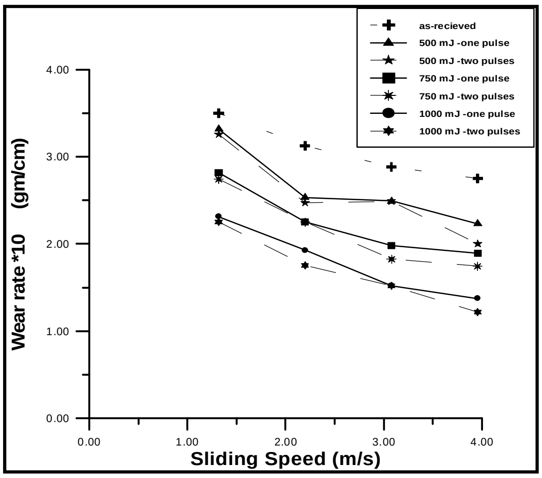
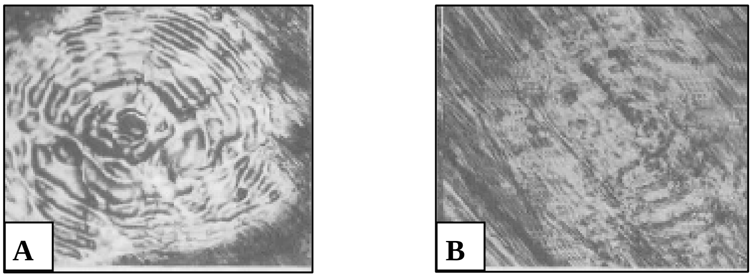


Figure (4) :Relationship between sliding speed and wear rate for loading 20N



1 pulse (1000 mJ) (250x)

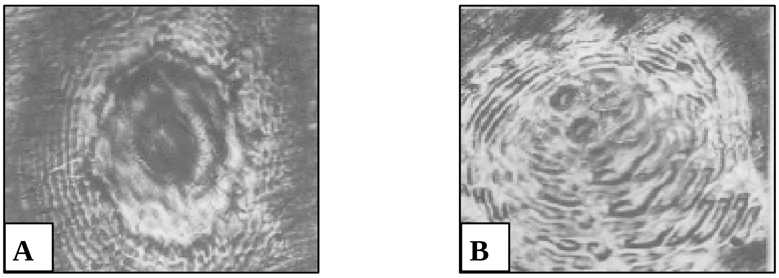
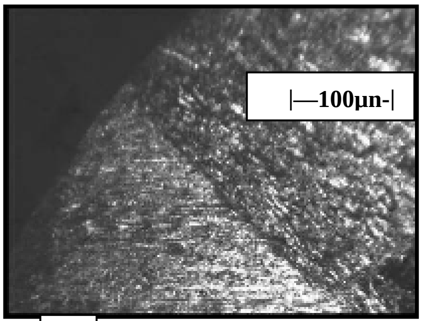
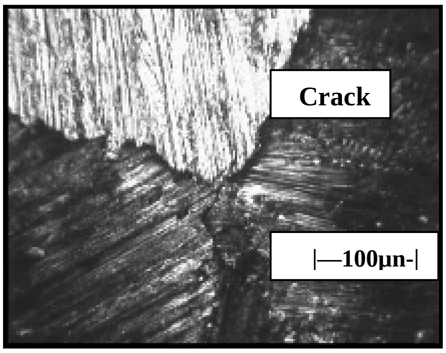


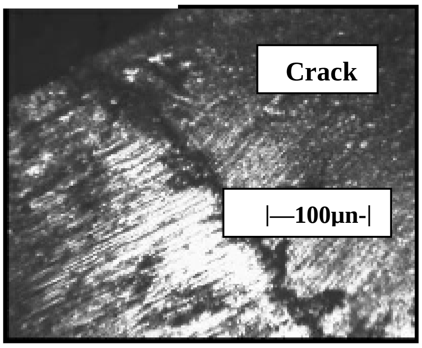
Figure (5): Laser treatment induced ripples: A- in the radiation affected zone (RAZ)and B - in the irradiation zone (IZ)



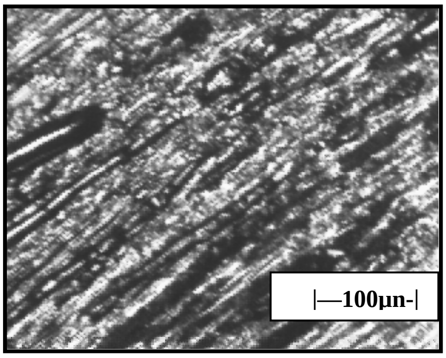
a **as-recieved (250 x)**



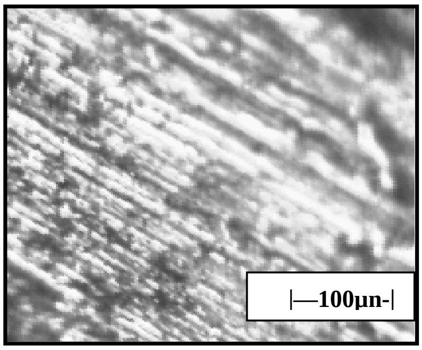
b1 **1 pulse(500 mJ) (250x)**



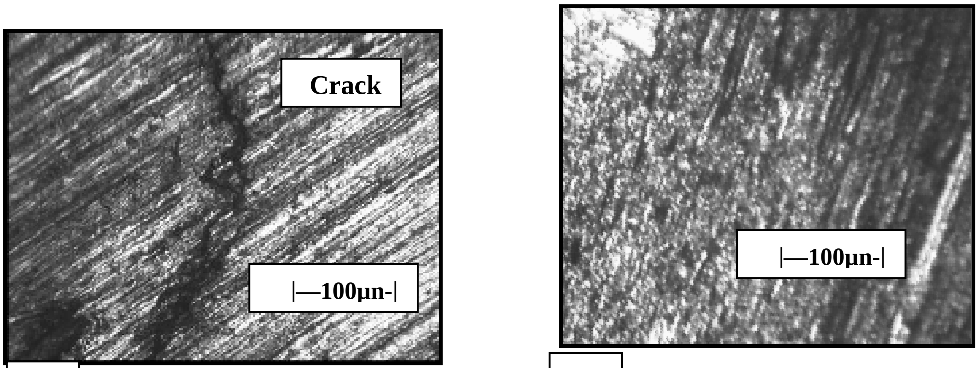
c1 **1 pulse(750 mJ) (250x)**



d1 **1 pulse (1000 mJ) (250x)**



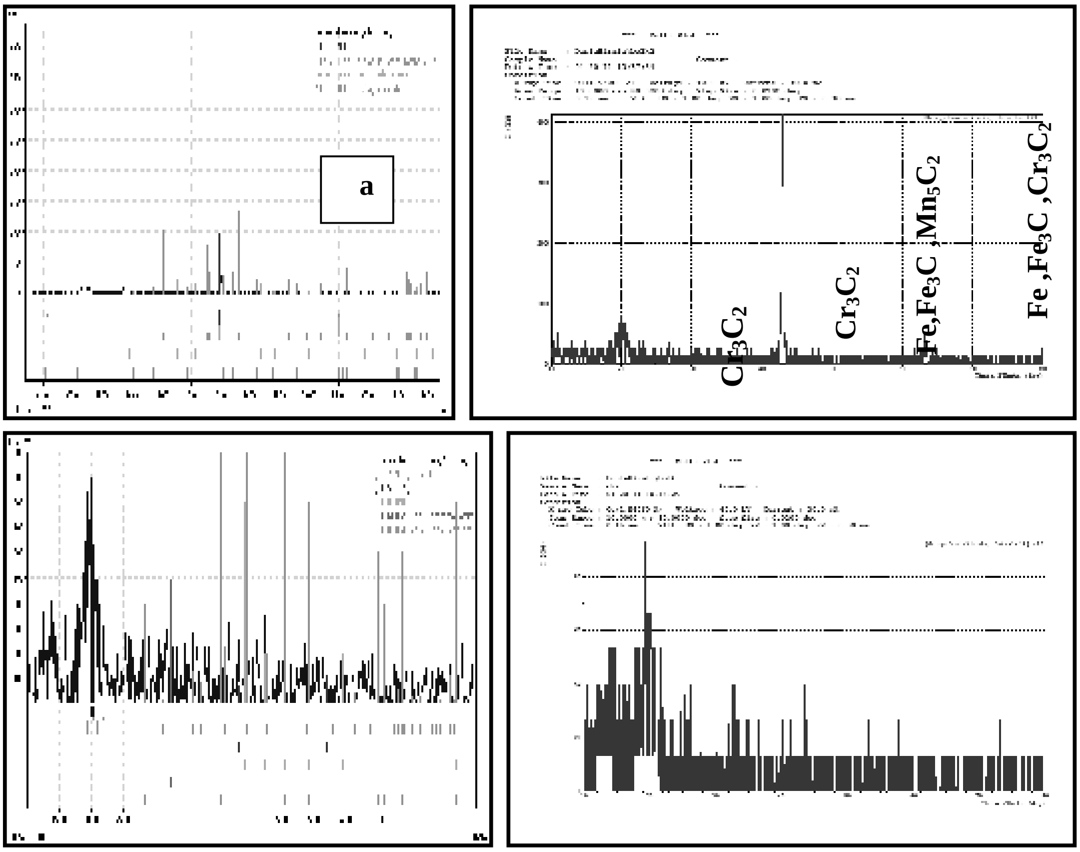
b2 **2 pulses(500 mJ) (250x)**



c2 2 pulses(750 mJ) (250x)

d2 2 pulses (1000 mJ) (250x)

Figure (6): Micrographes of wear surfaces for three levels of energies with one pulse and two pulses



X-ray analysis of the specimen before laser treatment by laser with one pulse (1000mJ)

Figure (7): X-ray analysis of the specimens before and after laser treatment