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# Effect of Laser Surface Treatment on Wear Resistance of $100Cr_6$ Steel

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## Abstract

The effect of laser surface heat treatment on wear resistance of $100Cr_6$ steel was investigated. In this work, $100Cr_6$ steel which is widely used in many industrial of automobiles hardened by using Nd: glass laser ($\lambda$=1.060µm, $\tau$=300µs). Three different laser energies have been used to perform hardening (0.3, 0.58 and 0.93 Joule). A pin-on-disc technique has been used to evaluate wear rate of the specimens as-received and specimens treated by Nd: glass laser at different applied loads and different sliding speeds with 420 r.p.m and 45 HRC of rotating disc. The results show that the wear rate increases with increasing applied load and decreases with increasing sliding speed, wear rate for laser energy 0.93 J less than another energies 0.3 and 0.5 J. Also the microhardness decreases with increasing in depth of hardening, and the microhardness for laser energy 0.93 J more than another energies for the same depth.

**Keywords:** wear resistance, glass laser, microhardness.

# تأثير المعاملة الحرارية السطحية بالليزر على مقاومة البلى للفولاذ $100Cr_6$

## الخلاصة

تمت دراسة تأثير المعاملة الحرارية السطحية بالليزر على مقاومة البلى للفولاذ $100Cr_6$. في هذا البحث تم استخدام الفولاذ $100Cr_6$ والذي يستخدم بشكل واسع في العديد من وسائط النقل والذي تم تصليده باستخدام ليزر نوع نيديوم- زجاج (ذو طول موجي 1.060 مايكرون وطول نبضة 300 مايكرو ثانية). في هذه الدراسة تم استخدام ثلاث طاقات ليزرية للحصول على التصليد (0.3, 0.58, 0.93) جول. استخدمت تقنية المسار على القرص لتحديد معدل البلى للعينات قبل وبعد المعاملة بواسطة الليزر نيديميوم-زجاج عند تسليط أحمال مختلفة وسرع انزلاق مختلفة وصلادة القرص الدوار (45HRC). وقد أظهرت النتائج إن معدل البلى يزداد مع زيادة الحمل المسلط ويقل مع زيادة سرعة الانزلاق، وان معدل البلى عند طاقة ليزر (0.93J) اقل مما هو عليه للطاقات الأخرى (0.3 and 0.58 J). وكذلك الصلادة المايكروية تقل مع زيادة عمق التصليد، وان الصلادة الدقيقة لطاقة الليزر (0.93 J) اكثر من بقية الطاقات ولنفس عمق التصليد.

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## Introduction

In recent years there has been interest in the use of laser technology for the realizations of wear, corrosion and oxidation resistant surfaces on engineering alloys based on steel [1-3]. The increasing demand of laser in material processing can be attributed to several unique advantages of laser namely, high productivity, automation worthiness, non contact processing, elimination of finishing operation, reduced processing coast, improved product quality, greater material utilization and minimum heat affected zone [4,5]. Laser processing technology is an advanced and highly efficient manufacturing method. It has been applied in airplane industry, defense industry, automobile industry, mechanical industry and material industry, etc. Due to extremely high laser output power density (more than $10^4$ W/cm$^2$) extremely quick heating speed and self-cooling speed ($10^3$-$10^6$ $^o$C/s) on the material surface, the process of laser material interaction is regarded as a very complex thermo-physical processes under the interaction between temperature, phase transformation and stress-strain [6-10].Victor G. was one of the first researchers for laser heat treatment, he studied the microstructure of metal after laser treatment [11]. Laser transformation hardening of steel surfaces is a process that can offer greater precision and less distortion than conventional surface hardening techniques. Arata, Li Ashby Easterling and others [12] have analyzed the effects of processing and materials parameters on the heat transfer and phase transformations aspects of laser hardening of plain carbon steel. In 1977 [13], H. E. cline and T. R. Anthony have described a thermal analysis for laser heating and melting materials was derived for a Gaussian source moving at a constant velocity. Calculations were presented for 304-stainless steel which are in agreement with experiment. Zeyad Aeyad Taha [14], has investigated the effect of pulsed Nd:glass laser on hardening depth, roughness and wear rates for three alloy steel (20 CH, 40 CH and 65G) and one aluminum silicon alloy (Al-25).

Many researchers have been published about laser surface treatment of low carbon steel. Little researchers have been carried out to reveal the influence of laser treatment of medium, high carbon steel and alloying steel. Hence the objective of the present paper is to study the effect of laser surface treatment on the wear resistance of $100Cr_6$ steel.

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## Experimental Procedure

The processed material ($100Cr_6$ steel alloy) was treated by pulsed Nd:glass laser ($\lambda$=1.060 $\mu$m, $\tau$=300$\mu$s ). Three different laser energies have been used to perform hardening (0.3, 0.58 and 0.93 Joule). Figure (1), shows the setup of Nd:glass laser used.

## Mechanical Properties

Table (1) illustrates the mechanical properties of the alloy used as-received.

## Chemical Composition

Table (2) shows the chemical composition of $100Cr_6$ in weight percentage

## Wear Test

Dry sliding wear apparatus type pin-on-disc was used to evaluate the wear behavior of the specimens before and after treatment by laser with 420 r.p.m and 45 HRC of rotating disc. Wear behavior classified into two groups as follows:

1. Changing the vertical load (5,10,15,20,25N) with constant time (30min) and constant sliding distance (5 cm).
2. Changing the sliding velocity (1.319, 2.199,3.078,3.958 m/s) with constant time (15 min) and constant vertical load (20N).

Figure (2) shows the apparatus of wear that used in this work.

## Measurement of wear Rate

Wear rate was measured by using the weighing method, each specimen was weighed before and after treatment by laser for each group by digital sensitive 0.0001 gm type (Mettler AE160). Wear rate calculated by the following equation:

wear rate = $\Delta W/S_D$ gm/cm. …..(1)

$\Delta W = W1-W2$ …...(2)

Where $\Delta W$ : changing in weight (gm)

W1, W2 : weight of specimen before and after the test (gm).

$S_D = 2\pi.r.n.t$ …....(3)

Where $S_D$ : sliding distance (cm).

r: radius from the center of the specimen to the center of the disc (cm).

n: No. of rotating disc (r.p.m).

t: time of sliding (min).

## Microhardness Test

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

$Hv=1.8544\ F/d^2_{(ave)}$ (kg f / $mm^2$) …..(4)

Where F: applied load (kg f)

d: the main diagonal of indentation (mm).

## Hardening Depth Measurement

Hardening depth is defined as a perpendicular distance from the surface to point at which the change in hardness,

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chemical composition or microstructure of the case and core cannot be distinguished. Hardness method used in this work to measure the depth of hardening, it is very accurate method since sharp change in hardness across region case and core.

**Microstructure Examination**

A computerized optical microscopy was used to examine the microstructure of the samples of wear test. Also for samples treated by laser with three level energies as mentioned previously. Photomicrographs were taken for samples which were examined.

**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 before and after treated by laser. Table (3) shows readings of the average of surface roughness for the alloy with three level of energies (0.3, 0.58 and 0.93J) due to the power intensity. From roughness test its show that when energy or power density increase the roughness of the surface increasing too and that is attributed to the heating effect of laser beam 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].
- Depth of hardening for the specimens treated by three level of energies was measured by using hardness method. Figure (3) shows the relation between the hardening number and the depth of hardening for the specimens with the three level of energies (0.3, 0.58 and 0.93J). From the figure its clear that the hardening number decreases with increasing in depth of hardening, that is due to a large gradient of temperatures which vary from the melting point to critical point across a layer from tens to hundreds of micrometers wide [17], thus micro hardness for 0.93J more than another energies leading to refining in structure which in turn causes increasing in micro hardness.
- Of the three principal causes of wear, abrasion, adhesion and corrosion, the one of most concern for metal working tools or for moving part applications is adhesion.

Adhesive wear manifests itself as galling, scoring, seizing or scuffing when clean metals come into contact with each other [18]. The effect of the loads on the wear rate is shown in Figure (4). The specimens were in a two conditions, as-received and laser surface treatment with

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three level of energies. The wear rate increases with increasing applied normal load. The curves of all the specimens shows three distinct regions, mild, transition and severe wear. The mild wear is explained in terms of oxide layer formation which is the true contact area of the matting surfaces, thus leading to a low wear at load range of (5-10N)[19]. The transition wear occurs within the load range of (10-20N) where a change from elastic to plastic deformation takes place and causes the fracture of the brittle oxide layer, leading the virgin metals to come into contact which increase the wear rate. The severe wear starts after 20N load. The increase of wear rate in this region is due to work hardening. These results in general are in agreement with the published data[20,21]. The curves of the specimens treated by laser shows low wear rates at all loads used in this study because of the best wear resistance was obtained in specimen hardened by (0.93J), wherever this observation is explained in refining of the microstructure. While the effect of sliding speed on wear rate is shown in figure (5).The wear rate decreases with increasing sliding speed. 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 [22], the heat dissipation at higher speed is lower than at lower speed [19]. This causes softening of the asperities and reduces the forces required to shear the welded points, so the wear rate will be lower.

Laser surface treatment of the specimens showed wear rates lower than as-received specimen because of the fine microstructure obtained in laser hardened case. Specimen shotted by laser with (0.93J) gives higher surface hardness, then more wear resistance than another energies (0.3, 0.58J).

Figure (7) shows the topography of specimens of wear test treated by laser energy 0.93J after loading by different loads. Increasing the load lead to make the grooves of wear more soft and fine because of increasing in microhardness.

## Conclusions

The experimental results indicate clearly an influence of the laser modification conditions of $100Cr_6$ steel alloy surface and wear resistance, which will be further used to perfect the technology to the level industrial feasibility. The best result for hardening obtained with laser energy (0.93J), that is due to the large gradient in heat due to more refining in structure and more

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increment in microhardness, also best result for wear resistance.Roughness for the specimen treated by laser with energy (0.93J) more than for the specimens treated by another level of energies (0.3 and 0,58J), using high value of power density with short period will lead to have ripples on the treated area and that will make the surface more rough.

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Table (1) mechanical properties of 100Cr6

| $S_y$ (MPa) | $S_u$ (MPa) | Elong.% | Brinell Hardness | G (Gpa) | E (Gpa) | µ | K |
|---|---|---|---|---|---|---|---|
| 310 | 840 | 7.2 | 211 | 88.46 | 230 | 0.3 | 287.5 |

The above data is the average of three readings

Table (2) Chemical Composition of the material used

| C | Mn | Si | P | S | Cr | Ni | Mo | Cu | Fe% |
|---|---|---|---|---|---|---|---|---|---|
| 1.05 | 0.40 | 0.23 | 0.016 | 0.009 | 1.77 | 0.07 | 0.03 | 0.17 | 96.122 |

The above analyses was done by Thermo ARL 3460 OE SPECTROMETER.

Table (3) Values of the average roughness for three level energies.

| Laser energy (Joule) | Average of surface roughness Ra ($\mu_m$) | Power density $(w/cm^2)*10^5$ |
|---|---|---|
| 0.3 | 0.3 | 1.3 |
| | 0.37 | 2.0 |
| | 0.42 | 3.0 |
| | 0.58 | 3.6 |
| 0.58 | 0.34 | 2.5 |
| | 0.42 | 3.8 |
| | 0.49 | 5.7 |
| | 0.60 | 6.6 |
| 0.93 | 0.38 | 4.0 |
| | 0.41 | 6.3 |
| | 0.45 | 4.1 |
| | 0.62 | 9.8 |

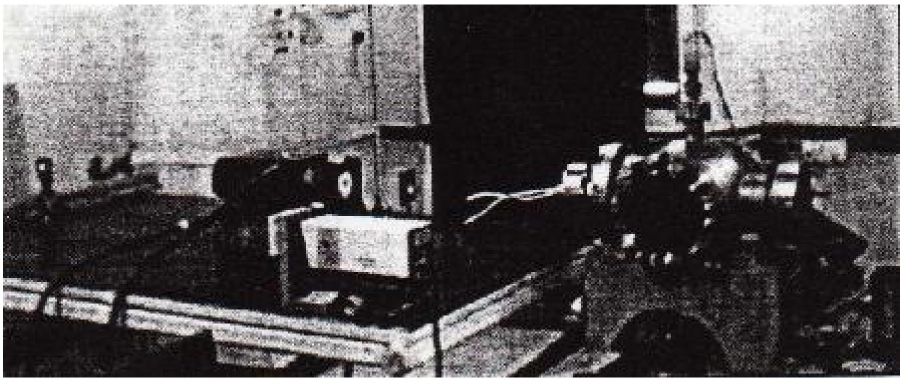

Figure (1) The setup of Nd: glass laser.

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**Figure (2) Setup of wear.**

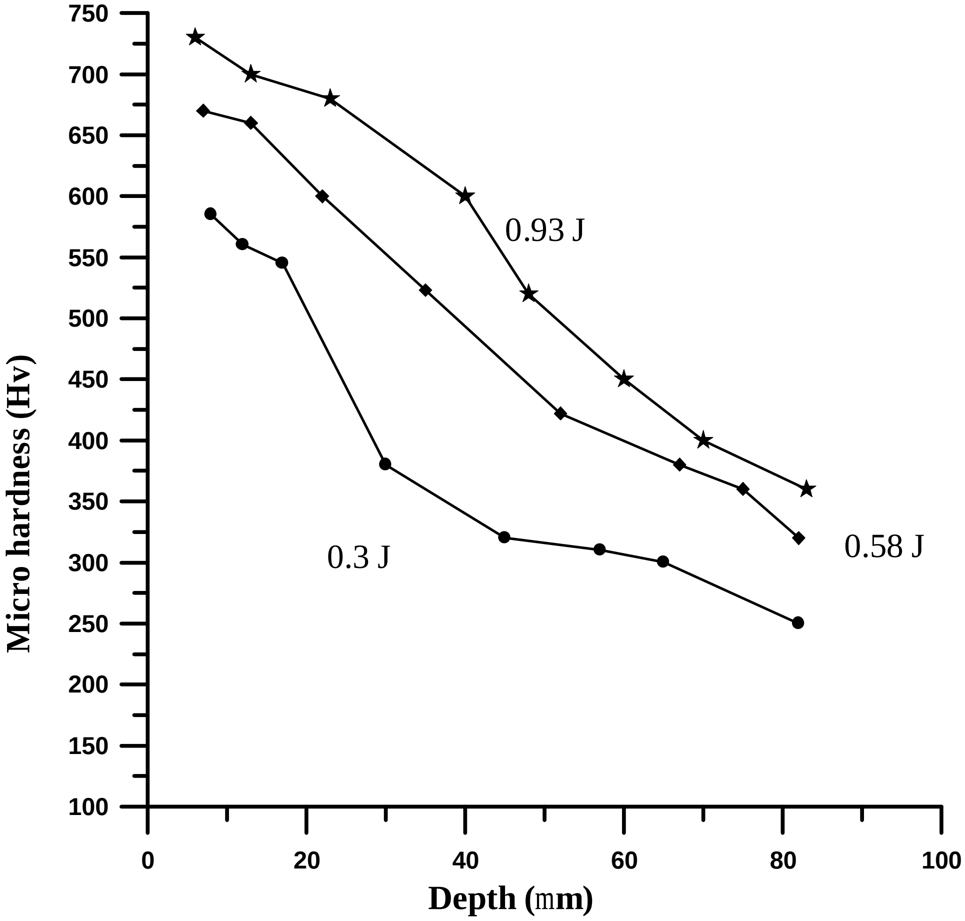

**Figure (3) Relationship between depth of Hardening and Micro hardness.**

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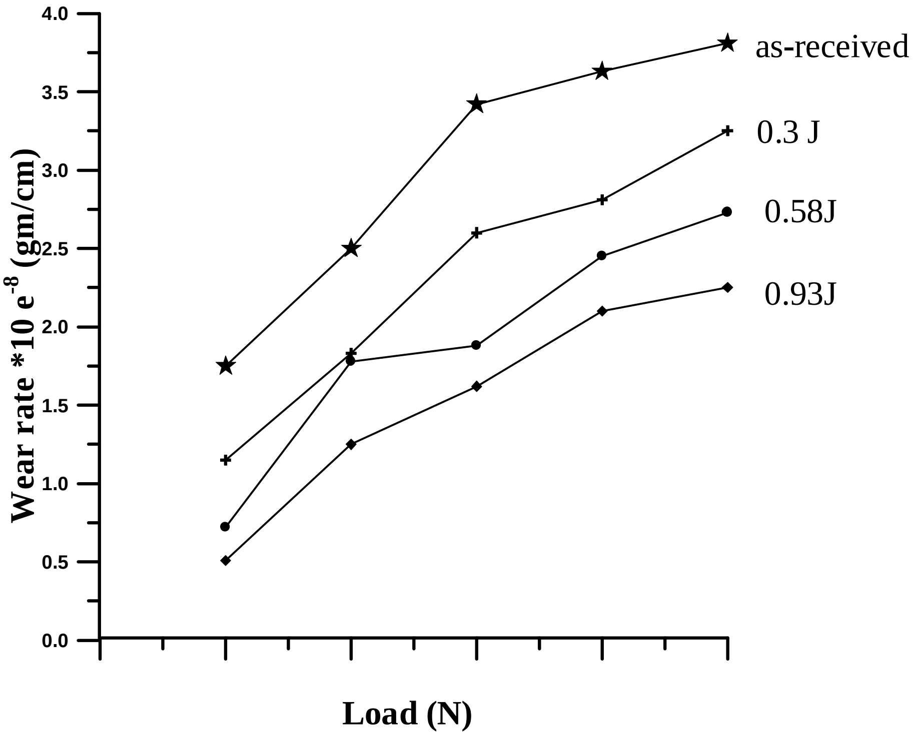

**Figure (4) Relationship between applied load and wear rate for sliding speed 2.199 m/s.**

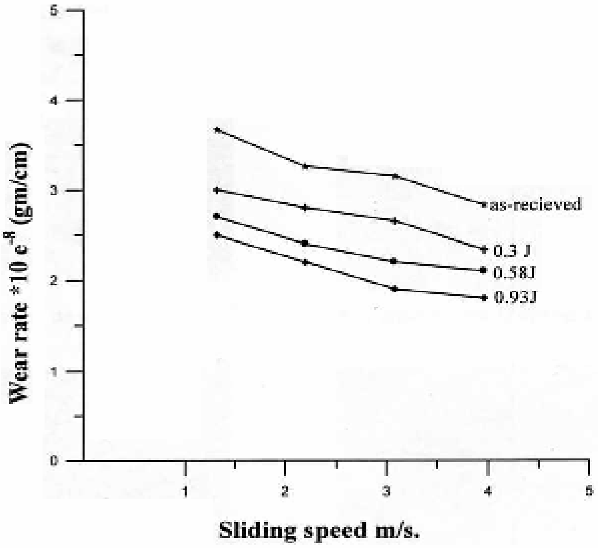

**Figure (5): Relationship between sliding speed and wear rate for loading 20N.**

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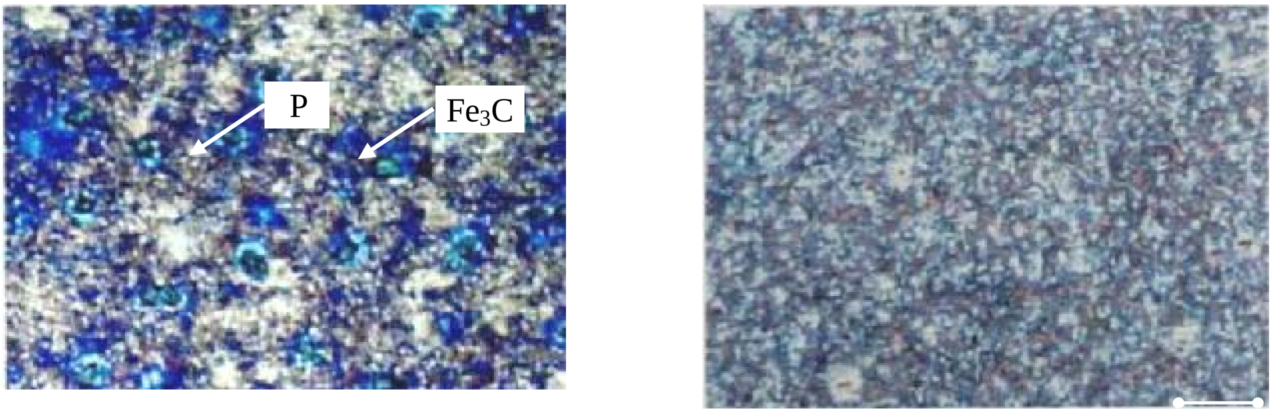
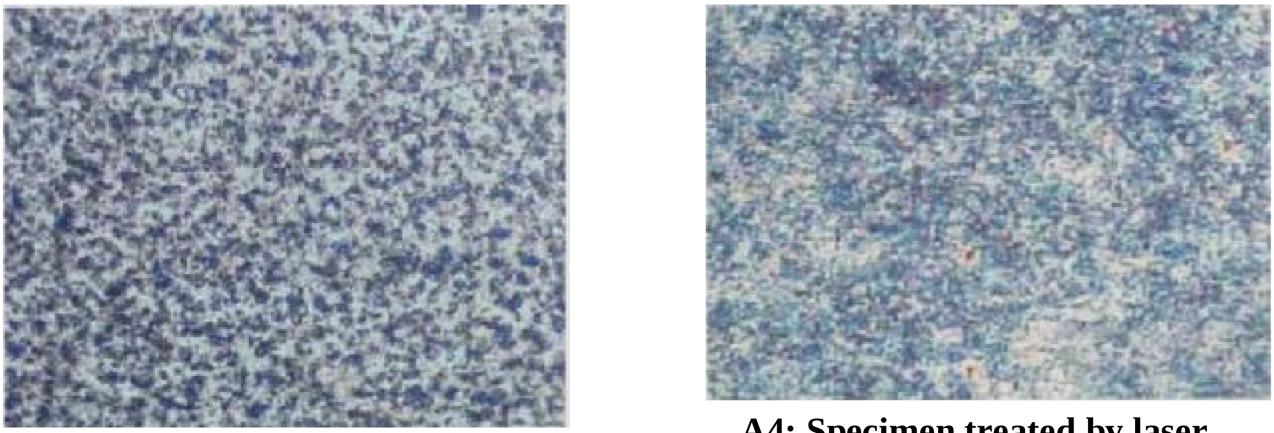


**A1: Specimen as-received.** **A2: Specimen treated by laser (0.3 J).**



**A3: Specimen treated by laser (0.58 J).** **A4: Specimen treated by laser (0.93 J).**

**Figure (6) A: photomicrograph of the specimens treated by Nd:glass Laser with magnification 200 X**

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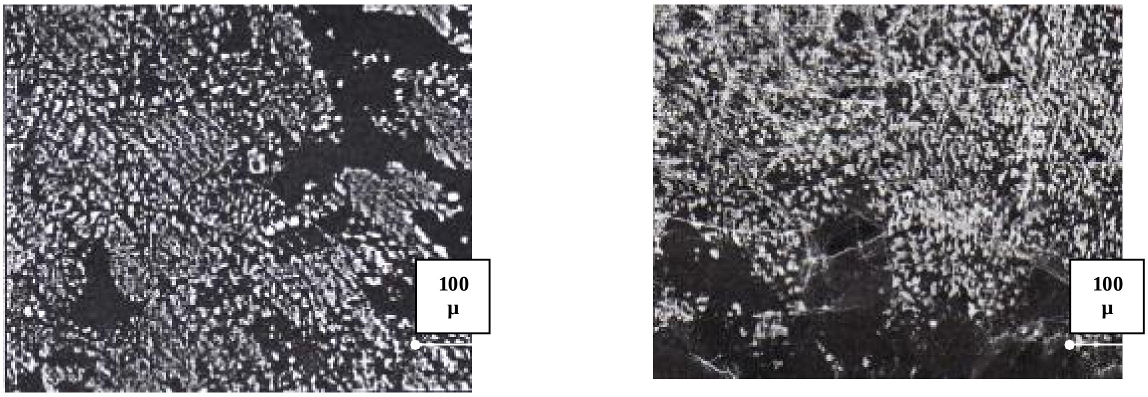
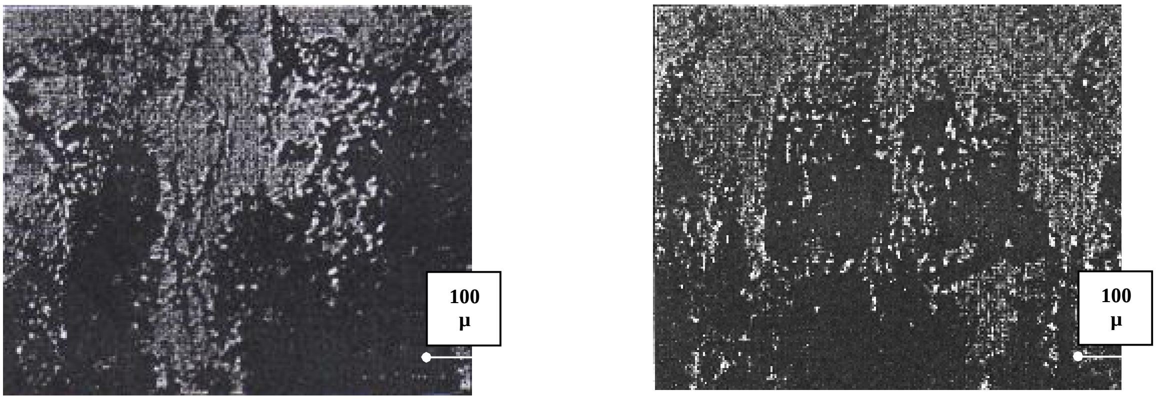


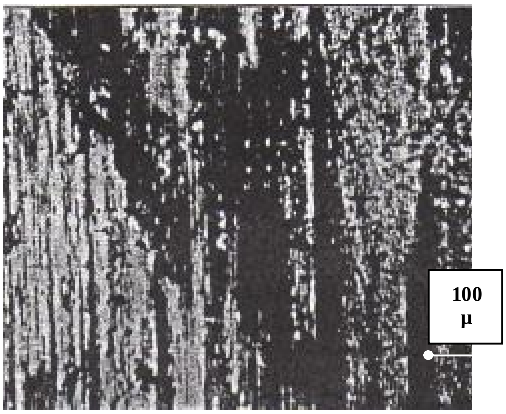
**B1: Specimen of wear loaded by (5N)**

**B2: Specimen of wear loaded by (10N)**



**B3: Specimen of wear loaded by (15N)**

**B4: Specimen of wear loaded by (20N)**



**B5: Specimen of wear loaded by (25N)**

**Figure (6) B: photomicrograph of specimens of wear test treated by laser energy 0.93 J with Magnification 200 X**

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