Eng. & Tech. Journal, Vol. 29, No. 8, 2011

Effect of Laser Surface Treatment on Mechanical Properties of CK45 Steel

Dr. Khansaa Dawood Selman* & Sabah N. mahmood*

Received on: 11/1 /2011
Accepted on:5 / 5/2011

Abstract

The research aims to study the effect of laser surface treatment on mechanical properties of CK45 steel which is widely used in Bolts, Axles Various, Connecting Rods and Hydraulic clamps.

Trails of laser hardening were carried out by using CW Nd: YAG laser with different powers 2.7, 3.3, and 4.3 Watt.

Mechanical tests were done for the specimens who were used in the research before and after treated by laser such as: Tensile test, Micro hardness. Also grain size measurement and microstructural evaluation were done by using computerized optical microscope. The results show that improvement in mechanical properties at laser power 4.3 watt obviously when compared with other laser powers.

From tensile test we show that increasing in yield strength, ultimate tensile strength Poisson's ratio and plasticity constant (k). Also decreasing in Young modulus, Rigidity of modulus and strain hardening coefficient (n). While microhardness results show that the highest value was obtained at laser with 4.3 watt power and decreased far from the surface. Metallographic of the specimen show that refining in grains size after the treatment with laser.

Keywords: Mechanical properties, CK45 steel, Tensile test, grain size, microhardness.

تاثير المعاملة الحرارية السطحية بالليزر على الخواص الميكانيكية لفولاذ CK45

الخلاصة

يهدف البحث الى دراسة تاثير المعاملة الحرارية السطحية بالليزرعلى الخواص الميكانيكية لسبيكة الفولاذ CK45 الذي يستخدم بشكل واسع في المسامير، مختلف انواع المساند ، اذرع التوصيل والمقابض الهيدروليكية .تمت عملية التصليد باستخدام ليزر نيديميوم – ياك المستمر وبقدرات مختلفة 2.7 ، 3.3 ، 4.3 واط . أجريت اختبارات ميكانيكية للعينات المستخدمة في البحث قبل وبعد اجراء المعاملة بالليزر مثل: اختبار الشد واختبار الصلادة الدقيقة. كذلك تم قياس الحجم الحبيبي وفحص البنية المجهرية باستعمال مجهر ضوئي مرتبط بحاسوب. اظهرت النتائج تحسن واضح في الخواص الميكانيكية عند قدرة ليزر 4.3 واط مقارنة مع قدرات الليزر الاخرى. من نتائج اختبار الشد نلاحظ زيادة في مقاومة الخضوع σ_y ، مقاومة الشد القصوى $\sigma_{U.T.S}$، نسبة بويسنP، وكذلك ثابت اللدونة K. نلاحظ ايضا نقصان في معامل يونك E ومعامل الجساءة G وثابت التصليد الانفعالي n.

*Electromechanical Engineering Department, University of Technology/Baghdad

https://doi.org/10.30684/ etj.29.8.15
University of Technology-Iraq, Baghdad, Iraq/2412-0758

بينما اظهرت نتائج اختبار الصلادة الدقيقة ان اعلى قيمة لهاعند قدرة ليزر 4.3 واط وتقل عند الابتعاد عن السطح وكذلك للقدرات الاخرى . اظهرت الصور المجهرية تنعيم في حجم الحبيبات بعد المعاملة بالليزر.

1-Introduction

Laser represents one of the most important inventions of 20th century. With their development it was possible to get highly intensive, monochromatic, coherent and highly polarized light waves [1].

For over 25 years, laser surface engineering techniques involving the subsequent rapid solidification of the molten surface have been to improve wear, corrosion and erosion resistance [2, 3]. The simplest application of laser processing , laser heating , involves the rapid heating of the surface layers to a temperature well below the melting point ,followed by rapid cooling [4].

The common advantages of laser surfacing compared to alternative processes are: Chemical cleanliness, Minimal heat input, No machining required, low cost, laser emits a beam of energy in the form of either continuously or pulsed [5,6].

The following processes have been developed for laser modification: surface melting, surface alloying, cladding and amorphisation [7].

Laser surface hardening is a relatively new and promising process for the thermal hardening of steel. Laser hardening of ferrous materials is an established process widely used to enhance the mechanical properties of highly stressed machine parts, such as gears and bearings [8, 9]. In surface treatment with a laser, the metallic surface is heated locally extremely rapidly and after the laser is switch off it is cools very rapidly. Hence the resultant structures are often metastable structures with particular properties [10, 11].

Victor (1983) [12] was one of the first researchers for laser heat treatment, he studied the microstructure of metal after laser treatment.

Duley W.W.(1983) [13] have described some constrains on the operating range for hardening of EN8 steel using CO_2 laser with laser power up to 2KW. Yaseen (1990) [14] investigated the laser treatment to harden carbon steel with 0.37% carbon content, he found that the hardness number increased to 1100HV when he used Nd:YAG laser with hardening depth (80-90)µm.

Ismail (1999) [15] studied the effect of laser energy and the focusing on the value of the hardness and the microstructure of low carbon steel AISI (1008) and he showed that there were differences in the hardness value and the depth of hardening. J. Grum (2007) [1] was made a comparison of various techniques of laser surface hardening for various kinds of structural and tool steels. He found that the different properties and residual stresses of hardened path of layer. While, LEI Sheng, et al, (2010) [6] were studied tribological properties of laser surface hardened GCr15 steel. The results show that laser surface hardened GCr15 steel exhibited superior wear resistance to their conventionally hardened specimens.

The aim of this investigation is performance the effect of laser surface treatment with different powers on microstructure, microhardness and tensile characteristics of the alloy.

2- Experimental Details :

2-1 Metal used:

In the present investigation we used CK45 steel, the nominal composition of the carbon steel is given in table (1), and table (2) shows mechanical properties of the alloy steel [16].

2-2 Heat Treatment:

Heat treatment was performed by using CW Nd: YAG laser at 1.06µm wave length and full capacity of laser system 5 watt. We applied three different laser powers 2.7, 3.3, 4.3 watt which were measured by using powermeter. Laser beam was applied from distance 30 cm for 10 min, by using beam spleter (4Cm length, 1.5Cm width) for tensile specimen, whilst for microhardness specimen we used converge lens to avoid the dispersion in the output power because the diameter of microhardness specimen (10mm).

2-3 Mechanical Tests:

A: Tensile test:

Tensile test was carried out for the specimens before and after treatment with laser Nd:YAG. Tensile test was done by using INSTRON 1195 machine with full capacity 2.5 ton.

Specimens for this test were manufactured according to ASTM – E8M Standard [17]. Fig (1) shows the specimen of tensile test.

From this test we calculate: True stress (σ), True strain (ε), Young modulus (E), Poisson's ratio (υ), Plasticity constant (K), strain-hardening coefficient (n) and Rigidity modulus (G). As the following:

* **True stress** = $\sigma = \frac{F}{Ac}$ *(Mpa)* (1)

* **True strain** = $\varepsilon = \ln\frac{L_c}{L_o}$… (2)

* **Plasticity constant (K) and Strain hardening coefficient (n)**

From power expression of the form:

* $\sigma = K * \varepsilon^{n}$ ……. (3)

Where:

k = Plasticity constant

n = Strain hardening coefficient

* **Rigidity modulus** $G = \frac{E}{2(1+\upsilon)}$ *(MPa)* ….. (4)

B: **Microhardness test:**

Microharness test was carried out by using (Digital Microhardness HVS1000 apparatus) made in china.

The magnification used was 400X and load 500 gm for 15 second. Many readings of the indentation length were taken for each sample, and … The … calcu… equation: [18].

Effect of laser surface treatment on mechanical properties of CK45 steel

* HV=$1.854 \times F/d^2$ (Kgf/mm^2) … (5)

Where:

F = applied load (kgf).

d = the mean diagonal of indentation (mm).

Case depth measurement:

Case depth is defined as the perpendicular distance from the surface to the point at which the change in hardness, chemical composition or microstructure of the case and core cannot be distinguished. Case depth is one of the deciding factors for a material to be used in practice. Hence, it is necessary to measure the case depth of the material so that the component can be used in service safely.

There are four methods of measuring case depth (Hardness method, Chemical method, Microstructure method and Microscope method). Hardness method used in this work to measure the depth of hardening, it is very accurate method since sharp change in hardness across case and core region can be measured.

From figure (2) which represent in indentor of the Vickers test, the depth of hardening (**X**) can be calculated experimentally from the equation:

$$*\boldsymbol{X} = \frac{\mathbf{L/2}}{\mathbf{Tan}\frac{\mathbf{136^{\circ}}}{\mathbf{2}}} \quad \ldots \quad (6)$$

Where: L = distance between two sides of the indentor.

C: **Microstructure Examination:**

A computerized optical microscopy was used to examine the microstructure of the specimens before and after treatment with Nd: YAG laser.

D: Grain size measurement

Particle size or grain size refers to the diameter of a grain of granular material. Grain intercept and planimetric methods are always applicable for determining average grain size [19]. However, in this work we used intercept method to determine the average grain size. In this method, more lines are superimposed over the structure at a known magnification. The true line length is divided by the number of grains intercepted by the line. This gives the average length of the line within the intercepted grains. Then the grain size can be calculated by using the following equation:

$$*\,G.S = \frac{L}{M \times N} \quad \ldots\ldots \quad (7)$$

Where:
L = Length of intercepted line.
M = Magnification.
N = Number of grains intercepted by the line at the grain boundaries.

3 – Results and Discussion:

3 -1 Result and Discussion of tensile test and Microhardness:

Table (4) shows the results of mechanical properties of the specimens which were used in this work.

The results show that the yield stress (σy), ultimate tensile strength ($\sigma_{U.T.S}$) increases with increasing laser power and the highest values were obtained for laser power 4.3 watt, and in turn lead to increase poison's ratio (υ) and plasticity constant (k).

While increasing in laser power lead to decrease of Young modulus (E), Rigidity modulus (G) and strain hardening coefficient (n). The reason for this is as following: when the power increases, the temperature at the surface alloy increases too, due to the absorption of the laser energy, this increment of the temperature allows the grains to be refined [20]. However, the overall strength level before laser treating was much lower than for the power 2.7, 3.3, and 4.3 watt and the laser treating made to raise the flow stress over the entire tensile stress – strain curve, and in turne decreasing Young modulus (E) and Rigidity modulus (G) [21].

This strengthening is evidently due to the treatment induced dislocation density of the power 4.3 watt compared with the power 3.3 watt and 2.7 watt. The highest of plasticity constant (k) obtained at power equal to 4.3 watt compared with 2.7, 3.3 watt, while the strain – hardening coefficient (n) of the power4.3 watt smallest than the other powers because of one the interesting effects is that treatment by laser can develop significant plastic strains in the metal and condense of dislocations, this lead to increasing in strain hardening and hardness [22].

Hence, most mechanical properties were improved due to refining of the grains as a result of laser treatment; also it causes to increase in hardness [23]. Figure (3) shows that the increasing in laser power lead to increase in microhardness due to the refining in the grain.

From Figure (4), it is clear that microhardness number decreases with the depth of hardening that is due to a large gradient of temperatures which vary across a layer from tens to hundreds of micrometers wide [24].

3-2 Results and Discussion of microstructure examination:

Optical microscopic examination indicated that the steel contains well-distributed mixture of ferrite and pearlite as shown in fig (5). From this figure it is shown that refining in grains because of one of the most important of laser surface engineering methods is laser surface hardening which is meant for only macrostructural modification of the surface without any change in composition [20]. Hence, we obtained that the most refining and homogeneous microstructure with power 4.3 watt when compared with the other power used in this investigation because of very high thermal gradient and ultrarapid solidification.

4 – Conclusions:

1–The best results for hardening obtained when laser power was 4.3 watt.

2 – Improvement in mechanical properties such as (σ_y, $\sigma_{u.t.s}$, E, υ, G), plasticity factors such as (K, n), also microhardness with laser power 4.3 watt.

3 – Refining of grains by using laser power of 4.3 watt more than that obtained by using power 2.7, 3.3 watt.

4 – Microhardness decreases with increasing in depth of hardening.

5-Reference:

[1] – J. Grum, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 24, ISSUE 1, PP 17-25, (2007).

[2] - T. N. Baker and M. S. Selamat, M. S. **"Surface engineering of Ti-6Al-4V by nitriding and powder alloying using a CW CO_2 laser"**, Materials Science and Technology, 24 (2), PP 189-200, ISSN 0267 – 0836, (2008).

[3] - K. G. Watkins, M. A. Mc Mahon and W. M. Steen, materials science and Engineering a 231, PP (55-61), (1997).

[4] – T. N. Baker, **"Laser surface modification of Ti alloy. In: surface Engineering of Light Alloys – Aluminum, Magnesium and Titanium**

Alloys", Wood head publications, ISBN1 - 84569 – 537 - 2 (In Press), (2010).

[5] - Mohammed Naeem M. naeem @gsig.com, **"LASER HEAT – TREATMENT"**.

[6] – LEI Sheng, LIU Quankun, MA Yuping and REN Jing Ming," **Wear performance of laser surface Hardened GCr15 steel "**, Journal of Wuhan university of Technology – Material Science. Ed 84 – 88. (2010).

[7] – Allan H. Clauer, Barry P. Fairand and Ben A.Wilcox, **"Laser shock Hardening of weld zones in Aluminum Alloy"**, Printed with permission from the metal society of AIME, PP (1-11).

[8]– W. Serbinski, J. I.Lubinski, K. Druet, **"Microstructure wear of cast aluminum alloy with laser modified surface layer"**, Advances in Materials Science,Vol.4,No. 2(4), December, PP (71-80), (2003).

[9] – C. Oros, **"Laser Surface Hardness"**, Journal of Optoelectronics and Advanced Materials, Vol.6, No.1, March, PP 325 – 328, (2004).

[10] – M. Carbucicchio, G. Meazza, **"Surface melting of a medium carbon steel by laser treatment"** Journal of Materials Science 18, PP 1543-1548, (1983).

[11] – Metals Handbook, Heat Treatment, 9th edition, volume 4, ASM publications, Ohio (1985).

[12] – Victor G. **"Laser Heat Treatment in laser material processing"**, Bass M (Ed), Vol.3, North Holland, USA. (1983).

[13] – Duley W. W. Laser processing and Analysis of Materials. Plenum Press, New York, (1983).

[14]– Yaseen S. K, **"The effect of laser on the mechanical behavior of carbon steel"**, MCS Thesis, University of technology (1990).

[15]– Ismail R. A. J. **"Laser surface Heat Treatment of low carbon steel AISI (1080)"** Tikrit. Univ. Eng. Sci. 6(3): 117-128 (1999).

[16] – Properties of 1045 steel By Alan Edwards, eHow Contributor
updated: October 21, (2010).

[17] – Annula, **"Book of ASTM Standard"**, Vol. 3.01 and 3.02 Philadelphia USA, (1988).

[18] – Bolton W. **"Engineering Materials Technology"**. Butter Worth Heineman, Oxford (1998).

[19]– ASTM international, **"Standard Test Methods for Determining Average Grain size",** Designation: E112 – $96\varepsilon^3$.

[20] – JDUTTA MAJUMOAR and MANNA, **"Laser processing of materials"**, Sadhana Vol.28, parts 3&4, PP (495 – 562), June / Augest (2003).

[21] – E. J. HEAR N, **"Mechanics of Material"**, 2nd Edition, Volum 1, P6, (1989).

[22] - A. H. Clauer, B. P. Fairand, **"Applications of laser in material processing, copyright"**,ASM International,

Materials park, PP (1-13), (1979).

[23] – ASTM Standardization News **"Comitte E-4 and Grain size Measurement"** May, PP (1-6), (1991).

[24] - Rykalin N., Uglov A., Zuev I. and Kokova A. **"Laser and Electronic Beam Material processing"**, Hand book, MIR publication, Moscow (1988).

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

Element	%C	%Mn	%Si	%Cr	%Ni	%Mo	%S	%P	%Fe
Actual value	0.46	0.65	Max0.40	Max0.40	Max0.40	0-0.1	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 [16].

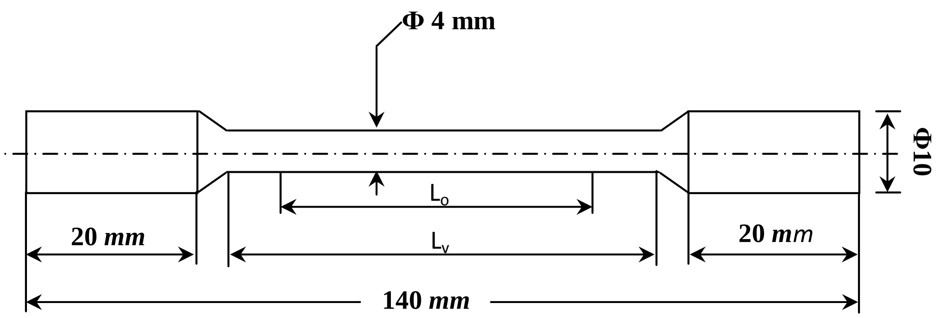
Yield Strength σ_y (MPa)	Tensile Strength (MPa)	Poisson's Ratio	Elastic Modulus (GPa)	Elongation (%)	Hardness(HV) Kg/mm^2
300 - 450	570	0.27-0.30	190-210	14 – 30%	180 - 220

Table (3): shows the results of grain size before and after treatment with laser.

Specimen	Grain size (µm)	
	α	P
Without treatment	16.1	15.8
treated with 2.7 watt	12.3	11.5
treated with 3.3 watt	7.8	6.7
treated with 4.3 watt	4.1	3.7

Table (4): Show the result of mechanical properties of the specimens.

Specimen	σ_y (MPa)	$\sigma_{U.T.S}$ (MPa)	E (GPa)	ט	G (GPa)	K (MPa)	n
Without treatment	590	975.19	206.9	0.316	78.60	741.31	0.633
treated with 2.7 watt	720	989.5	199.8	0.330	75.11	776.24	0.554
treated with3.3 watt	802	1063.6	199.44	0.340	74.41	831.76	0.5
treated with 4.3 watt	910	1151.2	195.47	0.390	70.31	891.25	0.428



Lv= Parallel Length = 80 mm

Lo= Gauge Length = 72 *mm*

Figure (1): Show the specimens of tensile test [17].

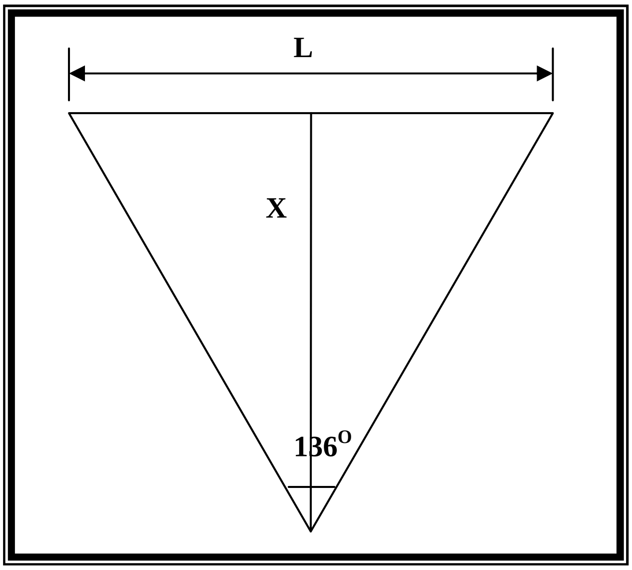


Figure (2): Show the indentor of the Vickers test

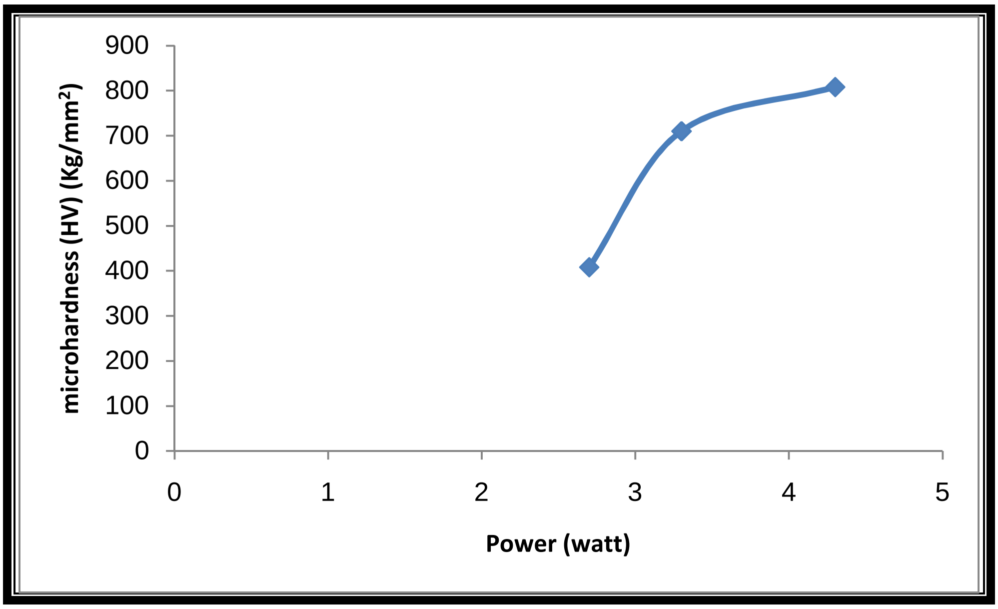


Figure (3): The relation between powers – microhardness.

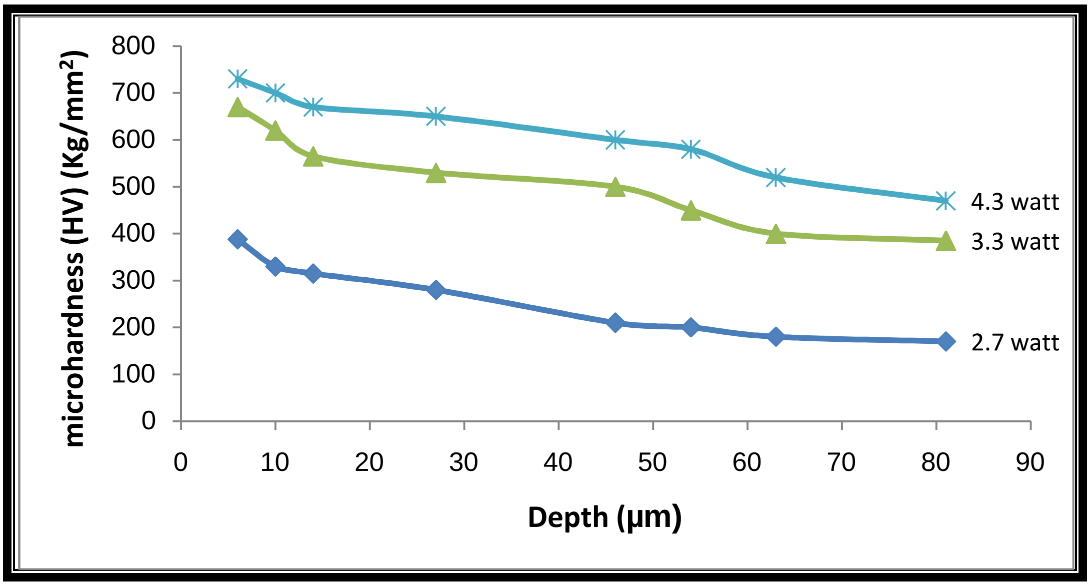
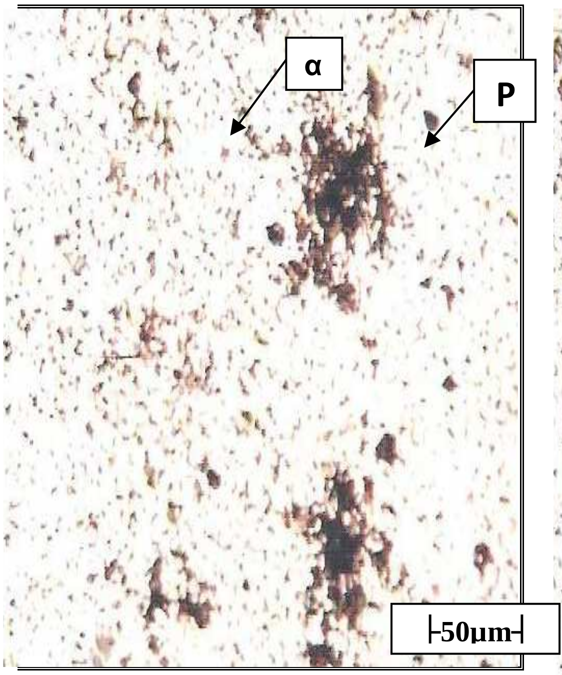
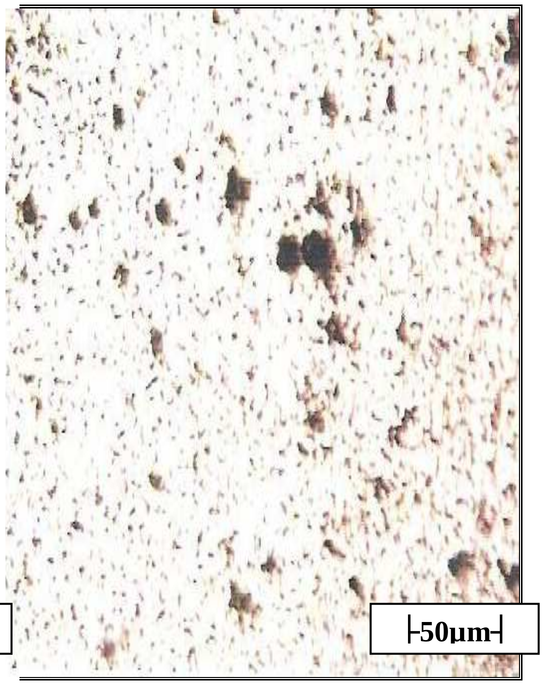


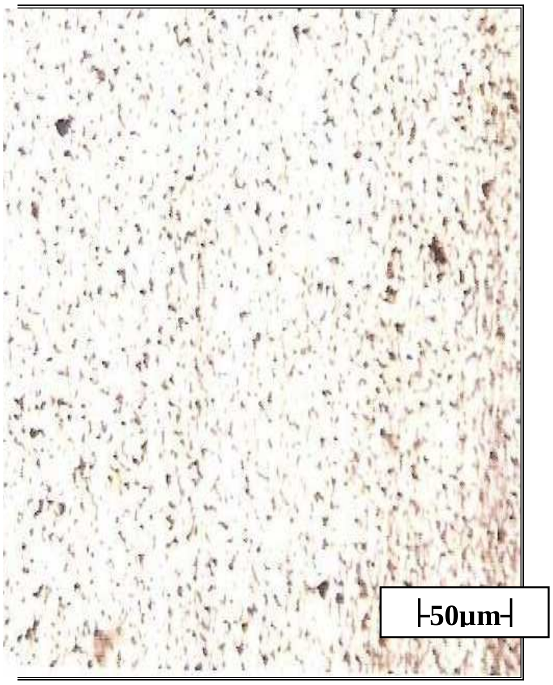
Figure (4): The relation between depths of hardening – Microhardness.



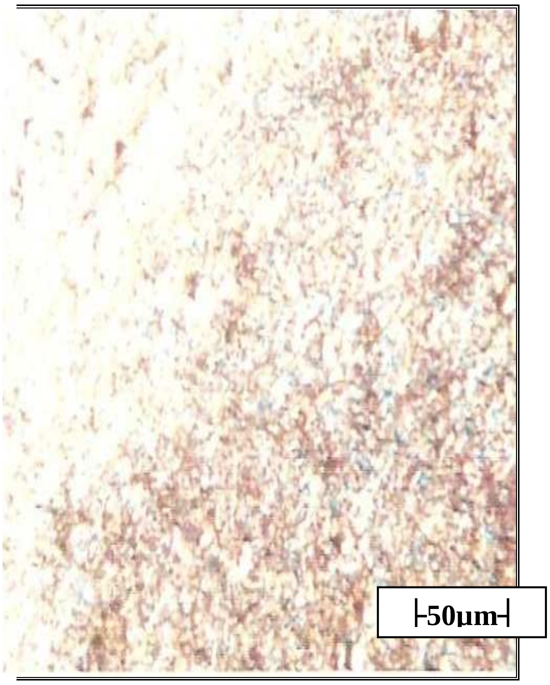
(a) Before heat treatment (270X)



(b) 2.7 watt (270X)



(b) 2.7 watt (270X)



(d) 4.3 Watt (270X)

Figure (5): Show Metallographic of the specimens before and after treatment with Nd: YAG laser.