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Effect of laser surface treatment on the some of mechanical properties of AISI 4130 steel

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Abstract *In this work the surface of an alloy of AISI 4130 steel is hardened by using CW Nd:YAG laser and then study the effect of laser surface hardening on mechanical properties such as yield strength (σy), ultimate tensile strength (σu.T.S), plasticity constant (k),strain hardening coefficient (n) , also evaluate the microstructure and microhardness during the hardening of the alloy. CW Nd:YAG laser was used to scan on the surface of samples by varying the laser beam energies (500,750,1000 mj) with travel speed 500 mm/min of the work table. There are many examinations were done for laser hardened of AISI 4130 steel such as an analysis of microstructure features by using an optical microscopy and microhardness. Also tensile test is carried out for the specimens before and after laser surface treatment. The results of this investigation showed that an improvement in mechanical properties after laser surface hardening, also microhardness decreases faraway the hardened surface toward the center of the specimen. While the microstructure examination showed that the laser energy 1000 mj lead to form fine plate martensite structure more than another energies 500 and 750 mj.*

Keywords*- Laser surface treatment, AISI 4130, mechanical properties.*

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1. Introduction

Surface engineering is one of the most important methods used to alter the microstructure and composition of the surface of an alloy without changing the bulk of alloy [1]. Depending on surface engineering, there are many methods were used for hardening the surface of an alloy either conventional methods such as flame hardening, induction hardening depending on thermal energy or non conventional methods such as laser hardening by applying high energy [2].

The laser is used to modify the surface of an alloy in order to improve wear resistance, corrosion and erosion resistance involving heating at high temperatures and then cooling with rates about 108 - 1010 Co/s in order to increase the mechanical properties and also to modify the microstructure by refining the grains which in turn lead to increasing the microhardness of the surface which treated by laser [3, 4].

Because of the high power density of the laser heat sources and the high processing temperatures often desired to be closed to the melting temperature of the materials, precise temperature measurement and control is essential for keeping the process stable and ensuring reproducible quality of the parts[4]. While in laser surface treatment of ferrous alloys, the limitations are low in comparison with the limitations of conventional heat treatments which were used for the same purpose [5, 6]. Depending on the nature of the application, laser processing can be applied based on the energy requirements which lead to increase the efficiency of the process in comparison to conventional methods [7].

When the surface of an alloy treated by laser, part of laser energy absorbed by the surface of alloy while another part of laser energy reflected by the surface of alloy. Nd:YAG laser is more suitable for hardening steel alloy than CO2 laser, it is attributed to that the wave length of Nd:YAG laser beam 1.064 nm is shorter than the wave length of CO2 laser 10.6 nm [8].

The aim of this investigation is to study the effect of laser surface hardening on microstructure and mechanical properties of AISI 4130 steel.

2. Materials and Methods

I: Materials and Methods

The low alloy steel AISI 4130 is used in this investigation. The most important application of this alloy is aircraft engine mounts, welded tubing. The chemical composition of this alloy is given in table (1), while the mechanical properties of it are given in table (2) [9].

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Table (1): Chemical composition of AISI 4130 steel alloy [9].

Elements	C	Si	Mn	Cr	Mo	P	S	Fe
Standard value	0.28-0.33	0.15-0.30	0.4-0.6	0.8-1.1	0.15-0.25	0.035	0.04	Rem.
Actual value	0.35	0.30	0.67	0.79	0.61	0.03	0.03	Rem.

Table (2): Mechanical properties of AISI 4130 steel [9].

Tensile strength (MPa)	Yield strength (MPa)	Modulus of Elasticity (GPa)	Elongation %	Poisson's ratio	Reduction in Area %	Hardness (HV) Kgf/mm^2
560	460	190-210	21.5	0.27-0.3	59.6	228

II.Preparation of the specimens

In this investigation an alloy of AISI 4130 steel is used, two types of the specimens were prepared: the first for tensile test while the second for microhardness. All of the specimens before and after laser surface treatment are prepared by grinding and polishing. The grinding was done by using emery papers (320, 500 and 1000) µm and then polished by using Al2O3 at 1 µm in particle size. The specimens were finally etched by nital solution (2% HNO3 + 98% alcohol) and made ready for the definition of microstructure and to measure the microhardness.

III.Laser surface treatment

In this investigation CW Nd:YAG laser was used for treating an alloy of AISI 4130 steel at wave length 1.064 nm with three different energies (500,750 and1000) mj. For tensile test specimens, the laser beam was applied from distance equal to 30 cm for 10 min by using beam splatter (4 cm length, 1.5 cm in width, whilst for microhardness specimens the laser beam was applied by using converge lens to avoid the dispersion in the output power because of the diameter of microhardness specimen is 1 cm.

3. Mechanical tests

I. Tensile test

Tensile test was done for the specimens before and after laser surface treatment by CW Nd:YAG laser. The specimens of this test were manufactured according to ASTM E8N standard [10]. Figure (1) shows the standard specimen of tensile test.

Tensile test was carried out for the specimens before and after laser surface treatment by using INSTRON1195 machine with full capacity 2.5 ton.

The mechanical properties such as true stress (σ), true strain (ε) and young modulus (E) can be calculated as following:

True stress = $\sigma = F/A$ (MPa) ………... (1)

True strain = $\varepsilon = \ln L/L_0$ …………….. (2)

Young Modulus = $E = \sigma/\varepsilon$ (GPa)……….. (3)

While the plasticity constant (k) and strain hardening coefficient (n) was calculated by the power expression of the form:

$\sigma = k \times \varepsilon^n$ …………..… (4)

Where:

k = plasticity constant

n = strain hardening coefficient

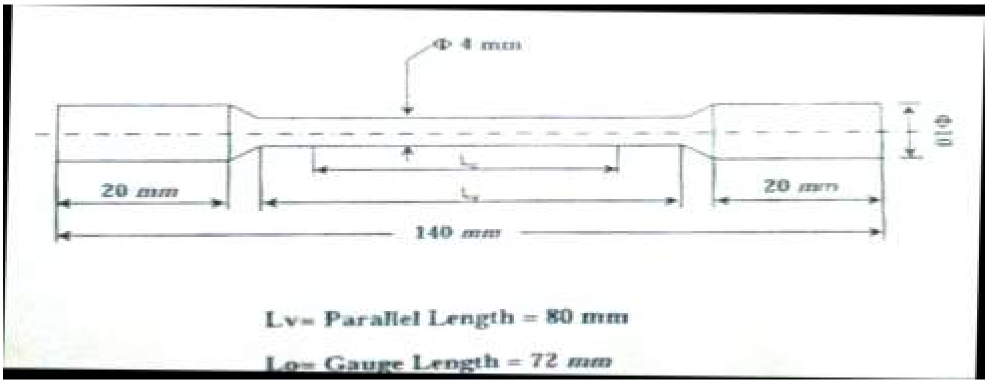

Figure.1:Standard specimen tensile test [10].

II. Microhardness Test

Microhardness test was performed for the specimens treated by CW Nd:YAG laser. This test was carried out by using (Digital Microhardness HVS 1000 apparatus) according to [11]. Many readings were taken by applying the load equal to 500 gm for 15 sec and magnification of microscope 250X. Microhardness values for the treated specimens were calculated by the following equation [11].

$$H_v = 1.8544\times\frac{F}{d^2}\ (kgf/mm^2) \qquad \ldots\ldots\ldots (5)$$

III.Depth of hardening

Depth of hardening can be measured practically by using optical microscopy, it is necessary to measure the depth of hardening so that the component can be used in service safely.

Depth of hardening can be calculated from the hardened surface to the point at which the hardness, microstructure and changing the phases without changing the chemical composition of the core [12].

Depth of hardening can be defined by using hardness method which is the most important method to measure the depth of hardening; also it is regarded to be an accurate method.

Vickers microhardness test represented in Fig (2), at which the distance between two sides of the indenter is (L), whilst the depth of hardening is (X), the depth of hardening (X) is calculated practically from the following equation [12]:

$$x = \frac{L/2}{\tan\frac{136^0}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where:

X = depth of hardening

L = distance between two sides of indenter

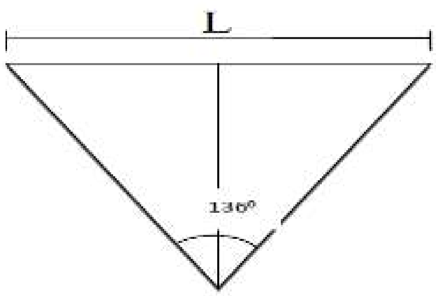

Figure. 2: The indenter of Vickers microhardness [12].

4. Examination of microstructure

The microstructure examination of the specimens before and after laser surface treatment was done by using the computerized optical microscopy to define the phases resulted from the surface treatment by CW Nd:YAG laser.

5. Results and Discussion

I.Results and Discussion of microstructure

Laser surface treatment is one of the most important processes used to harden the case of steel alloy changing the phases without changing the chemical composition of it.

In this investigation the microstructure of the specimens treated by Nd:YAG laser were examined by computerized metallurgical microscope. Laser surface hardening is performed by varying the laser beam energy at 500,750 and 1000 mj. The microstructure of the specimens before laser surface treatment as shown in Fig (3) that the main phases are ferrite and pearlite , while after the laser surface treatment austenizing occur which lead to form austenite phase and at the same time dissolving the carbides at the grain boundaries, and the rapid cooling occur which lead to self quenching and in turn lead to transform the austenite partially or completely to martensite [13].

The microstructure of hardened zone consists of martensite with small amount of retained austenite. This work exhibit that the higher energy 1000 mj leads to form fine plate martensite structure more than another energies 500 and 750 mj. Figure (3) shows that obviously.

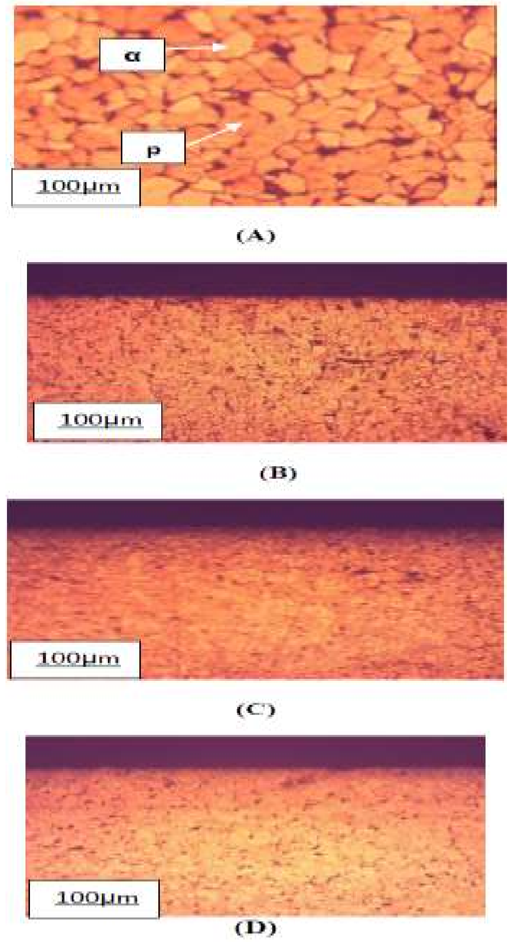

Figure. 3: Photomicrographs of the specimens before and after laser surface treatment with magnification 250X.

A: As-received. B: Specimen treated by laser with 500 mj. C: Specimen treated by laser with 750 mj. D: Specimen treated by laser with 1000 mj.

II.Results and Discussion of Mechanical properties

A- 1.Results and Discussion of tensile test

In this investigation, the resulting values of mechanical properties which obtained from tensile test showed that increasing the values of σ_y, $\sigma_{u.T.S}$, k.

Also at the same time the laser surface treatment leads to decreasing the values of E and n as shown in Fig (4) and (5). These values listed in Table (3) as the following:

It is attributed to that the heating duration in laser treatment shorter than the conventional heat treatment such as induction hardening which in turn lead to obtain less distortion and less surface oxidation. After laser surface treatment rapid cooling occurred and the heated region quenched by itself, so that the specimen surface is hardened and its mechanical properties is modified and improved.

The mechanical properties of the specimens treated by laser are different from the surface toward the base of it because of the rate of changing in temperature is high from the surface to the center and at the same time the temperature gradient is also high. The results of this study are agreed with [14].

2.Results and Discussion of Microhardness and the depth of hardening

Microhardness test was done in this work for the specimens treated by Nd:YAG laser, the values of the microhardness at the top surface of treated specimens are more than that the values toward the core of the specimens.

The value of microhardness for 1000 mj energy is more than that for 500 and 750 mj because of the microstructure attained of the specimen surface is fine plate martensite while the microstructure for 500 mj is coarse plate martensite due to less heat input. At the same time for 750 mj the microstructure is between of 500 mj and 1000 mj for the same reason mentioned previously.

The depth of hardening is dependent on laser energy, increasing the input energy leads to increase the depth of hardening as shown in Fig (6), it is attributed to that the same reason which is mentioned above for microhardness. This results are agreed with [15].

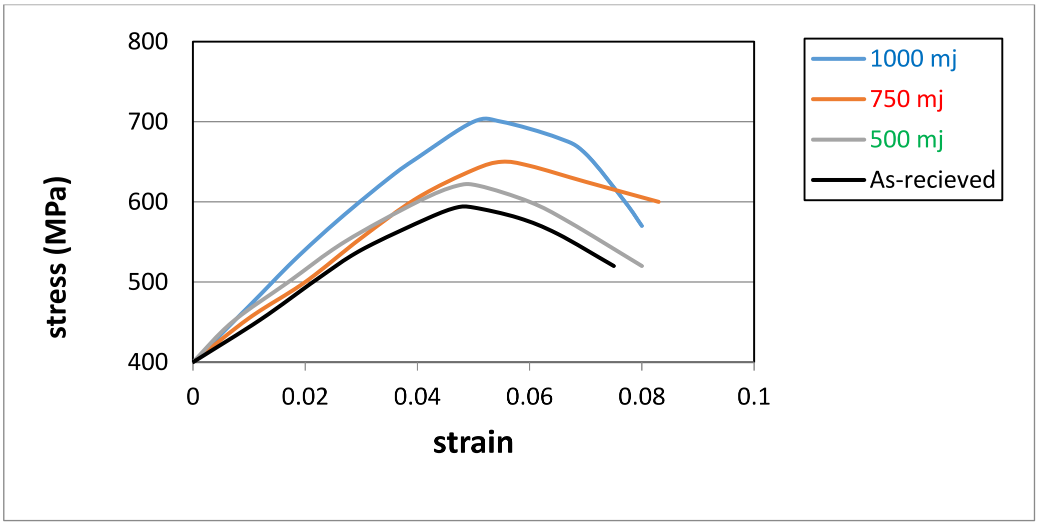

Figure. 4: Stress-strain of the specimens before and after laser surface treatment at different laser beam energy.

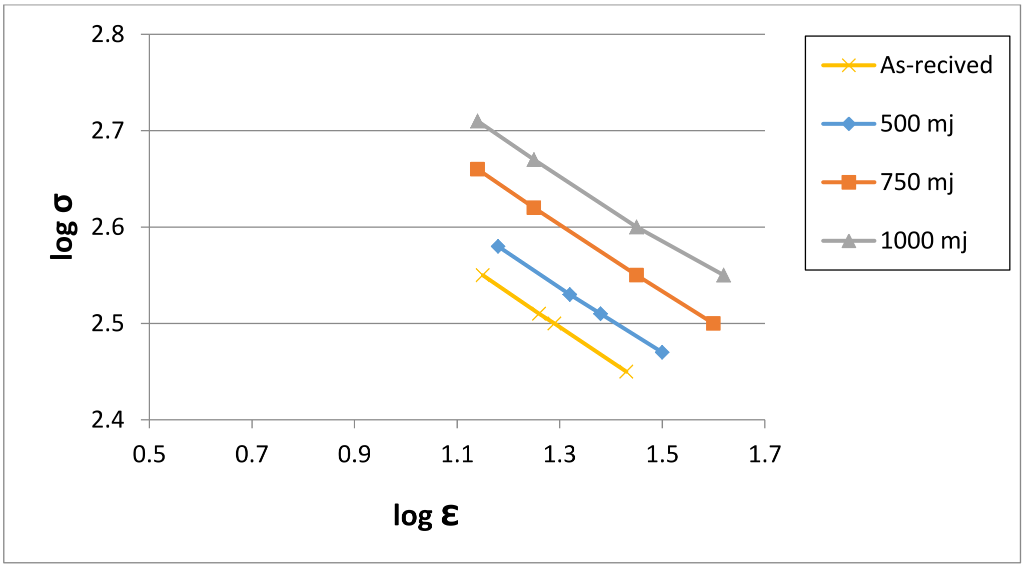

Figure. 5: Log σ- log ε of the specimens before and after laser surface treatment at different laser beam energy.

Table (3):The results of tensile test.

Specimen	σ_y (MPa)	$\sigma_{u.T.S}$ (MPa)	E (GPa)	K (MPa)	n
Without treatment	460	560	190-210	752.1	0.612
Treated by 500 mj	573	625	198.35	773.4	0.537
Treated by 750 mj	620	665	195.71	825.7	0.501
Treated by 1000mj	669	775	189.92	885.3	0.478

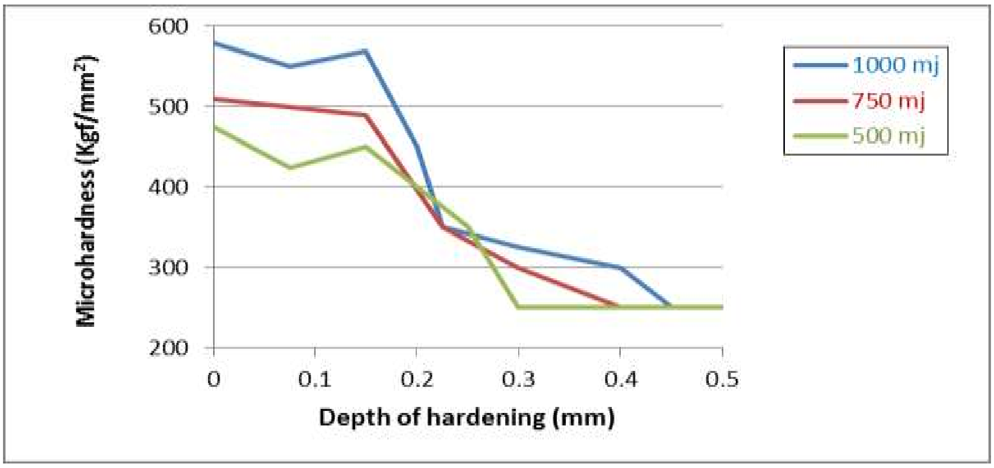

Figure. 6: The microhardness and depth of hardening for the specimens treated by different laser beam energy.

6.Conclusions

1.Increasing Nd:YAG laser energy leads to increase the values of σy, σu.T.s, and k, also decreasing of E and n.

2.Increasing Nd:YAG laser energy leads to increase the microhardness, at the same time the depth of hardening increases with decreasing the microhardness.

3. This investigation exhibits that the higher energy 1000 mj leads to form fine plate martensite structure comparing with another energies 500 mj and 750 mj.

References

[1] Purushothaman Dinesh Babu, Gengusamy Naidue Buvanashekaran, Karupuudaiyar R. Balasubramanian, "Experimental studies on the microstructure and hardness of laser transformation hardening of low alloy steel", Transactions of the Canadian Society for Mechanical Engineering, Vol. 36, No. 3, 2012.

[2] Euro inox, The European Stainless Steel Develop Association, "Surface Hardening of Stainless Steel", Materials and Applications Series, Vol. 20, 2015.

[3] Buvanashekaran, G., "Laser surface transformation hardening on medium carbon steel using high power laser beam", International Conference of the International Institute of welding, Chennai, India, pp17-22, 2011.

[4] M. Gowshikan, S. Balasubramanian, “A Review on laser surface modification of High Carbon Steel Components”, International Journal of Innovative Research and studies, Vol.3 Issue 10, PP.187-197, 2014.

[5] Steen, W.M., Laser Material Processing, Springer-Verlag London Limited, 1991.

[6] Dutta Majumdar, J. Nath, A.K. and Manna, "Studies on laser surface melting of tool steel- part II: Mechanical properties of the surface", Surface and Coatings Technology, Vol. 204, No. 9-10, pp 1326-1329, 2010.

[7] Mitra Radmanesh, Amirkianoosh Kiani, "Nd:YAG Laser Pulses Ablation Threshold of Stainless Steel 304", Material Science and Applications, Vol. 6, pp 634-645, 2015.

[8] Gurm, J and Strum, R. "Laser surface melt-hardening of gray and nodular irons", Applied Surface Science, Vol. 109/110, pp 128-132, 1997.

[9] AZO Materials, AISI 4130 Alloy Steel (UNS G41300).

[10] Annula,"Book of ASTM Standard", Vol. 3.02 and 3.03 Philadeliphia USA, 1988.

[11] Bolton W. "Engineering Materials Technology", Butter Worth Heinemann. Oxford 1988.

[12] Ziad Aeyad Taha "Laser surface heat treatment for steel and aluminum alloys" Msc thesis, Baghdad University, 2003.

[13] MitraRadmanesh, AmirkianooshKiani, ”ND:YAG laser pulses Ablation Threshold of stainless steel 304”,Materials Sciences andApplications,,Vol.6,pp 634-645,2015.

[14] M. Seifert, K. Anhalt, C. Baltruschat, S. Bonss and B. Brennner, “precise temperature calibration for laser heat treatment”, Journal of Sensors and Sensors Systems, 3, PP. 47-54, 2014.

[15] Khansaa Dawood Selman, Sabah N. mahmood, "effect of laser surface treatment on mechanical properties of CK45 Steel", Eng.& Tech. Journal, Vol. 29, No. 8, 2011.