Investigation The Effect of Nd:YAG Laser on The Hardness and Corrosion Resistance of Carbon steel AISI 1017

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Abstract: -

The influence of Nd:YAG laser on the surface hardness and corrosion resistance of AISI 1017 carbon steel was studied. Samples of the steel were treated with Nd:YAG laser, 532nm wavelength and energy of 200, 220 and 240 mJ. The corrosion test was done by using potentiostate instrument at 23°C in sample of water from Tigress River and salt groundwater (Yousifia well 90m below the surface of the ground). The results exhibited that there were improvement in the corrosion resistance of the steel where the best results were obtained at laser energy of 200mJ and the value of corrosion rate reduced from (7.577mpy) to (2.362 mpy) in water sample from Tigress river and from (8.878 mpy) to (3.051 mpy) in water sample from salt well and this mean that there was about 68.8 % improvement in corrosion resistance. In addition to this improvement, there was improvement in surface hardness of the steel at energy of 200 mJ, where the hardness improved from 167 HV to 200.3 HV.

Keywords: carbon steel, Nd:YAG laser, corrosion resistance, surface hardness.

1. Introduction

Most metallic materials experience interaction with surroundings. Frequently, this interactions damage a material's utility and lead to deterioration of its appearance, mechanical properties (e.g., strength and ductility), physical and other properties. Mechanisms of deteriorative are differ from material to other. In metallic materials, there is loss in material either via the formation of nonmetallic film (oxidation), scale or by dissolution (corrosion) [5, 16]. Corrosion is the result of the deterioration of alloys or metals as a result of revers interaction with surrounding environment [2, 17]. The driving force for a material to oxidize is its free energy of oxidation and when the material react with oxygen, this energy will released [12, 9].

Steel as an alloy of iron and carbon is regarded common engineering material and it is applied in a wide range of application like appliances and automobile and play a major role in machine design for base plates, chutes, housings, structural members and countless machine components [10, 13]. Low carbon steel has carbon content of 0.15% to 0.35%, and it is the most common form of steel as it provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile because of its lower carbon content. It has lower tensile strength and is malleable [7, 8].

2. laser shock peening (LSP)

Laser is a technological operation in which there are several parameters connected with each other leads to interaction of material with laser radiation. This Interaction is the result of the transformation of electromagnetic energy to a thermal energy and it is connected with the absorption level where it is defined as an amount of energy absorbed via material from the total amount of energy falling on to the surface of material as explained in **Fig. 1.** This ratio of absorption depends on [11]:

1. Material optical constant, which depends on absorption index and coefficient of reflection.
2. Laser radiation properties (power density, wave length and polarization).
3. Surface chemical composition (graphite layers, nitride, oxide …etc.)
4. Surface topography (roughness).
5. Angle of radiation and temperature [11].

The high power laser development has enabled the industrial usage of lasers in the engineering materials, e.g. laser welding and cutting, laser cladding and alloying and laser used for transformation hardening. In particular, the laser treatment got a great interest due to the prospect to heat the surface of material locally without affecting the bulk of material and it will generate novel microstructure due to high cooling rate. Often, for these applications, Nd:YAG and CO_2 laser are used [6].

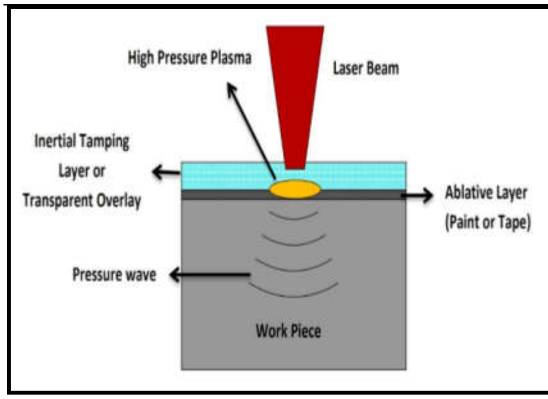

Fig. 1 basic principle of LSP [1]

During the operation of laser shock processing, the following parameters have significant impacts to the peening effect and need to be adjusted in accordance to different material systems: spot size, laser energy, duration time, overlap rate, wavelength of the laser beam and beam profile [4,15].

laser shock processing lead to improvement in mechanical properties of material especially in fatigue life, corrosion resistance, toughness and hardness.

It has been studies in many types of metallic material including steels, titanium alloys and aluminum alloys [3,14].

3. Experimental work

Low carbon steel AISI 1017 was used for this research. The steel was analysis chemically and by contrast the results with American standard, it was obvious that it was AISI 1017 carbon steel as indicated in **Table. 1**.

Table. 1 Chemical Composition of the Used Steel

Elements	Actual value	Standard value
Fe %	Bal.	99.11 - 99.56
C %	0.174	0.14 – 2.0
Si %	0.185	-
Mn %	0.585	0.3 – 0.60
P %	0.009	≤ 0.040
S %	0.022	≤ 0.050
Cr %	0.165	-
W %	0.046	-
Ni %	0.062	-
Cu %	0.130	-
V %	0.001	-
Al %	0.021	-
Mo %	0.009	-

The steel was obey to stress relive treatment via placing it in furnace for 3 hours at a temperature of 200°C to relieve stresses.

3.1 Corrosive mediums

To investigate the corrosion resistance of low carbon steel, two different mediums were used (as indicated in **Table. 2**) as follows:

1. Water sample from Tigress River at upstream Samara′a barrage.
2. Water sample from groundwater (Yousifia salt well 90m below surface of the ground).

Table. 2 Chemical Analysis of Water Samples

Type of Analysis	Samara′a barrage	Yousifia salt well
pH	7.3	8
EC (μs/Cm)	440	9430
T.D.S (mg/l)	296	6100
Ca^{+2} (mg/l)	28	445
Na^{+} (mg/l)	46	762
Cl^{-} (mg/l)	85	998
HCO_3^{-} (mg/l)	18	611
SO_4^{2-} (mg/l)	78	1643
Mg^{2+} (mg/l)	16	200
K^{+} (mg/l)	2	25
NO_3^{-} (mg/l)	2	2
CO_3^{2-} (mg/l)	0	0

3.2 Laser shock peening

Typical laser system was applied, type Nd:YAG laser as demonstrated in **Fig. 2.** The parameters used in this study were:

1. Nd:YAG laser/2nd harmonic generation.
2. Wavelength = 532nm.
3. Diameter of laser spot = 2.2 mm.
4. Pulse duration = 10 Nano seconds.
5. Frequency = 1 Hz.
6. Pulse energy = 200, 220 and 240 mJ

7. Distance between the lens of laser and the specimen = 12cm.

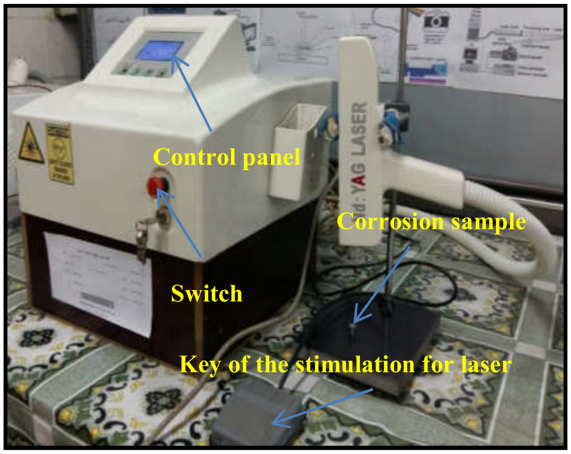

Fig. 2 Nd:YAG Laser Device

3.3 Corrosion test

Corrosion test was applied to measure the corrosion rate for the specimens via applying Gamry series (G300) potentiostat as indicated in **Fig. 3**, the experiments carried out by Tafel test. This test was performed at room temperature (23°C).

Fig. 3 Electrochemical Corrosion Cell Connected with Potentiostat Instrument

3.3.1 Electrochemical polarization tests in water sample from Tigress River

The corrosion test was carrying out for the steel before and after laser treatment. This test was performed in a sample of water from Tigress River at room temperature (23°C). **Fig. 4** indicates Tafel tests for steel specimens in this water. It was clear that there are slight differences in cathodic reactions, fastest cathodic reaction was for the sample without making laser treatment on it which means it has the highest corrosion rate, while the slowest was in the test of sample that treated with laser at energy of 200mJ, this means that it has the lowest corrosion rate and better corrosion resistance because the heat of laser make an effect on the samples near the effect of annealing heat treatment and the grain size doubled after treatment with laser in addition to the change in faces where the ferrite face become the prevailing face on the surface of the steel samples after treatment and the perlite face was reduced extremely.

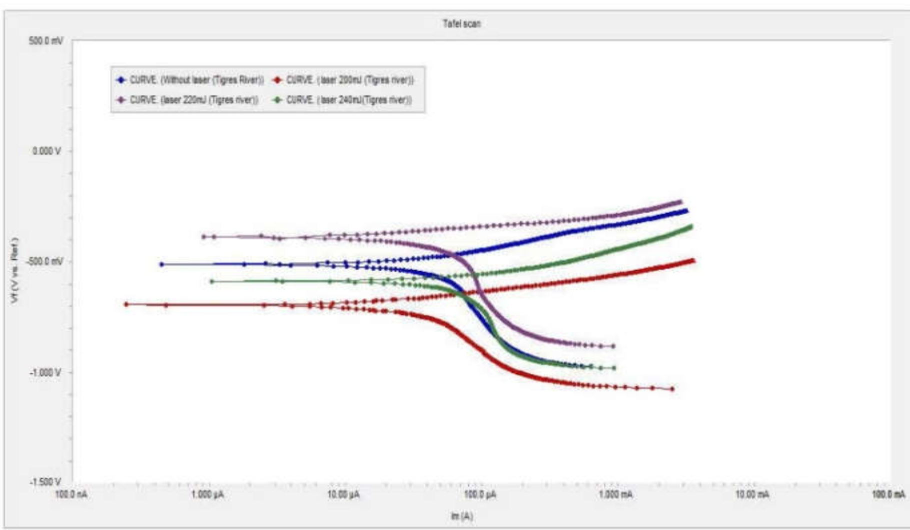

Fig. 4 Tafel tests for (AISI 1017) steel in water sample from Tigress river before and after treatment with laser at energy of (200, 220 and 240mJ)

The corrosion rate decreased with decreasing the energy of laser until reaching lowest value when the sample treated with energy of 200mJ as indicated in **Table. 3**,the laser have revers effect on the steel at energy above 240 mJ because the high energy of laser will raise the temperature of sample to a high temperature leads to damage in sample where the surface of sample becomes brown because the grains at the surface of the sample subjected to burn due to the high energy which lead to generate high temperature at the surface.

Table. 3 the results of corrosion tests in water sample from Tigress river before and after laser treatment

Sample	I_{corr} (μA)	E_{corr} (mV)	Corr. Rate (mpy)
Without treatment	87.60	-511.60	7.577
Treated at 200mJ	**27.30**	**-694.0**	**2.362**
Treated at 220mJ	51.90	-575.0	4.487
Treated at 240mJ	77.20	-586.0	6.671

3.3.2 Electrochemical polarization tests before and after laser treatment in water sample from groundwater (Yousifia salt well 90m below ground surface)

The corrosion test was done on the steel before and after laser treatment. This test was performed in a sample of water from groundwater (Yousifia salt well 90m below ground surface) at room temperature (23°C). **Fig. 5** indicates Tafel test for steel specimens in this water. It was clear that there were slight differences in cathodic reactions, fastest cathodic reaction was for the sample without making laser treatment on it which means it has the highest corrosion rate, while the slowest was in the test of sample that treated with laser at energy of 200mJ, this means that it has the lowest corrosion rate and better corrosion resistance.

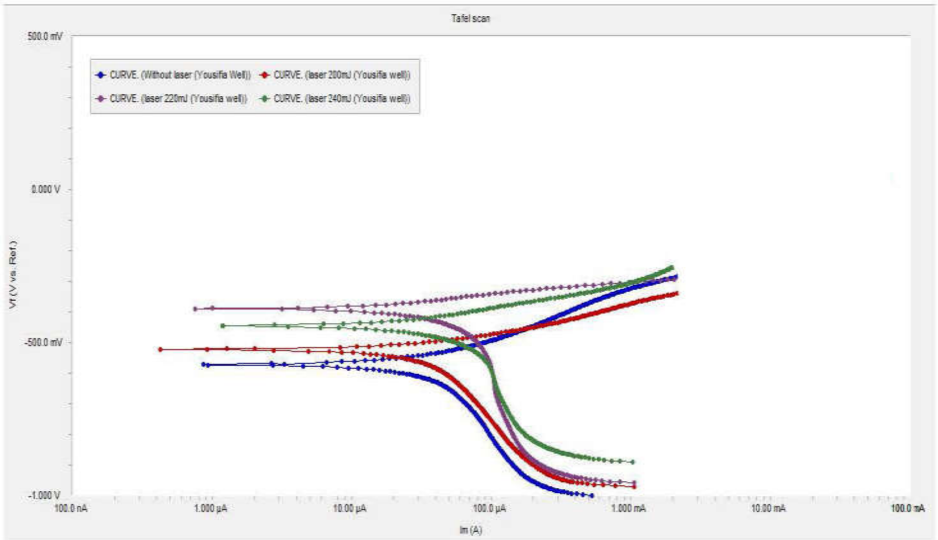

Fig. 5 Tafel tests for (AISI 1017) steel in water sample from groundwater before and after treatment with laser at energy of (200, 220 and 240 mJ)

The corrosion rate decreased with decreasing the energy of laser until reach to lowest value when the sample treated with energy of 200mJ as indicated in **Table. 4**, the laser have revers effect on the steel at energy above 240 mJ because the high energy of laser will raise the temperature of sample to a high temperature lead to damage in sample where the surface of sample becomes brown because the grains at the surface of the sample subjected to burn due to the high energy which lead to generate high temperature at the surface.

Table. 4 The results of corrosion tests in groundwater before and after laser treatment

Sample	I_{corr} (µA)	E_{corr} (mV)	Corr. Rate (mpy)
Without treatment	130.0	-572.0	8.878
Treated at 200mJ	**35.30**	**-522.0**	**3.051**
Treated at 220mJ	69.00	-389.0	5.965
Treated at 240mJ	89.40	-445.0	7.730

3.4 Microhardness test

Vickers hardness test was done on samples before and after laser shock peening, this test helps in measuring the surface hardness of the samples as shown in **Fig. 6**. and the Vickers hardness test calculated inside the device according to the equation:

$$HV = 1.8540\ (P/d^2)$$

Where: P = Load (kgf)

d = Indenter diameter (mm)

The samples before the test should be polished in order to obtain best results.

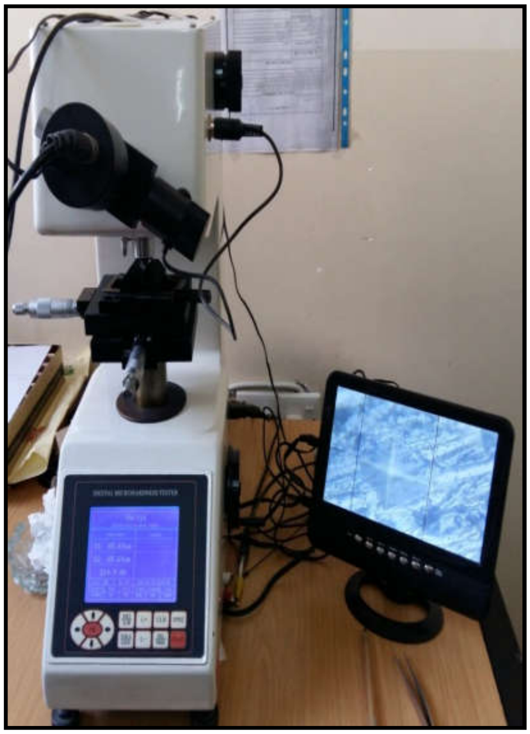

Fig. 6 Digital Micro Vickers Hardness Device

surface hardness for the steel enhanced as shown in **Table. 5**. it can be remarked that the hardness value increased and it became (200.3 HV) for sample treated with laser at 200mJ because of the laser radiation which leads to improvement in surface hardness because of the effect of rapid heating and cooling of the grains at the surface, while the hardness decreased with increasing laser energy above 240mJ because high energy generated high temperature at the surface and cause damage to the sample where the surface of sample becomes brown because the grains at the surface of the sample subjected to burn due to the high energy which lead to generate high temperature at the surface and this effect was indicated in **Fig. 7**.

Table. 5 Result of Micro Vickers hardness (HV) test before and after treatment with laser

Sample	Micro Vickers hardness (HV)
Without treatment	167
Treatment with laser at 200 mJ	**200.3**
Treatment with laser at 220 mJ	195.1
Treatment with laser at 240 mJ	189.6

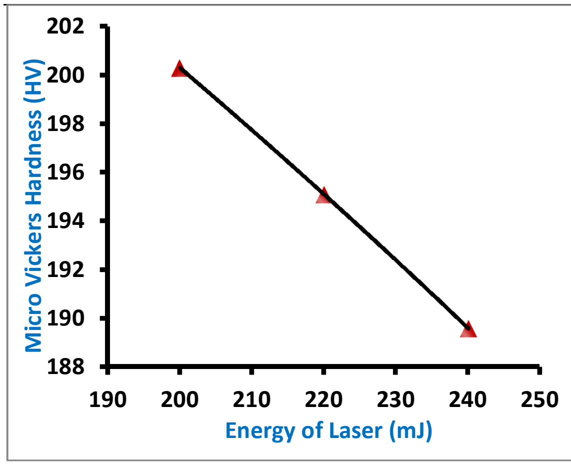

Fig. 7 Relationship between energy of laser and surface hardness

3.5 X-Ray Diffraction test

XRD technique was used to study the effect of laser on the surface of the steel and compared between the sample before and after treatment with laser at energy of 200 mJ. There was difference in intensity before and after treatment with laser as indicated in **Fig. 8**. For the case of sample treated with laser, the XRD pattern exhibited peaks centered at 2θ = (44.6738º, 65.0777º, 82.3495º and 98.9324º) which correspond to the planes of (110, 200, 211, 220 and 310) it agrees with the card have mineral name (Iron, syn).

From this test it was clear that the laser treatment resulted in a combination of the grains which have ferrite phase and displacement the carbon at the boundaries of the grains. This change resulted in improvement in the corrosion resistance and surface hardness of the steel.

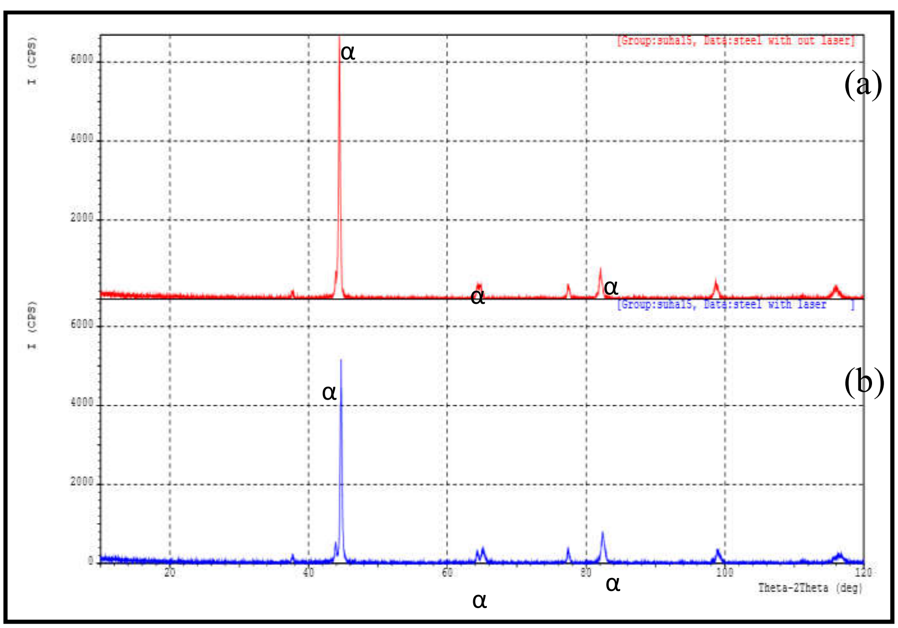

Fig. 8 X-Ray Diffraction Inspection

3.6 Microstructure test

Microstructure test was done to help in study the effect of laser on the surface of the steel and compare between the sample before and after treatment with laser at energy of 200 mJ. From microstructure test it was evident that there was difference in the grain size and arrangement of the grains. The grain size for certain grain was 23.443 micron before treatment with laser and for certain grain after treatment was 50.687 micron as indicated in **Fig. 9** and **Fig. 10**. From comparison between them it was clear that the grain size was bigger after treatment with laser and that was one of the reasons which lead to improvement in the corrosion resistance and surface hardness of the steel. The treatment with laser lead to raising the temperature of the steel and cooling it fast and during this the grains merged with each other and it haven't the time to retain to the original state because of fast cooling.

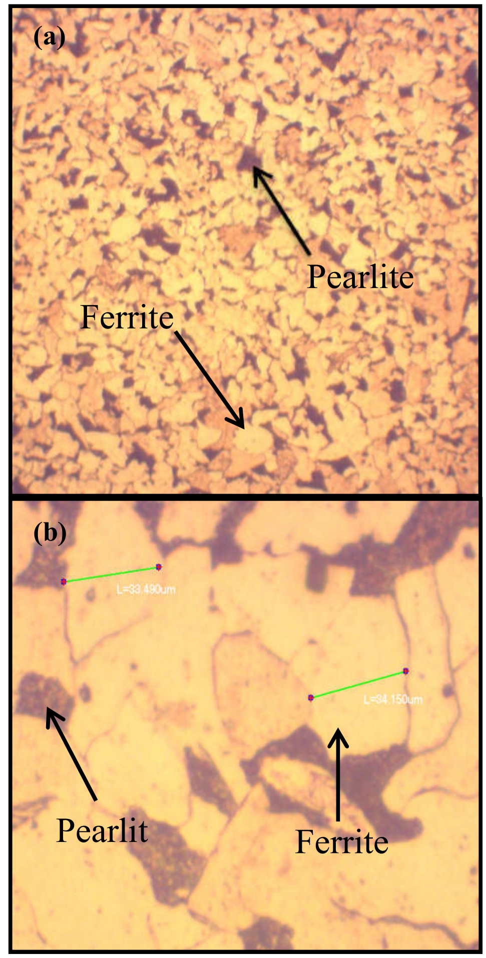

Fig. 9 Microstructure for (AISI 1017) carbon steel which shows the grain size before laser treatment.
(a)Magnification (X100),
(b)Magnification (X400)

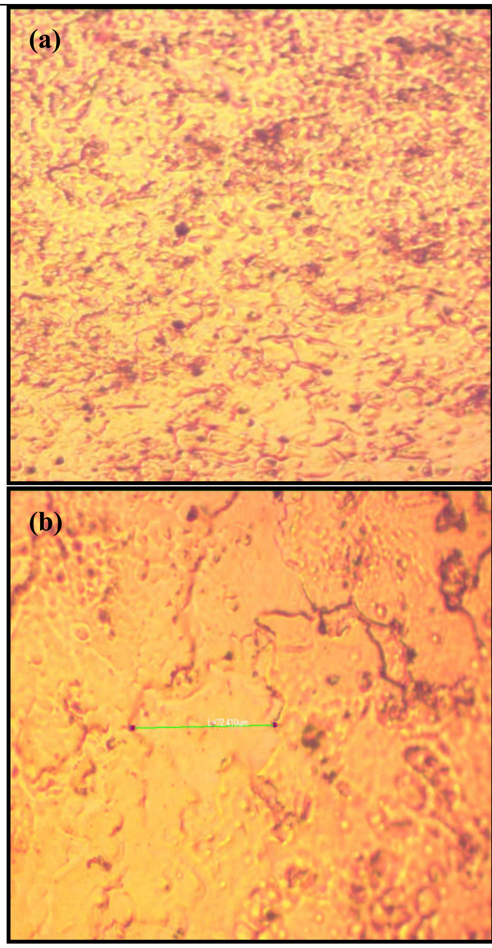

Fig. 10 Microstructure for (AISI 1017) carbon steel which shows the grain size after laser treatment at 200mJ.
(a)Magnification (X100)
(b)Magnification (X400)

4. Conclusion

Laser shock peening which done on AISI 1017 carbon steel caused improvement in the hardness and corrosion resistance of this steel, this improvement abstracted in the following points:

1. Improvement in corrosion resistance and the better result was at laser energy of 200mJ, where the corrosion rate reduced from 7.577mpy to 2.362mpy in water sample of Tigress river and from 8.878mpy to 3.051mpy in water sample of salt groundwater
2. Reducing energy of laser resulted in improvement in surface hardness, where the hardness improved from 167 HV to 200.3 HV at laser energy of 200mJ.
3. Treatment the carbon steel with laser at energy of (200mJ) lead to double the microstructure of the steel which resulted in improve the corrosion resistance and surface hardness.
4. Treatment the carbon steel with laser at energy of (200mJ) lead to make ferrite phase is the prevailing phase which resulted in improve the corrosion resistance and little improvement in the surface hardness.

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البحث في تأثير ليزر أنيدياك على الصلادة ومقاومة التآكل لفولاذ كاربوني (AISI 1017)

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في هذا البحث درس تأثير ليزر انيدياك على الصلادة السطحية ومقاومة التآكل للفولاذ الكربوني (AISI 1017). عينات الفولاذ تعرضت لهذا الليزر بطول موجي 532 نانو متر وطاقة بمقدار 200, 220 و 240 ملي جول. جهاز المجهاد الساكن هو الجهاز الذي استعمل لاختبار التآكل عند 23 درجة مؤية في عينات من مياه نهر دجلة ومياه جوفية مالحة (بئر اليوسفية على عمق 90 متر تحت سطح الارض). النتائج اظهرت انه هناك تحسن في مقاومة الفولاذ للتآكل. وكانت افضل النتائج عند طاقة 200 ملي جول حيث قلت نسبة التآكل من 7.577 مل بالسنة الى 2.362 مل بالسنة في عينات مياه نهر دجلة وقلت من 8.878 مل بالسنة الى 3.051 مل بالسنة في عينات مياه البئر المالح. بالاضافة الى هذا التحسن هناك تحسن في الصلادة السطحية للفولاذ عند طاقة 200 ملي جول من 167 الى 200.3.

الكلمات المفتاحية : فولاذ كربوني, ليزر أنيدياك (Nd-YAG), مقاومة التآكل, الصلادة السطحية.