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Influence of Nd:YAG Laser Energy on Mechanical properties of Nitriding Steel

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Abstract

Desired mechanical properties like microstructure, micro hardness and wear resistance are the key parameters for which low carbon steel (AISI 1006) are widely selected. Surface heat treatment applied to improve these properties; traditionally surface heat treatments like induction hardening, in recent time's laser surface hardening. In this work, thermochemical treatment (liquid nitriding) by using mixture from 61% NaCN, 15% K_2CO_3 and 24% KCL and followed by Nd:YAG laser surface treatment was done . The laser parameter were energy (0.89, 2, 4 and 9) J, spot diameter (0.790 ,0.٣٣, 0.٢٨٣ and 0.224) mm, pulses duration (1, 2.33, 4.47 and 9.87) ms with fix wavelength 1604nm. Laser surface treatment cycle was melting the layer surface, holding and rapid cooling in air medium. Optical microscopy (OM) and scanning electron microscope (SEM) has been used to study the microstructures and cross-sectional of molted and heat affected zones respectively. The wear test was done to measure the wear rate by using pin -on-disk principles were satisfied. The result shown that increasing in laser energy effects to increase in the area of melted and heat affected zones of nitriding steel. Also increasing in laser energy led to increase micro hardness about 61%, while wear rate decrease about 40 % and increased depth of molted zone.

Keywords: Nd: YAG Pulsed Laser, Laser Energy, Nitriding Steel, Wear Resistance.

تأثير طاقه الليزر النبضيNd:YAG على الخصائص الميكانيكه للفولاذ المنترد

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الخلاصة :

الخصائص الميكانيه المرغوبه مثل البنيه المجهريه , الصلابه الدقيقه ومقاومه التأكل هي المعاملات الرتيسه التي يتم اختيار الفولاذ المنخفض الكاربون (AISI1006) لها على نطاق واسع . ولتحسين هذه الخصائص يم تطبيق المعالجه الحراريه السطحيه,المعاملات الحراريه التقليديه مثل التصلب بالحث وفي الاونه الاخيره تصلب السطح بالليزر.في هذا العمل تم اجراء المعالجه الحراريه الكيمائيه (النترده السائله)باستخدام خليط مكون من ٦١%سينانيد الصوديوم ,١٥٪ كاربونات البوتاسيوم و ٢٤٪ من كلوريد البوتاسيوم ,متبوعا بالمعالجه السطحيه بالليزر النبضي Nd :YAG كانت متغيرات الليزر ,طاقه ٠,٨٩ ,٢ ,٤, و٩ جول ,قطر النبضه ٠,٣٣ ,٠,٢٢٤،٠,٧٩٠ و ٠,٢٨٣ مليمتر ,مده النبضه ١ ,٤,٤٧،٢,٣٣ و ٩,٨٧ ملي ثانيه مع طول موجه ثابت ١٠٦٤نانومتر .تم استخدام المجهر الضوئي(OM) والمجهر الالكتروني الماسح(SEM) لدراسه الهياكل المجهريه والمقاطع العرضيه للمناطق المتأثره بالحراره على التوالي .تم اجراء فحص التاكل لمعرفه معدل التأكل, .أظهرت النتائج ان زياده زياده طاقه الليزر ادت الى زياده في مساحه المنطقه المنصهره والمنطقه المتاثره بالحراره من الفولاذ المنترد ,كما أدت الزياده في طاقه الليزر الى زياده الصلابه الدقيقه بحوالي ٦١٪ بينما انخفض معدل التاكل بحوالي ٤٠٪ وزياده عمق المنطقه المنصهره.

1. Introduction

Heat treatment on low carbon steel which is easily available and having all material properties that are acceptable for many applications is most important factors to improve properties such as hardness, ductility, roughness and wear rate to meet desired engineering applications in determining how they will perform in service. There are many techniques of surface hardening applied on the surface of ferrous materials such as case hardening, carburizing, carbonitriding, nitriding and flame. This technical causes thermal distortion of the parts, so that required refinishing surface. The classification of different surface engineering technologies by using laser beam depends on the different physical changes in the surface and laser parameters. [1]. The use of laser science and technology in the development of materials made significant progress due to the flexibility of control of the beam's interaction, with regard to wavelength, , and the wide choice of interaction environments [2].Application of laser technology in material surface modification takes advantage of heat energy from the laser beam to change the materials' surface properties.Laser surface treatment has more advantages over the conventional methods which include local heating of the required area without altering the substrate material properties, precision and high speed of operation, and low cost ,laser is used in several engineering application for surface hardening such as internal composition part, valves ,pipe fitting and pressure containing part[3]

C.J. Copola, et al (2002) [4] the study presents the influence of Nd:YAG laser (1064 nm) and XeCl excimer laser (308 nm) energy per pulse, number of shots, background pressure and nitrogen atmosphere, on the low carbon steel samples phases formed during irradiation ,founded that the better corrosion performance of the nitride sample was observed, mainly after pre-corrosion treatment and at a mode rate fluence .

Mahmoudi, et al. (2009) [5] presented study laser treated by pulsed Nd:YAG laser, the AlSI martensitic stainless steel hardening by pulsed Nd : YAG, and studied the effect of process parameters laser pulse energy, duration time and travel speed on the depth of laser treated area . The results showed that the hardness was up to (490 VH) of AlSI 420 with the best laser parameter

M. A. Abdulrazzaq (2016) [6] the study present the limitation of surface carburizing for low carbon steel in oil solution. The micro structure, mechanical properties; hardness and wear resistance has been investigated taken different temperatures; (850, 900, and 950 ˚C) with constant time (2 hr) of carburizing process. The results shows that at carburizing temperature (850 ˚C), the hardness was increases from the inside to outside of specimen from (102 to HV 250), while increases for temperatures (900 and 950 ˚C) from (105 to 272 HV), and to (192 HV) respectively. This experiment also been conducted for wear resistance for harder samples which was at 950 ˚C carburized sample for three times (2, 4 and, 6 hr) and the wear rate was (9.99*10-6 g/m) at 2 hr), and for (4 hr) it was (12.7*10-6 g/m) and at (6 hr) it was (15.13*10-6 g/m).

F.Z. Benlahreche et al.(2017)[7] gave detailed of the physicochemical properties of a low carbon steel C15 by a nitriding treatment in a salt bath at 580C. The result show that nitriding is an effective method of surface treatment to improve the mechanical and electrochemical behavior of C15 low alloy steel, increasing the nitrogen content by direct diffusion through the surface, while keeping the unchangeable and tenacious heart that to absorb deformation and shocks.

Shahad etal,(2018)[8]presented study of Nd-YAG laser parameters such as laser energy, pulse duration effected on the microstructure, micro hardness, surface roughness and wear resistance of surface gray cast iron. The results showed that increasing in laser energy led to increase the area of melted zone and heat affected zone, which resulted from the formation of marten site and irregular graphite, increasing in micro hardness value. the roughness of the samples was decreased by about (27%), weight loss and the wear rate decreased by about (78%) after laser treatment with pulse duration 0.8ms .

Abbas alwan et al(2019) [9] concerned with improvement the surface microstructure and micro hardness of valves metal type cast iron by applied CO2 pulsed wave laser .The laser parameters are energy 1.8, 2, and 2.5 J, pulse repetition rate 1-3 pulse/sec and spot diameter are 0.87, 0.75 and 0.59 mm at fix wavelength 10600 nm and. The results have shown that the improvement of microstructure by consists of irregular graphite due to increasing of laser energy.Also increasing in laser energy effect to increase micro hardness in heat affect and molten zones area

The aims of this study are to improve the microstructure and mechanical properties of low carbon steel AISI(1006) and nitriding steel AISI (1006) after different Laser energies .

2. Material and Method

2.1 Materials

The metals were used in this experiments was the low carbon steel AISI 1006 .Which provided by scientific office with the commercial name class [10, 11, 12]. The chemical compositions of the specimens which used in this experimental were shown in Table 1 and the mechanical properties of this metal were shown in Table 2

2. 2 Preparation of specimens

The specimen's preparation started by machine cutting of specimens according to the desired tests dimensions. The dimensions were diameter 10mm and 5mm height for the micro hardness test. The sample dimensions for wear test were 10mm diameter and10 mm height. The samples preparation for microstructures test were grind by using silicon carbide paper with different grids 120,180, 220,400,600 and 1200 after that the samples polishing by using special cloth and polishing paste Al 2O3 solution. The nital solution which used for etching the specimen is formed of 95% alcohol and 5% HNO3 and then the specimen washed with distilled water and alcohol. After that the samples washed by alcohol before laser treatment to remove the oils from the metal surface.

2.3 Thermo chemical treatment (liquid nitriding)

Liquid nitriding treatment was done by mixture contain from 61% NaCN, 15% K2CO3 and 24% KCL mixed well and then wrapped the samples in sheet of stainless steel 304 and immersed it in the mixture. The heat treatment was done by three stages, heat stage by using the furnace at temperature 560 oC for 30 min, the second stage was held time at 500C for two hours in furnace and followed by third stage; is cooling rate by quenchinginwater.

2.4 Laser surface hardening

In this work the specification of pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet; Nd: Y3Al5O12) with wave length 1064 nm , and pulse duration (50ms), the frequency (1-100) Hz, the maximum power the of laser beam (7.5 Kw),at energies value (0.89,2,4 and9J) with pulse duration as 0.89, 2.33, 4.47 and 9.87J , using an energy source to heat metals, laser light is directed to the work piece resulting in absorption and reflection of light. Absorption by metals is highly dependent on the wavelength of light, material type, angle of incidence and surface condition the shorter the wavelength, the better light is absorbed [13].

Table 1: The chemical compositions of the specimens

Elements	Actual value Wt.%	Standard value Wt.%
C	0.074	0.08
Si	0.011	0.6
Mn	0.403	0.25-0.4
P	0.011	0.04
S	0.024	0.05
Cu	0.173	0.40
Cr	0.090	---
Mo	0.008	---
Ni	0.072	---
Al	0.007	---
Co	0.011	---
Fe	Bal.	Bal.

Table (2): Mechanical properties of low carbon steel AISI 1006

Micro hardness (HV)	131
Tensile strength (MPa)	370
Poission Ratio	0.290
Thermal Conductivity (J/kg C^0)	24.3- 65.2
Density (g/cm^3)	7.85
Specific heat (J/kg K)	450 -2081

2.5 Wear rate.

Wear rate was calculated by used the device as shown in Fig. 1.The device consists of a rotary electric motor with a speed of 490 r. p. m which attached to a gearbox and shaft were the sample is a mounted, pin —on-disk principles were satisfied to measure the wear rate. A sensitive electronic balance was used for measuring the weight and light load 1000gm was used. The speed of sliding was equal to 4.2 mm/min and the distance of sliding wear was equal to 82mm.The samples were weighed before and after the test. The wear rate was calculated from the following equation:

W.R=(W2-W1)/S×t ………………………(1)

S.D= S × t (mm) ……………… ….…….. (2)

Where,

W.R.: is the wear rate (gm/mm), W1: is the sample mass before wear test (gm), W2: is the sample mass after wear test (gm), S.D: is the distance of sliding wear (mm), S: is the Speed of sliding (mm/min) and t :is the time of sliding (min)

Figure (1): Device of Wear Test

3. Results and discussion

3.1 Effect of laser energy on microstructure Nd:YAG laser parameters beam diameter 0.6mm, four different energies values, with wave length 1064 nm and cooling in air media as shown in Table 3. The molten area was found to be affected by the laser energy values. Increasing laser energy led to increase in the laser beam divergence and then increase in the area of melted and heat affected zones. The distribution of the electromagnetic field to a few energies for pattern Gaussian is characterized by a small divergence, hence, the heat generated increased with increasing the laser energy. The molted size after nitriding was increased with increasing the laser energy as shown in Table 4 .

Table (3): Laser Nd-YAG Parameters

Laser energy E(J)	Pulse duration T (*ms*)	Spot area A (cm^2)
0.89	1	0.000790
2	2.33	٠,٠٠٠٣٣
4	4.47	٠,٠٠٠٢٨٣
9	9.87	0.000224

Table (4): Effect of Energy in Melted Spot Size.

Sample NO.	Laser energy E(J)	Pulse duration T(ms)	Base metal Melted spot size (mm)	After nitriding Melted spot size (mm)
1	0.89	1	----	----
2	2	2.33	----	----
3	4	4.47	0.039	0.044
4	9	9.87	0.082	0.314

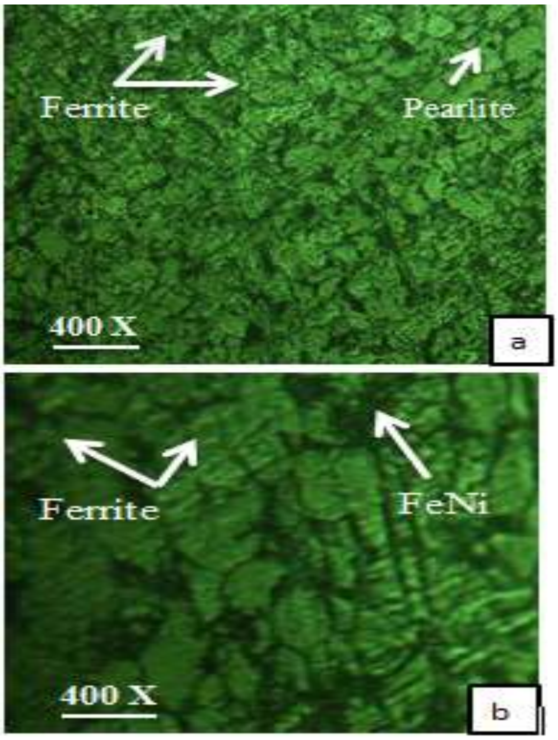

Figure (2): Micro Structure of Samples, A: Base Metal and B: after Nitriding .at 400X

The results of XRD (X-ray Diffraction) test which explain Alfa –Iron (α —Fe) phase for base metal , as shown in fig .3-A, the effect of laser treatment on nitriding steel after nitrides formation as shown in fig.3-B .These results with a agreements with researcher [14].

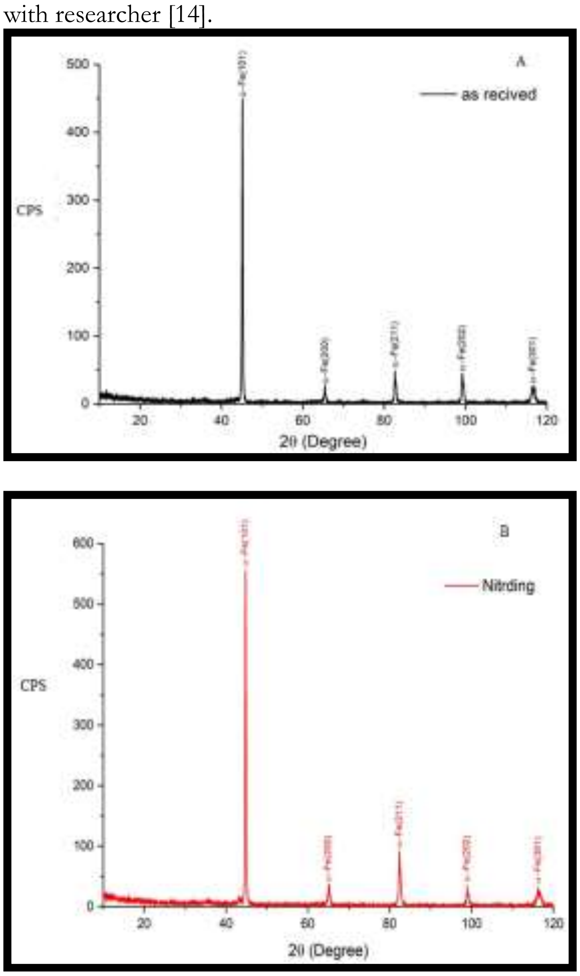

Figure (3): X-Ray Diffraction of specimens, A; As-received and B; Nitriding steel

The shape of melted pool with defined depth were depended on the laser energies values0.89 J and 2.33 J were found to be insufficient to perform laser treatment as shown in Fig. 4;A and Fig. 4;B. Also we found increase molten area with increase laser energy as shown in Fig. 4;C and Fig. 4;D. It noted increase melted zone size (MZ) and heat affected zone (HAZ) with increase laser energies and pulse duration. The laser interaction with metal surface after nitriding was illustrated in Fig .5 ;A, show incomplete fusion at low laser energy at 0.89 J, while large size of the molten zone associated with the laser energy at 4J and 9 J as shown in Fig. 5; C and D, because formation of new phase Fe4N. These results are agreements with researcher. [15]

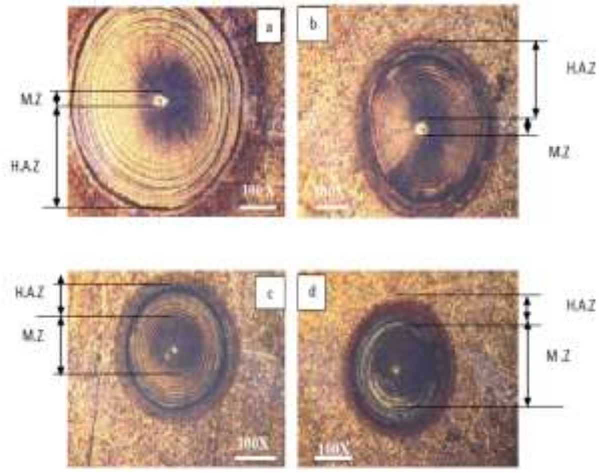

Figure (4): Effect of laser energy of microstructure (base metal),(A: 1J at 100X),(B:2J at100X),(C:4J at100X),(D:9J at 100X)

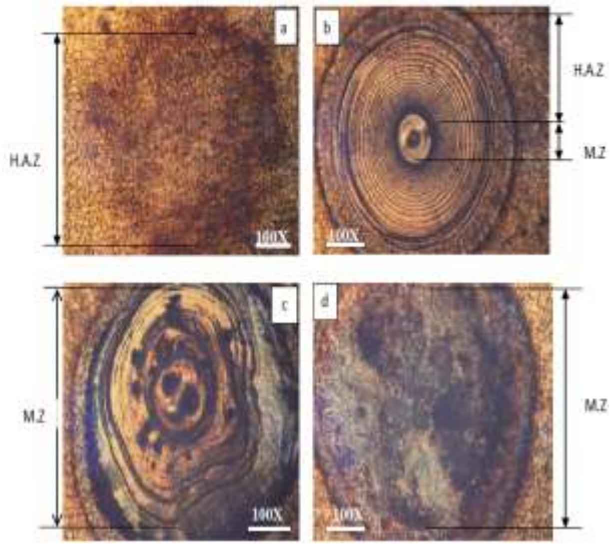

Figure (5): Effect of laser energy of microstructure (nitriding steel), (A: 1J at 100x), (B:2J at100x), (C:4J at100x),(D:9J at 100x)

3.2 Effect of laser energy on the Micro hardness.

The effect of changing in the laser energy, pulse width and power density on the laser surface melting effect is reported in this work. The results of the samples after laser surface treatment with different laser energy and pulse duration for base metal and nitriding steel samples were calculated and correlated with the obtained surface melting are shown in Tables 5and Table 6.

It is shown from this table that the size of the spot area affected by the increases of laser energy and spot diameters, as increase spot diameters lead to decrease in hardness of surface metal, micro hardness was increase with increase in laser energies due to martensite formation and followed by quenching in air cooling, while energy density increase with increased laser energy. These results with high matching with result of [4].

Table (5): Hardness of base metal with different pulses laser energies

Laser energy (J)	Pulse duration (ms)	Spot area (cm^2)	Peak power (W)	Power density (W/cm^2)	Energy density (kJ/cm^2)	Hardness (HV)
0.89	1	0.00079	890	12.7×10^5	11.3×10^2	727.1
2	2.33	0.00033	843	12.04×10^5	28.1×10^2	751.1
4	4.47	0.00028	894	9.93×10^5	44.4×10^2	857.6
9	9.87	0. 00224	910	4.5×10^5	45×10^2	952.4

Table (6): Hardness of nitriding steel with different pulse laser energies.

Laser energy (J)	Pulse duration (ms)	Spot area (cm^2)	peak power (W)	Power density (W/cm^2)	Energy density (kJ/cm^2)	Hardness (HV)
0.89	1	0.00093	890	9.5×10^5	9.5×10^2	989.5
2	2.33	0.00090	843	4.2×10^5	9.7×10^2	1070.9
4	4.47	0.00087	894	2.2×10^5	9.8×10^2	1158.6
9	9.87	0.00065	910	1.5×10^5	14×10^2	1497.1

3.3Effect of laser energy on metal topography.

An increasing in laser energy effect to increase the depth of melted zone as shown in Fig. 6 and Fig.7 low magnification SEM images of the microstructure of the untreated sample (base metal) .Fig .6;A, shown the melted depth at energy 4J(39.95 μm).Fig.6;B, the melted depth of the laser pulse at energy 9J(82.86μm). Fig .7 shows low magnification SEM images of the microstructure of the nitriding steel .Fig .7:A: white layer which compound from α-Fe4N phase and γ Fe3Nphase ,it's very hard layer with thickness about (0.039mm) that effect to improve surface properties. Fig .7:B shows the effect of laser energy on the metal surface ,melted depth of laser pulses in the surface of the metal at 4J (44.44μm) and (58.97 μm) at energy 9J. These results are agreements with researcher [9].

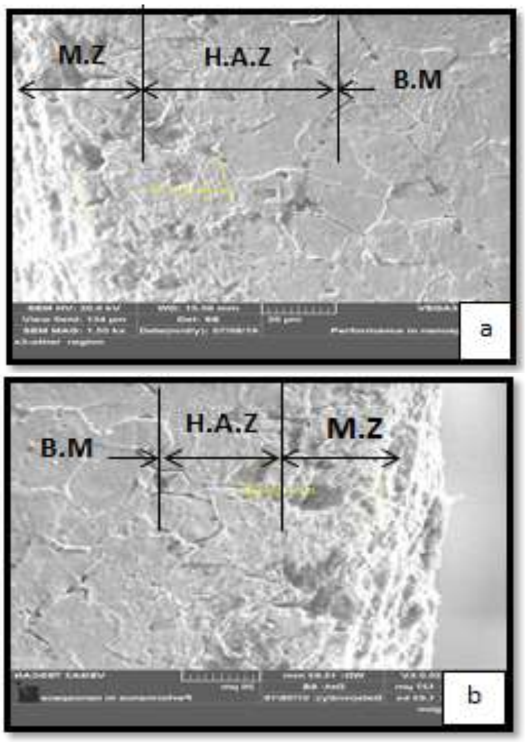

Figure (6): SEM Image for Base Metal.(A: at 4J, B :at 9J

3.4 Effect of pulse laser energy on wear characteristic:

Wear rate was calculated for the samples by applying equation (1) and (2),taken at least three reading for mass loss at different time (10,20,30) min, with rotating speed 490 r.p.m.at laser energy (0.89 ,2,4and9J).An increase laser energy lead to increase in mass loss as shown in Fig.8. Wear rate decreases with increase hardness values due to martensite formation when increase laser energy as shown in Fig.10.These results is agreements with research [15, 16].

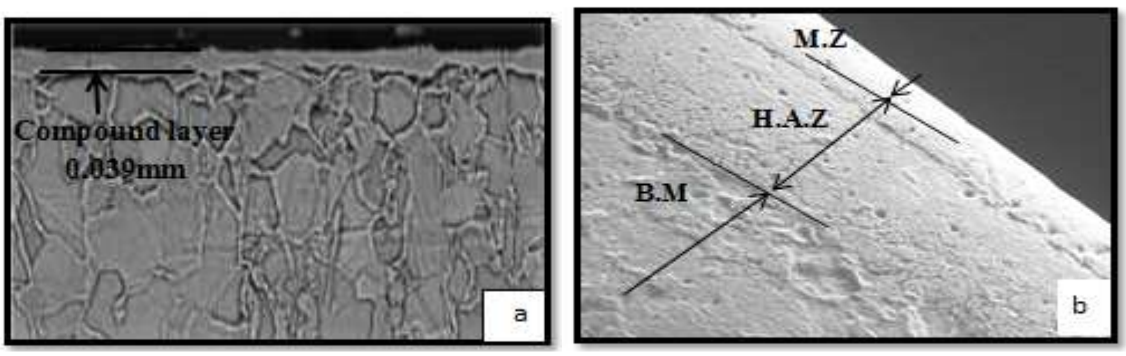

Figure (7): SEM image for Nitriding Steel. a: white layer, b: microstructure after laser treatment

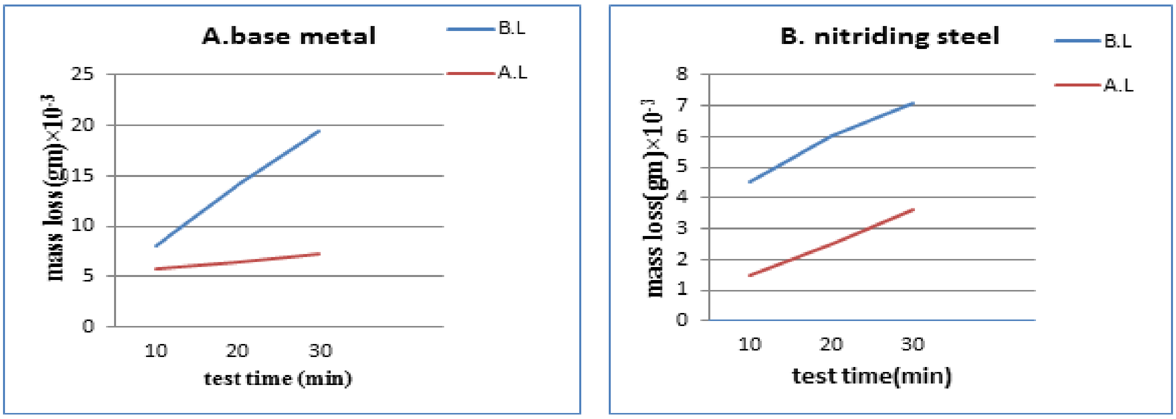

Figure (8): The relationship between the mass loss and the period time. A: Base metal and B: Nitriding steel, B.L (before laser), A.L(after laser)

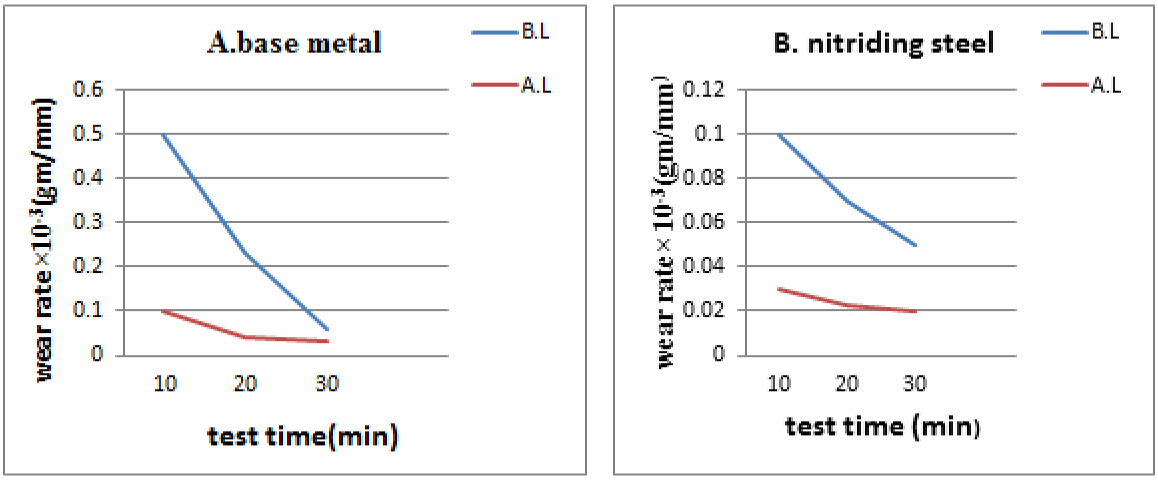

Figure (9): The relationship between the wear rate and the period time. A: Base Metal and B: Nitriding Steel, B.L (before laser), A.L(after laser).

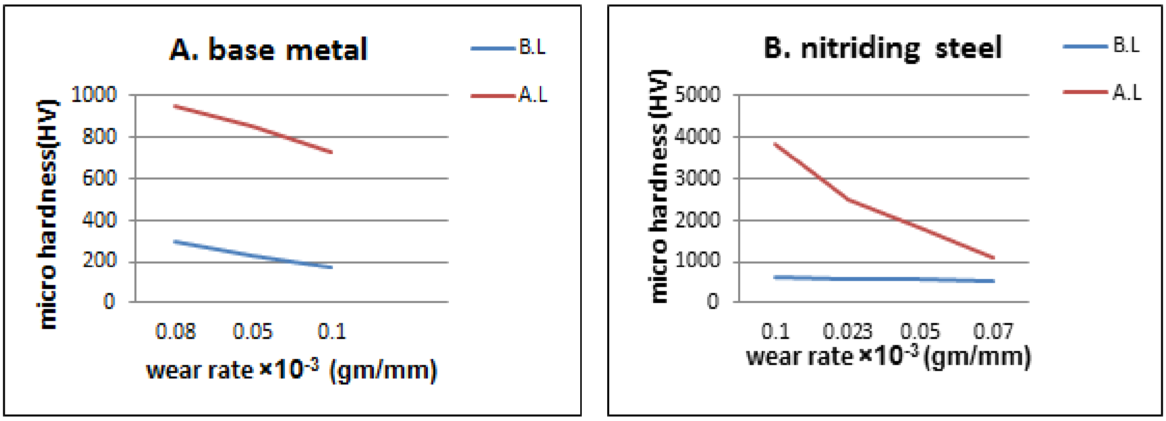

Figure (10): The relationship between the wear rate and micro hardness. A: Base metal and B: Nitriding steel, B.L (before laser), A.L(after laser).

4. Conclusion.

1. Improvement of microstructure and micro hardness of low carbon steel by using thermo chemical treatment type liquid nitriding.
2. Formation of martensite and iron carbide phases due to laser surface treatment.
3. An increase in laser energy that effect to increase micro hardness in heat affect and molten zones.
4. Increasing laser energy led to increases of molted spot size.
5. Increase depth and size of molted zone with increase of laser energy.
6. Decrease in wears resistance with increase laser energies.

5. References:

[1] Janina M R "Metallography and micro structures of cast iron". Hand book, volume 9, Metallography and Microstructures, 2010.

[2] USA. J. Kusinski, M. B .A" Laser modification of the materials surface layer" a Technical Sciences, Vol. 60, No. 4 , 2012.

[3] Hwang, J.H. "Laser Surface Hardening of Gray Cast Iron used for Piston Ring", Journal of Materials Engineering and Performance , Vol.11, p.p: 294-300 , Korea,2002.

[4] A.I. Katsamas, G.N. Haidemenopoulos" Laser-beam carburizing of low-alloy steels" Surface and Coatings Technology 139. 183191,2001.

[5] C.J. Copolaa, I. Avrama, M.C. Terzzolia, S. Duhaldea*, C. Moralesa,T. Pe´reza, F. Audeberta, Ph. Delaporteb, M. Sentis," Influence of laser parameters on the nitriding of low carbon steel" Applied Surface Science 197–198 896–903,2002.

[6] Monterio W A "Micro structural and mechanical characterization of gray cast iron and AL Si alloy after laser beam hardening". Journal of Materials Science Forum 638-642,769-774. 2010.

[٧]WU Gan*, WANG Rui, YANG Jang-ping, CHEN Xue-kang, CAO Sheng-zhu, GUO Wan-tu, SHANG kai-wen,Wei Bo, Wang Xiao-yi, Wang Lan-xi" Study of laser nitriding on the GCR15 steel surface".science direct, Physics Procedia 18 285–290,2011.

[٨]Tarak Amine & Joseph W. Newkirk ,Hussam El-Din F. El-Sheikh , Frank Liou,"Microstructural and hardness investigation of tool steel D2 processed by laser surface melting and alloying" Int J Adv Manuf Technol) 73:1427–1435,2014

[٩]Dr. Mohammed Abdulraoof Abdulrazzaq," Investigation the Mechanical Properties of Carburized Low Carbon Steel" Int. Journal of Engineering Research and Application .ISSN: 2248-9622, Vol. 6, Issue 9, (Part -2) September 2016, pp.59-64

[١٠] Poppy Puspitasari1, Sandy Yudha1, Mochammad Afit Muflich1,Andoko Andoko1, Sukarni Sukarni1, Heru Suryant "Hardness Improvement on Low Carbon Steel using Pack Carbonitriding Method with Holding Time Variation" 1Mechanical Engineering Department, Faculty of Engineering, Universitas Negeri Malang, Malang,

[11] F.Z. Benlahrechea;* and E. Nouicerb." Improvement of Surface Properties of Low Carbon Steel by Nitriding Treatment" Special Issue of the 6th International Congress & Exhibition (APMAS2016), Maslak, Istanbul, Turkey, June 1–3, 2016

[12] Shahad Sabah Aziz, Abbas S Alwan and Kadhum Ahmed Abed" Influence of Nd- YAG Laser Beam on Microstructure and Wear Characteristics of Gray Cast Iron". Bioch. Cell. Arc. 19(1), 000-000 2019.

[١٣]Abbas S. Alwan, Enass A. Khalid and Sameer K. Fayyadh" Improvement the surface Propertise of Metal Valves Used in Agriculture Engine by Using CO2 Laser Beam" Biochem. Cell. Arch. Vol. 19, No. 1, pp. 1581-1585, 2019.

[14] Laber, A."Tribological properties of cast conditioned by a Technological surface layer and Material Micro structure", Journal of Vibroengineering , p.p: 468-476 , 2011.

[15] Kennedy, D., Xue, X., and Mihaylova, E., "Current and Future Applications of Surface , Engineering" the Engineers Journal of Technical Vol.59, p.p: 287-292, 2005.

[16] Vereuzub, O., "Classification of Laser Beam Induced Surface Engineering Technologies and in sit4 Synthesis of Steel Matrix Surface Nano Composites" Surface Engineering journal, Vol. 27, p.p: 428-435, 2011.

[17] Alaa Fathel Edan "Simulation Study of Carbon Steel Phase Transformation using Nd:YAG laser Pulse" University of Technology,2008.

[18] Dr. A. Devaraju.,"A Critical Review on Different type of Wear of Material" International Journal of Mechanical Engineering and Technology (IJMET) Vol. 6, No. 11.2015.

[19] Khansaa, D.S. "Effect of laser surface Treatment on wear Resistance of 100 Cr6 Steel" Journal of Engineering and Technology, Vol. 27, No.6 , 2009.

[20] A Mohamad, A.K., Salal, D.S. and Ghazalia, M.J., "The Effect of laser surface Hardening on the wear and Friction Characteristics of Acicular Bainitic Ductile Iron", Internation Jornal of Mechanical and Materials Engineering (IJMME), Vol. 4, No.2 p.p : 167-171, 2009.