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Effect of Nd-YAG Laser Pulses on Mechanical Properties of Carbontriding Steel type (AISI 1006)

Ansam A. Aziz†*, Enas A. Khalid†, Abbas S. Alwan‡

†Department of Automated Manufacturing Engineering, Al-Khwarizmi College of Engineering, University of Baghdad, Iraq.

‡Department of medical Instrumentation Technical Engineering, Electrical Engineering Technical Collage, Middle Technical University

*Corresponding Author Email: ansam.g.aziz@gmail.com

ABSTRACT: Nd: YAG laser was applied to modify the surface characteristics of carbonitriding steel, such as microstructure, surface roughness, micro hardness and wear resistance. In this work; traditionally surface heat treatments carbonitriding was done on low carbon steel type AISI (1006) by using mixture from 40% NaCN ,30% Na2CO3 and 30% NACL ,followed applied Nd: YAG laser surface treatment. The laser parameters were energy 0.89, 2, 4 and 9 J, pulses duration 1, 2.33, 4.47and 9.87 ms, spot diameter 0.1049,0.1065,0.1077 and 0.1092 mm, with fix wavelength 1604nm. The laser surface treatment cycles wasmelting 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 by using pin -on-disk principles were satisfied to measure the wear rate. The result shown that increasing in laser energy effects to increase in the area of melted and heat affected zones of nitriding steel. Also increase in laser Pulses duration lead to increases in micro hardness increased which increased about 81% while wear rate decreased 69%.

KEYWORDS: Carbonitriding steel, Nd: YAG pulsed laser, pulses duration, wear resistance

INTRODUCTION

Heat treatment is the term used to describe the controlled heating and cooling of materials for the purpose of altering their structures and properties. The same material can be made weak and ductile for ease in manufacture, and then retreated to provide high strength and good fracture resistance for use and application. Because both physical and mechanical properties (such as machinability, toughness, strength and wear resistance) can be altered by heat treatment, and these changes can be induced with no concurrent change in product shape, heat treatment is one of the most important and widely used manufacturing processes [1]. 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. Laser surface hardening is one of the new technologies for selective surface treatment and primarily used in steel with, the classification of different surface engineering technologies by using laser beam depends on the different physical changes in the surface and laser parameters .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, low cost and don't required any accessories ,laser is used in several engineering application for surface hardening such as internal composition part, valves ,pipe fitting and pressure containing part[2,3].

Mahmoudi, et al. (2009) [4] 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

Shu-hung Yeh, et al .2011 [5] Investigated the corrosion behavior of the nitro carburized hot work steels. The nitro carburizing treatment was conducted in a570°C salt bath for 40, 80, and 120 minutes, respectively. The thickness of compound layers of all nitro carburized specimens was about 1-3 μm. As increasing treatment time, compound layer was translated from homogeneous to non-homogeneous.The results show the ε-phase (Fe_3N) and γ'-phase (Fe_4N) were appeared on the nitro carburized specimen. The micro hardness profiles of the nitro carburized exhibited that the maximum case hardness. There is no evident difference on corrosion current density with prolonging nitro carburizing treatment for both steels.

Shahad etal. 2018 [6] ,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 al2019 [7], Deal with modify the surface microstructure and micro hardness of valves metal type cast iron by applied CO_2 pulsed wave laser. The laser parameters are energy 1.8, 2, and 2.5 J, and pulse repetition rate 1-3 pulse/sec. The results shown that the modification of microstructure by consists of irregular graphite with increase laser energy, 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 carbonitriding steel AISI (1006) after different Laser energies and pules duration.

MATERIAL

The low carbon steel AISI 1006 carbonitriding steel which used in this study provided by scientific office with the commercial name class [8]. The chemical compositions of the specimens which used in this experimental was shown in Table 1 and the mechanical properties of this metal were shown in Table 2.

Table 1. Chemical composition of low carbon steel AISI 1006.

Elements	Actual Value wt%	Standard Value wt%
C	0.07	0.08
Si	0.011	_
Mn	0.403	0.25-0.4
P	0.011	0.04
S	0.024	0.05
Cr	0.090	_
Mo	0.008	_
Ni	0.072	_
Al	0.007	_
Cu	0.173	_
Co	0.011	_
Fe	Bal	_

Table 2. the properties of low carbon steel AISI 1006

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

Preparation of specimens

The specimen’s preparation started by machine cutting of specimens according to the desired tests dimensions. For micro hardness test the dimensions were 10mm diameter and height was 5mm. The sample dimensions for wear test were diameter of 10mm and10mm height. The samples preparation for microstructures test were grind by using silicon carbide paper with different grids 120, 220,400,600 and 1200 after that the samples polishing by using special cloth and polishing paste Al 2O3 solution. The nital solution which is formed of 5% HNO3 and 95% alcohol using for etching the specimen and then washed with distilled water and alcohol. After that alcohol was used to wash the samples and remove oils from the surface before laser treatment.

THERMO CHEMICAL TREATMENT (CARBONITRIDING)

Carbonitrding is one of surface modification techniques in which both carbon and nitrogen are added to the surface layer of steel at predetermined temperature $(800\text{-}900)^0$C for (2-10) hour followed by quenching ,to increase the surface hardness of a metal, thereby reducing wear. In this work after clean samples and remove rust and oxides and roughness form it surfaces. Thermochemical treatment done by using mixture content from 40% NaCN ,30% Na_2CO_3 and 30% NACL, heat treatment was done by three stages, heat stage by using the furnace at temperature 950 ^{o}C for 30 min, the second stage was held time at 900C for two hours in furnace and followed by third stage; is cooling rate by quenching in water .

Wear test

The wear test advice shown in Figure 1 was used to compute the wear rate. The advice 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. Light load 1000gm was used and a sensitive electronic balance was used for measuring the weight. The distance of sliding wear was equal to 82mm and the speed of sliding was equal to 4.2 mm/min. The weight loss at time 10, 20 and 30 min. The samples were weighed before and after the test. The wear rate was calculated from the following equation:

$$W.R=(W2-W1)/S\times t \quad (1)$$

$$S.\ D. = S \times t\ (mm) \quad (2)$$

Where,

W.R. : is the wear rate (gm/mm), *W*1: is the sample mass before wear test (gm), *W*2: 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).

RESULTS AND DISSCUSION

Effect of laser pulse energy on microstructure

The Nd:YAG laser parameter with fixed wave length 1064 nm, beam diameter 0.6mm, different four laser energies values, spot area, pulse duration and cooling in air media as shown in Table 3. The molten area was found to be affected by the laser energies 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. After carbonitriding process the molted size was increased with increasing the laser energy value as shown in Table .4.

Table 3. Laser Nd-YAG Parameters

Laser pulses energy (J)	Pulse duration(*ms*)	Spot area(mm^2)
0.89	1	0.01
2	2.33	0.0091
4	4.47	0.009
9	9.87	0.008

Table 4. Effect of energy in melted spot size.

Laser pulses energy (J)	Laser pulse duration(ms)	Base metal Melted spot size(mm)	After Carbonitriding melted spot size(mm)
0.89	1	0.071	0.01
2	2.33	0.077	0.084
4	4.47	0.247	0.254
9	9.87	0.368	1.01

The micro structure of the specimen before and after laser treatment shown in Fig .2, a; the microstructure of the base metal before treated which consists of coarse grain from perlite and ferrite phases, but after carbonitriding processes, which consists of fine grain from perlite and ferrite phases as shown in Fig .2, b. Figure 3-a: show the analysis of XRD (X-ray Diffraction) which explain the Alfa –Iron (α -Fe) phase, and carbonitriding treatment as shown in Figure 3-b. These results with a agreements with researcher [9].

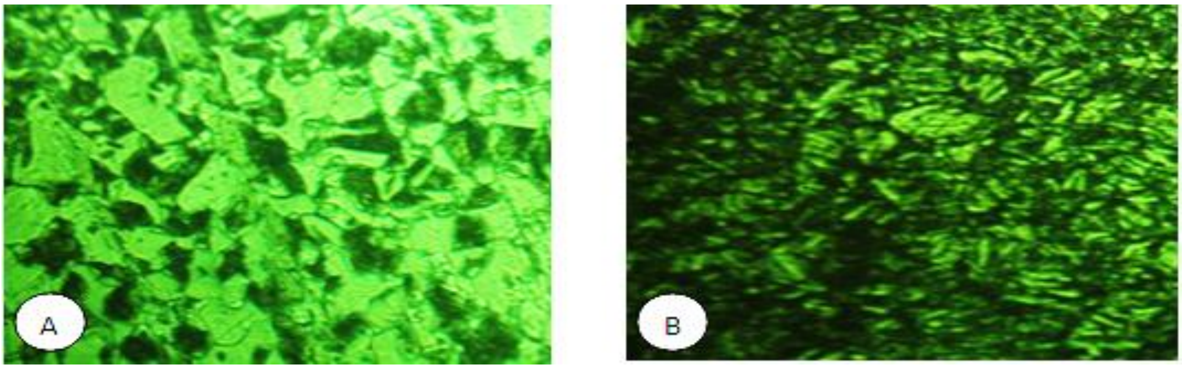
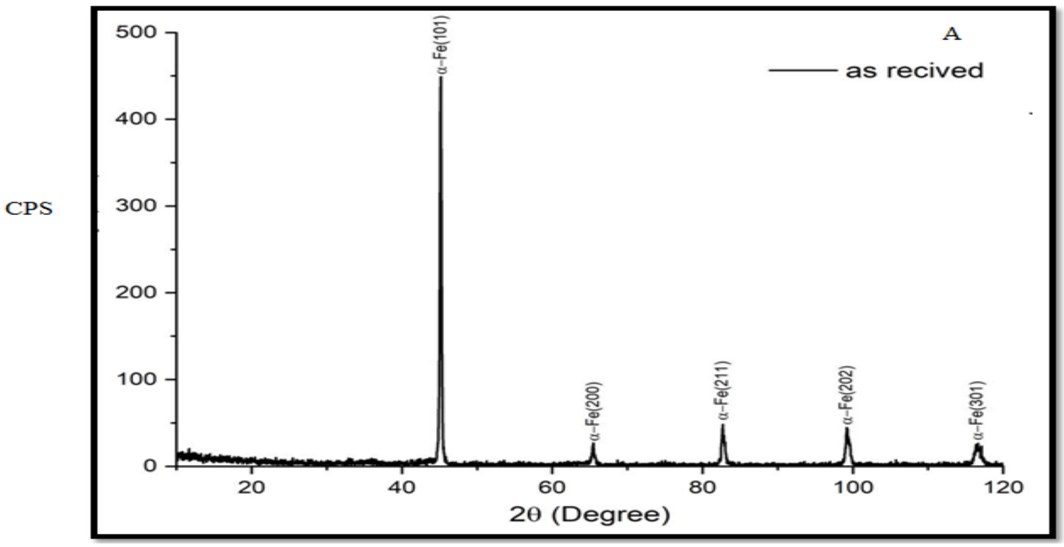


Figure 2. Micro structure of samples, A: base metal and B: after carbonitriding at 40X.



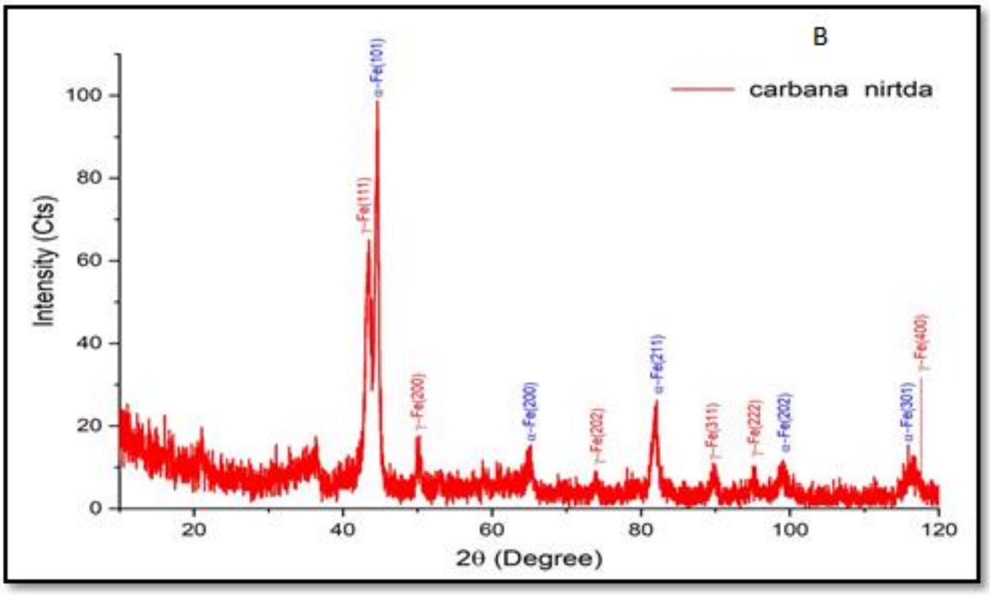


Figure 3. X-Ray diffraction of specimens, A; base metal and B; after carbonitriding

The energies estimations of 0.89J and 2J were seen as deficient to perform laser treatment as appeared in Figure 4 a and b. Additionally we discovered increase molten area with increase pulses energy as appeared in Figure 4 c and d. The laser collaboration with metal surface in the surface of carbonitriding was shown 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 Figure 5; C and D, because formation of new phaseFe_3C ,Fe_4N. These results are agreements with researcher [10].

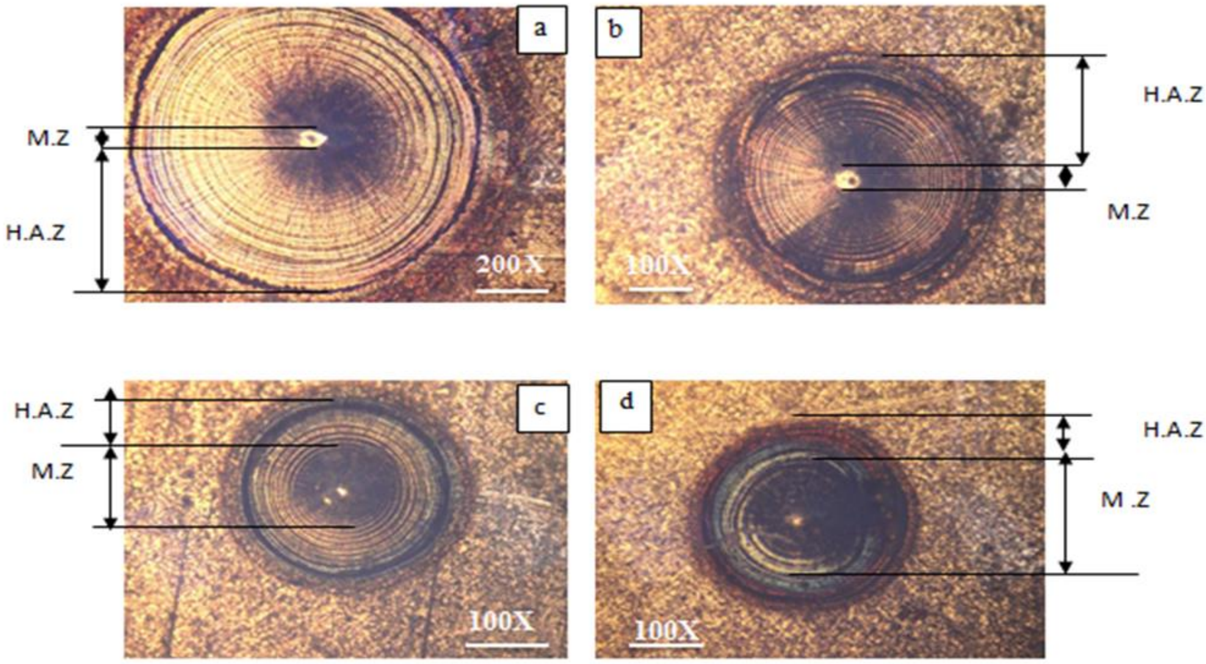


Figure 4. shows the molten pool of base metal after laser melting with different energies and pulse duration (A: 0.89J with 1*ms*), (B: 2J with 2.33*ms*), (C: 4Jwith 4.47 *ms*),(D:9J with *9.87ms*).

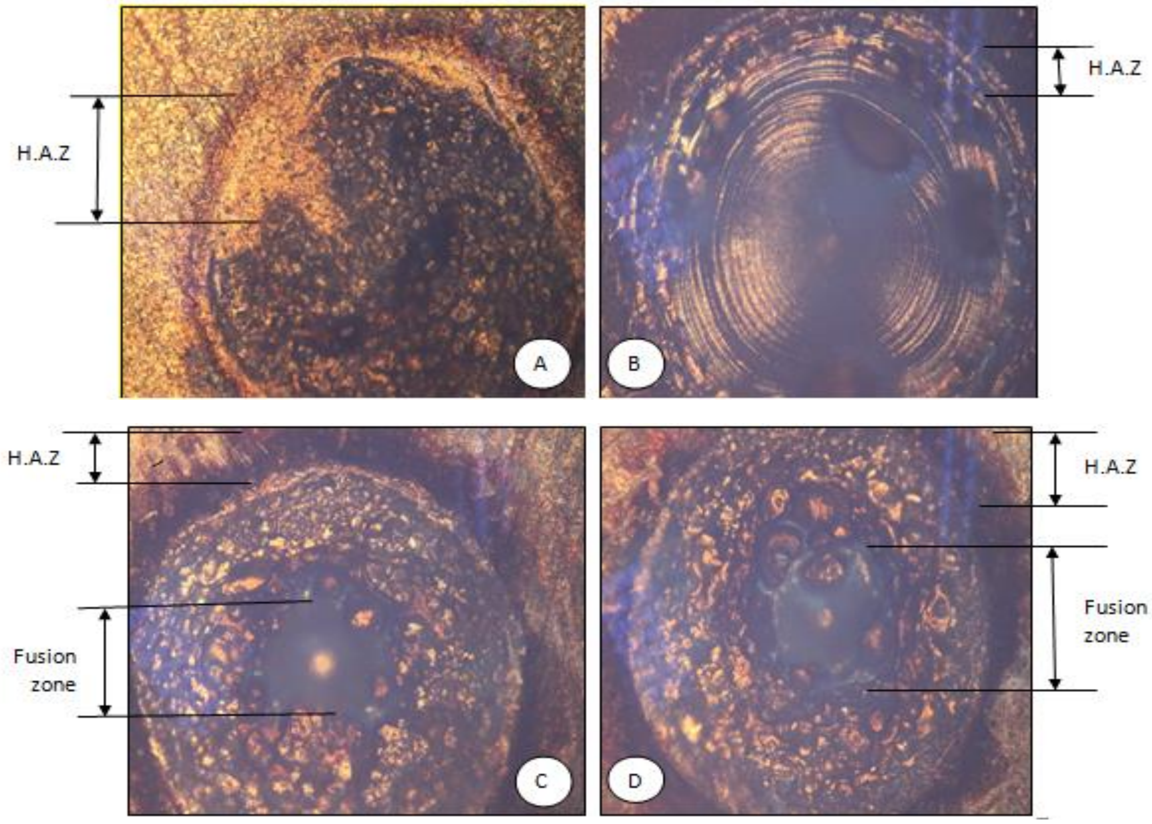


Figure 5. shows the molten pool of carbonitriding steel after laser melting with different energies and pulse duration (A: 0.89J with 1ms), (B: 2J with 2.33ms), (C: 4Jwith 4.47 ms),(D:9J with 9.87ms).

Effect of laser pulses energy on the Micro hardness.

The effect of changing in the laser energy, pulse width and power density on the laser surface softening impact is accounted for in this work. The results of the samples after laser treatment with different four laser pulses energy for as received steel samples were calculated and correlated with the obtained surface melting are shown in Tables 5. It is appear from this table that increase in laser pulses energy lead to increase in micro hardness, peak power, power density, energy density and decrease in the spot area. Also, we found increases in micro hardness values due to rapid cooling and carbide and nitrides formation after laser surface melting of carbonitriding steel as appear in Table 6. found higher hardness values after laser treatment of carbonitriding steel (Table 6) compared with base metal (Table 5), because of carbides and nitrides formation which had high hardness. These results with high matching with result of [11].

Table 5. Hardness of base metal with different laser pulses energy

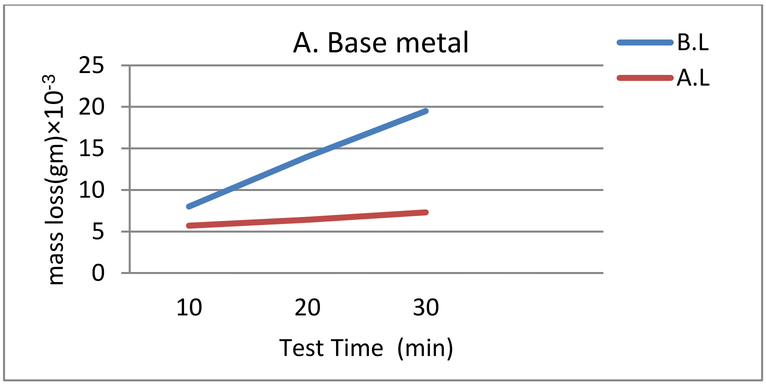
Laser energy (J)	Pulse duration (ms)	Spot area (mm2)	Peak power (W)	Power density (W/cm2)	Energy density (kJ)/cm2	Hardness (HV)
0.89	1	0.0078	890	114	114	195
2	2.33	0.00332	843	253	106	230
4	4.47	0.00292	894	306	68	279
9	9.87	0.00226	910	402	43	467

Table 6. Hardness of carbonitriding steel with different laser pulses energy

Laser energy (J)	Pules duration (*ms*)	Spot area (mm^2)	peak power (W)	Power density (W/cm^2)	Energy density (kJ/cm^2)	hardness (HV)
0.89	1	0.00 94	890	94.7	94.7	883
2	2.33	0. 0092	843	91.6	38.6	1011.3
4	4.47	0.0088	894	100	22.4	1382
9	9.87	0.00864	910	105	11.2	1503

Effect of laser pulses energy on wear characteristic

Major causes of improvement in wear resistance the increase in hardness due to increase in heating rate generation followed by rapid cooling. Increase in pulse energy led to increase in surface hardness which led to increase in mass loss as shown in Figures 6 and 7. Increase in hardness values which effect to decreases in wear rate as shown in Figure 8. These results are agreements with researchers [12]



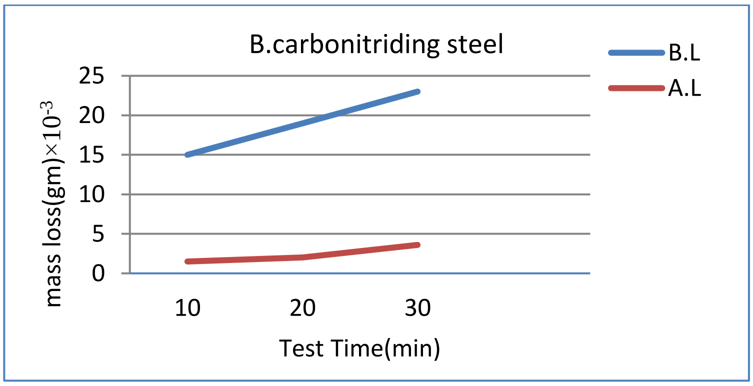


Figure 6. shows the relationship between the mass loss and the period time.A: base metal and B: carbonitriding g steel, B.L (befor laser), A.L (after laser).

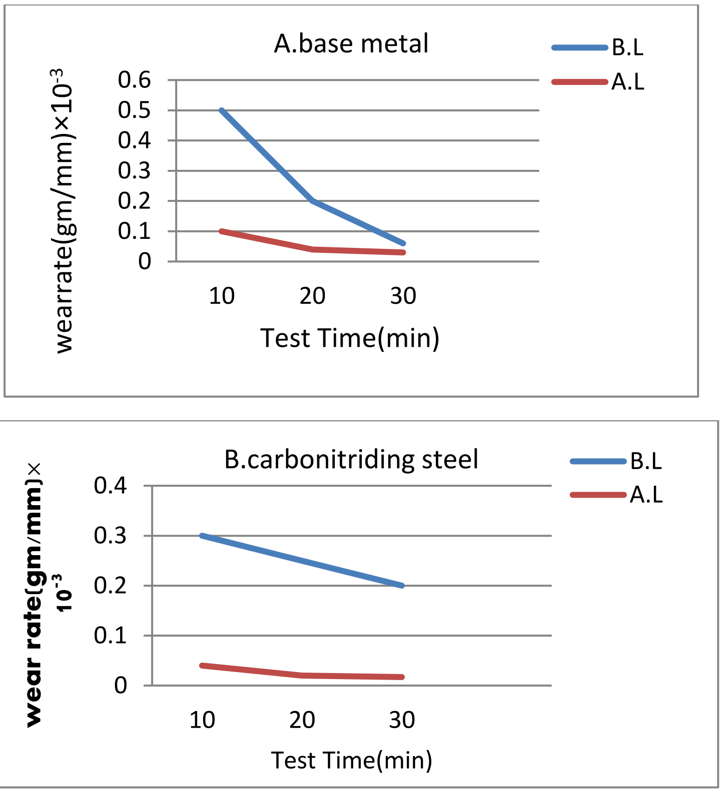


Figure 7. shows the relationship between the wear rate and the period time. A: base metal and B: carbonitriding steel, B.L (befor laser), A.L (after laser).

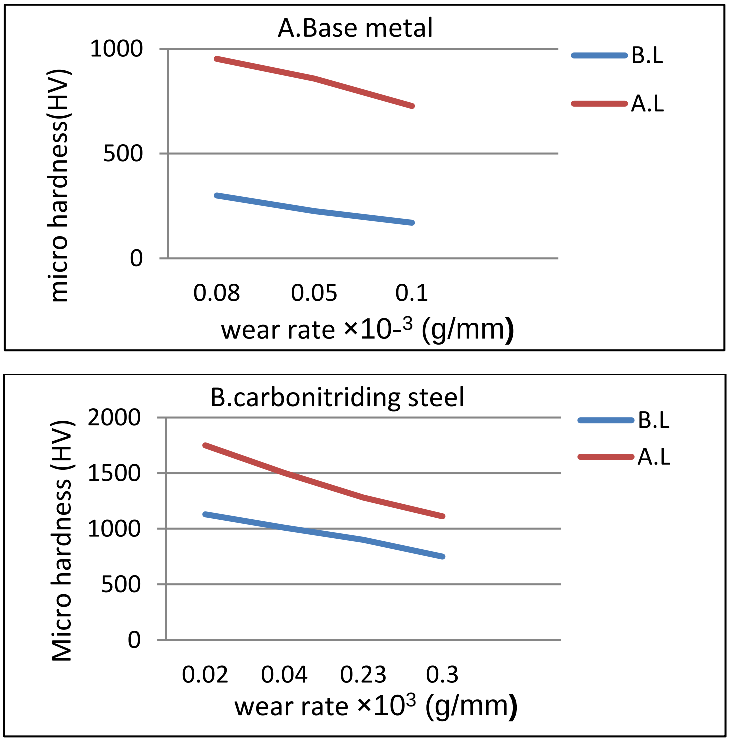


Figure 8. shows the relationship between the wear rate and micro hardness. A: base metal and B: carbonitriding steel, B.L (befor laser), A.L (after laser).

CONCLUSION AND RECOMMENDATIONS

1. Modification of microstructure, micro hardness and wear resistance of low carbon steel by using surface thermo chemical treatment type carbonitriding.

2. An increase in laser pulse energy lead to formation of martensite phase in low carbon steel, while formation iron carbide and iron nitride in carbonitriding steel after laser surface treatment which increase micro hardness and wear resistance of surface layer.

3. Heat effect zone and depth of molted zone increase due to increase of laser energy and laser pulse duration.

4. Increase in laser pulse energy lead to increase in peak power, power density and increase depth and size of molted spot size.

5. An increase in laser energy lead to decrease in mass loss (wear resistance was reduced by increasing laser pulse energy).

In a future study, possible to study the effect of other type of thermo chemical treatment such as : gas carburizing and gas nitriding on low carbon steel , study the effect of different other laser systems such as : (CO_2, fiber and high power diode laser) for the same metal (low carbon steel)

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