The Iraqi Journal For Mechanical And Material Engineering, Vol.17, No4, Dec. 2017

SURFACE LAYERS CHARACTERISTICS OF THREE DIFFERENT STEEL ALLOYS HARDENED BY ND: YAG LASER

Khansaa Dawood Salman **Asifa Mahdi Mohammed** **Enas Mozahim Abed**
khansaadawood@yahoo.com

ABSTRACT

Laser surface treatment is an effective way to improve the characteristics of surface layers for the most alloys. In the present work, three different steel alloys: low carbon steel A3115, medium carbon steel 1045 and high carbon steel 52100 were hardened by Nd: YAG laser at 1.064nm wave length with 1000mj energy. An experiments with Nd: YAG laser were carried out to study the effect of laser hardening process on the microstructure, roughness, microhardness during laser hardening of the three alloys. All of surface layers characteristics were analyses using optical microscope. Laser surface treatment enhanced the characteristics of surface layers for all the alloys. Also Nd: YAG laser surface treatment produced plate martensite for 52100 alloy more than A3115 and 1045 alloys. From the results is obtained finer martensite, an excellentroughness and larger microhardness for this alloy. The aim of present investigation study the effect of Nd: YAG laser hardening on the characteristics of surface layers for three different steel alloys (A3115, 1045, 52100) .

KEY WORD: Laser surface treatment, steel alloys, surface layers characteristics

خواص الطبقات السطحية لثلاث انواع مختلفة من سبائك الفولاذ المصلدة بالليزر نيديميوم – ياك

خنساء داود سلمان عاصفة مهدي محمد ايناس مزاحم عبد

الخلاصة :-

تعتبر المعاملة السطحية بالليزر من الطرق الفعالة في تحسين خواص الطبقات السطحية لأغلب السبائك . في البحث الحالي تم تصليد ثلاث انواع مختلفة من سبائك الفولاذ: فولاذ منخفض الكاربون A3115, فولاذ متوسط الكاربون 1045 والفولاذ العالي الكاربون 52100 بالليزر نيديميوم– ياك ذو الطول الموجي 1.064nm وبطاقة 1000mj. اجريت تجارب باستخدام الليزر نيديميوم – ياك لدراسة تأثير عملية التصليد بالليزر على البنية المجهرية, الخشونة, الصلادة الدقيقة اثناء التصليد بالليزر للسبائك الثلاثة . تم دراسة معظم خواص الأسطح للسبائك باستخدام المجهر الضوئي . اظهرت المعاملة السطحية بالليزر الى زيادة خواص الطبقات السطحية ولجميع السبائك, كذلك أدت المعاملة السطحية بالليزر إلى تكوين مارتنسايت رقائقي للسبيكة52100 اكثر نعومة مما هو عليه للسبيكتين 1045,A3115. من النتائج تم الحصول على أفضل خشونة وأعلى صلادة دقيقة لنفس السبيكة . الهدف من البحث الحالي هو دراسة تأثير التصليد بالليزر نيديميوم – ياك على خواص الطبقات السطحية لثلاث سبائك مختلفة من الفولاذ (A3115, 1045, 52100). .

Received: 2015 - 12 - 28
Accepted: 2016 - 4 - 21

INTRODUCTION

Since 1960s the laser is considered as a preferred technique for surface treatment. In material processing the laser have been known to enhance surface hardening, wear and corrosion resistance and prevent cracking of metals and alloys when compared with conventional methods [S .SathikBasha, 2014] . **The** hardened surface by laser can have superior chemical, physical and mechanical properties. The depth of hardening can be controlled by the power density and the scan speed in CW laser hardening or by the time of interaction with an alloy in pulse laser hardening **H.Visscher [1994].** In recent years, laser surface hardening becomes a widely used method to create hard phases on to a surface of substrate. This is due to the availability of high energy lasers that enable to focus high energy on a small defined area **L.F.Garcia [2013].** The laser heat treatment allows obtaining surface layers of high hardness and no forming the cracks. However, the operation characteristics of these layers depend on the condition of heat treatment and the chemical composition of an alloy hardened by laser **JanuszLubas [2011].** Laser processing and laser surface treatment of variety of metals and alloys have become a popular topic of study, because of it involves high concentrated heating of solid targets which in turn enable several types of structural changes, such as hardening and surface patterning by using high energy with temporal distribution and precision in dimensions; therefore to define a particular application it is necessary to choose the most optimal pulse duration **MitraRadmanesh [2015].** By using laser as heat treatment, the laser energy absorbed by the surface of an alloy and then can be transformed into thermal energy, which in turn lead to local heat treating or melting, producing phase transformations. After heating by laser, the rapid cooling can lead to create some microstructures with high hardness values **Olga TURCAN [2014]**.After the laser treatment, there are different zones were formed within the surface area as shown in Fig. 1, **Kuang, J, H. , Hung [2012] .** There are many literature surveys in this field, Purushothaman **Purushothaman Dinesh Babu . [2012]** made an experimental investigation to study the effects of laser hardening process parameters and the microstructure and hardness during laser hardening of EN25 steel. While Mitra Radmanesh and Amirkianoosh Kiani **Mitra Radmanesh [2015]** were studied the effects of power and pulse duration on the structure of stainless steel type 304 and optimized laser parameters for desired laser penetration and heat- affected areas on the surface **.** Whilst Khalid Osman Sharaf **Khalid Osman Sharaf [2011]** studies the influence of laser surface heat treatment on mechanical properties and wear resistance of high carbon- low alloy steel. The specimens were hardened by using ND: glass laser at three different laser energies.

EXPERIMENTAL WORK

In this work three different steel alloys: low carbon steel A3115, medium carbon steel 1045 and high carbon steel 52100 were used for surface treatment with 1 cm in diameter and 0.5cm in thickness. The chemical composition of these alloys is given in table1 **[Current Location]**, whilst the mechanical properties of the same alloys are given in table 2 **.[Current Location]** .

Laser surface treatment

Prior to laser surface treatment, preparing the surfaces of the specimens by grinding them with emery papers (320, 500, 1000µm) with alumina at 1µm in particle size and then polished by diamond paste with suitable cloth. In this work the specimens were irradiated with microsecond Nd: YAG pulses to create the predetermined bullet – point pattern across them. The experiments were done by using a pulsed Nd: YAG laser system with energy of

1000mj, beam diameter of 20μm, wave length 1064nm. To avoid any misalignment with the movement of laser beam, care must be taken to clamp the specimen. There are many tests were made to estimate the condition of the surface of each alloy after laser surface treatment, these tests are:

Microstructure examination

An optical microscope is used to define the microstructure of the specimen before and after laser surface treatment, also define phase transformation as a result of this treatment.

Microhardness test

Microhardness test was done for the specimens after laser surface treatment by using (Digital Microhardness HVS 1000 apparatus) made in china; this test was carried out in engineering material department. The applied load for this test is 500gm for 15 second with 300X as a magnification for the microscope which is aided microhardness apparatus. There are many readings were taken for each specimen treated by Nd: YAG laser. Vickers microhardness is calculated by using the formula **Bolton w [1998].**

Measurement the depth of hardening

The depth of hardening can be calculated as a perpendicular distance from the treated surface toward the core of the specimen, which at it the hardness and microstructure are not changes. One of the most important methods used to define the depth of hardening is the hardness method .Depth of hardening is defined by using optical microscope with 300X as a magnification.

Roughness test

Roughness test is carried out for the specimens before and after laser surface treatment by using an apparatus type Talysurf-4 product by English Taylor-Hobson Company, this test was done in Metallurgy and production Department. The pin scans over the surfaces of the specimens before and after laser treatment, and then the reading taken from the apparatus directly. Four readings were taken for each specimen.

Tensile test

Tensile test was carried out by using Introns 1195 machine with full capacity 2.5 ton for the specimens before laser surface treatment by Nd: YAG laser. The specimens for this test were manufactured according to **Annula [1988**]. Figure (2) shows the standard tensile specimen, while figure (3) shows the relationships between the stresses – strain for these specimens as- received .This relationship is obtained by using the following equations:

$$\sigma \text{ (Stress)} = \frac{F}{A} \frac{N}{mm2} \qquad (1)$$

$$\varepsilon \text{ (Strain)} = \ln \frac{L}{L_0} \qquad (2)$$

RESULTS AND DISCUSSION

Effect of laser surface treatment on microstructure .

The microstructure of treated specimens by Nd: YAG laser should be examined by optical microscope because of any changing in hardening properties lead to changing in microstructure of the treated specimens. Before laser surface treatment, the microstructure of low carbon steel A3115 and medium carbon steel 1045 contains ferrite (white region), fine pearlite (dark region), while the microstructure of high carbon steel 52100 contains little ferrite with pearlite and cementite as shown in figure (4). By using laser surface hardening, heating and cooling processes are occurred simultaneously because of the time is very short. During heating and because of the high temperature gradient, austenite forms and at the same time carbides partially dissolve in the grain boundaries. After heating the rapid cooling will occur and lead to transform the austenite to martensite partially or completely. After laser surface treatment, there are three different zones forms as the following: 1- Hardened zone (HZ): Which is formed at the top region and consist of martensitic structure completely. 2-Trasition zone (TZ): This is formed below the hardened zone and consists of partly austenite and hardened zone eventually. 3- Base zone (BZ): Which is represent to the base material, there is no any modification in structure when the material exposure to laser irradiation. Figure (5) shows the three different zones as in fig. (5). After laser surface treatment the specimens were prepared by cutting them with normal direction to the irradiation direction, and then the treated surfaces of the specimens were ground with emery papers (500, 1000) µm and polished with suitable cloth by using diamond paste. Finally the specimens were etching with nital as a solution of etching to evaluate the microstructure of treated specimens and to measure the microhardness by using an optical microscope. Photomicrographs for 52100 alloy treated by laser were showed that the martensite phase forming as a result of laser treatment is finer than another alloys A3115 and 1045, which they are treated with the same condition in this study. It is attributed to that the cooling after heating by laser for alloy 52100 is more rapidly than A3115 and 1045 alloys, also the absorbed energy for this alloy more than another alloys treated with the same conditions.As it is known, during laser processing austenite forms during heating and carbides partially dissolve in the grain boundaries. During cooling, austenite transforms completely or partially to martensite and thus the microstructure of the hardened zone (Hz) consists of martensite containing a small amount of retained austenite. In the neighborhood of hardened zone with the base material, a very narrow transition zone (TZ) is observed, consisting of matensite and traces of the initial pearlitc structure. While the microstructure of base zone (BZ) contains ferrite (white region) and fine pearlite (dark region). It must be mentioned here that the alloying elements and its percentages play an important role in phase transformations which occurred as a result of laser surface treatment and microstructure obtained from this treatment .

Effect of laser surface treatment on micro hardness and depth of hardening .

The depth of hardening is changing with the percentage of carbon of the different alloys which were used in this work, because of it is related with the formation of phases and micro hardness as a result of laser surface treatment. The important advantage of laser surface treatment the ability to control the heat energy to the treated region, which in turn the input energy is dependent on the absorptivity. Part of laser energy is absorbed by the surface of an alloy and the remaining of laser energy is reflected from the surface .It is clear that the average micro hardness in the hardened zone more than the average micro hardness in the transition zone, whilst the base zone below the transition zone is maintained in the same level of the hardness as-received without any change. There are many readings were taken for each treated specimen. It showed that 52100 alloy have larger value of micro hardness than A3115 and 1045 alloys, it is perhaps attributed to that the carbon content for this alloy is more than another alloys for this work. It was found that with increasing %C of steel alloys hardness increases, as a result of the phase transformation occurring in treated layers. Figure (6) shows that obviously the relationship between micro hardness and the depth of hardening below the surface hardened layer for different steel alloys at the energy 1000 mJ. The hardened depth depends strongly on the laser parameters used such as laser beam energy, wave length, spot size, laser beam speed and the distance between laser source and specimen. This results agreed with **Hirogaki [2001**] .

Effect of laser surface treatment on surface roughness .

In general, laser surface treatment leads to make the surface more roughness; roughness is required for high energy as in this work equal to 1000 mj. To evaluate the topographic roughness an optical microscope must be used. Figure (7) shows that there are many ripples formed as a result of laser surface treatment , it is observed that the area contact between laser beam and the alloy surface make concentrated rings (ripples) within the hardened zone (Hz), for A3115 and 1045, while for 52100 irradiated by pulse laser, the ripples were observed in heat affected zone (HAZ). Since all this takes place during an extremely short period, because of there is no time for the melt to flatten and then the space region freezes with the ripples. Table (3) gives the values of roughness about the specimens treated by Nd:YAG laser, from this table it is obviously that the readings of roughness increases with increasing in % C for the specimens for this work. This attributed to that increasing %C leads to increase in hardness and in turn leads to increases the ripples which make the roughness for 52100 alloy more than the roughness for A3115 alloy and 1045 alloy steel alloys it is also for that the same reason mentioned above previously .

CONCLUSIONS

Laser surface treatment leads to improve the characteristics of surface layers for the alloys used in this work as the following:
1- The microstructure of 52100 alloy after laser surface treatment produces finer plate martensite more than for A3115 alloy and1045 alloy.
2- The alloy 52100 gives the highest micro hardness than A3115 and 1045 alloys.
3- Micro hardness decreasing with increasing in the depth of hardening for all the alloys used in this work .
4- The values of roughness for the alloy 52100 more than for A3115 alloy and 1045 alloy.

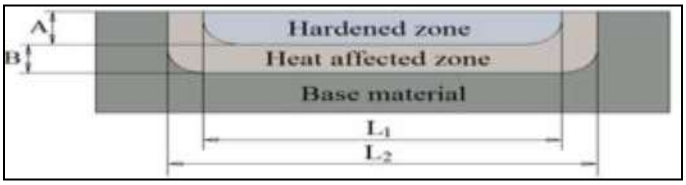

Fig.1.Different zones of laser transformation hardening [7] .

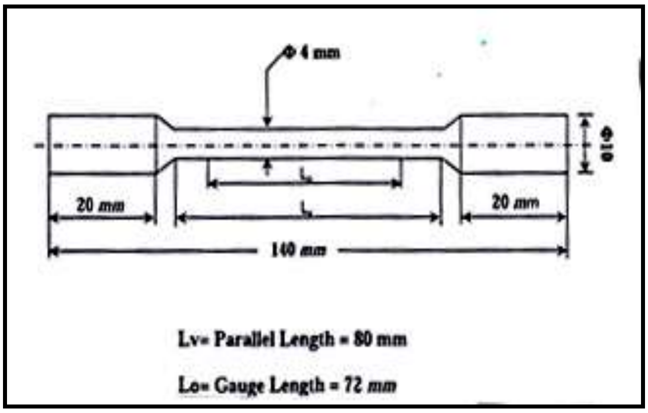

Fig.2. Standard specimen of tensile test [13].

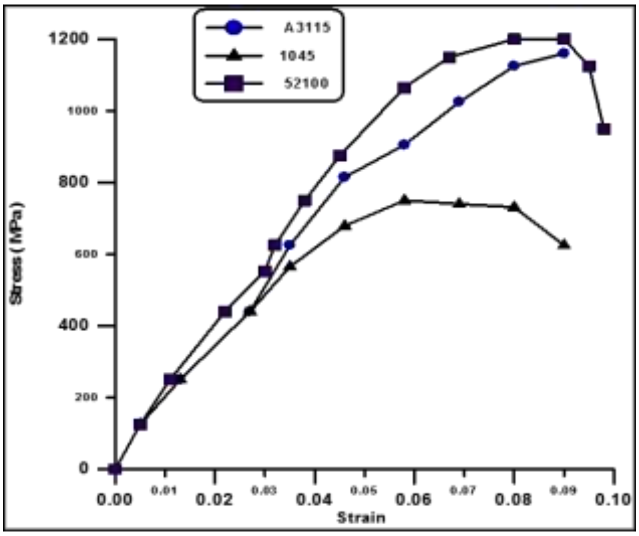

Fig.3.The relationships between stress– strain for the specimens as- received.

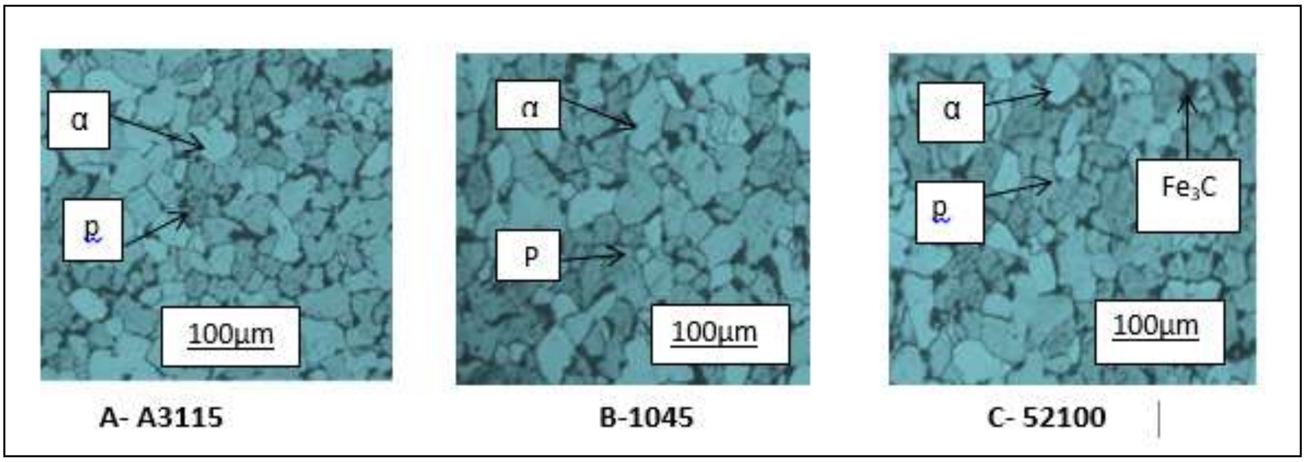

Fig.4. Photomicrographs show the microstructure of the specimens as - received with 300X asa magnification.

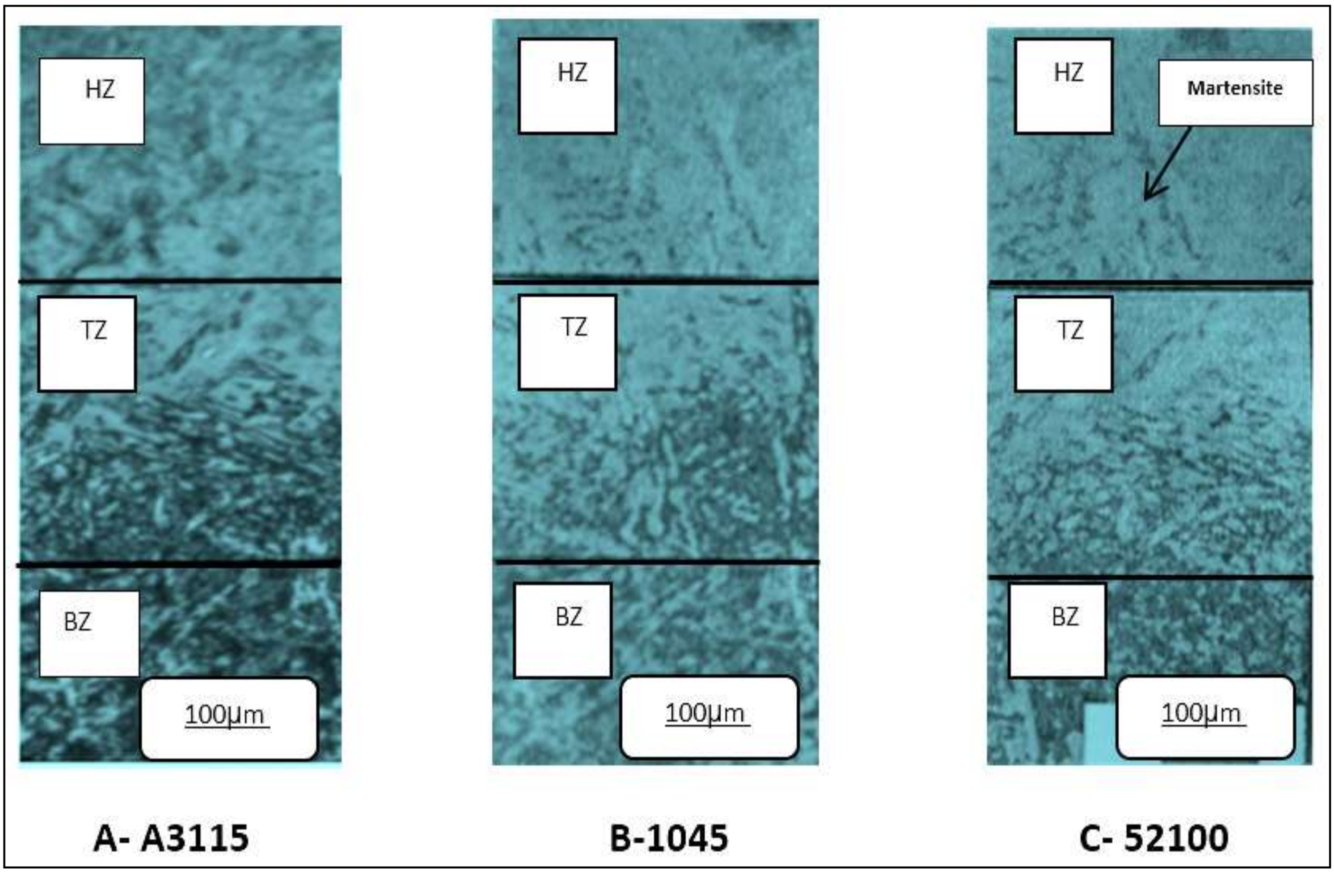

Fig.5. Photomicrographs of the specimens treated by laser showing the different hardened zones with 300X as a magnification.

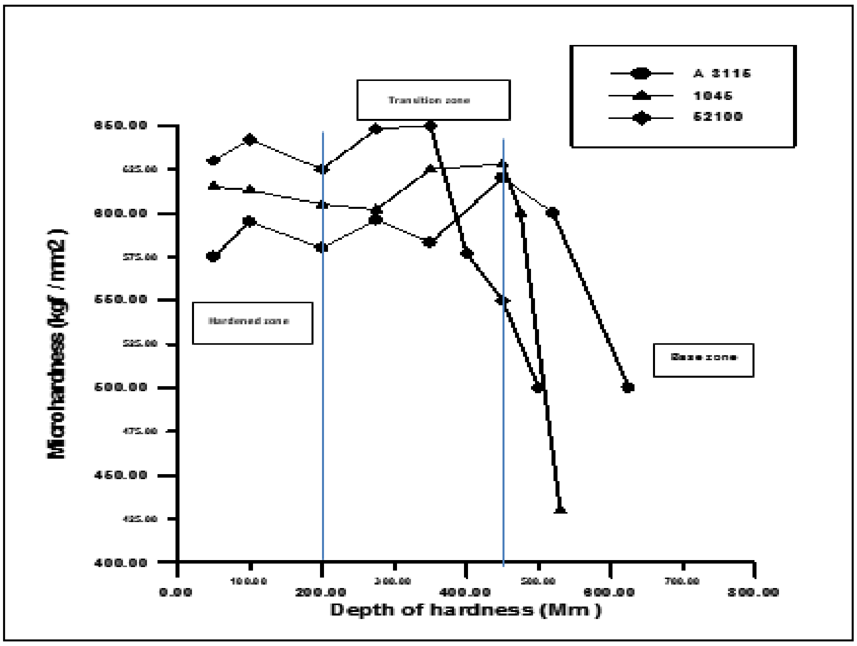

Fig.6. Relationship between microhardness and the depth of hardening of three alloys after laser surface treatment.

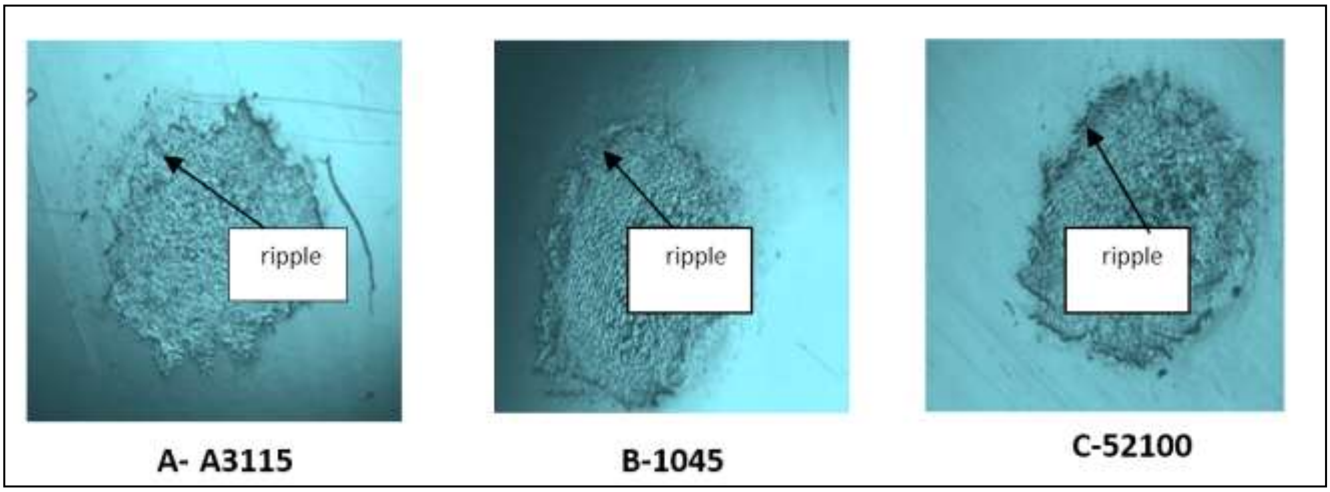

Fig. 7. Photomicrographs of the specimens as after treated by laser showing the ripples .

Table (1): Chemical composition of three different steel alloys [1] .

Alloy	Elements (wt%)							
	C	Si	Mn	Cr	Ni	Mo	P	S
A3115	0.13-0.18	0.2-0.35	0.4-0.6	0.55-o.75	1.1-1.4	_	0.04	0.04
1045	0.4-0.5	_	0.6-0.9	_	_	_	0.04	0.05
52100	0.95-1.1	0.15_0.35	0.25-0.45	1.3- 1.6	0.25	0.1	0.015	0.015

Table (2): Mechanical properties of three different alloys [1] .

Alloy	σy (µpa)	σu.T.S (µpa)	E (GPA)	Elongation %	Poisson's ratio	Hardness (Hv)
A3115	1034	1158	190 - 210	15	0.27-0.30	350
1045	310	565	200	16	0.29	565
52100	1034	1158	190 -210	15	0.27-0.30	350

Table (3): Values of the average roughness for three different alloysbefore and after laser treatment with 1000mJ.

Alloy	Average of surface roughness Ra(μm) for the specimens before laser surface treatment	Average of surface roughness Ra(μm) for the specimens after laser surface treatment
A1135	0.211	0.260
	0.267	0.318
	0.312	0.365
	0.385	0.415
1045	0.250	0.283
	0.272	0.378
	0.328	0.409
	0.397	0.438
52100	0.271	0.325
	0.299	0.392
	0.373	0.440
	0.416	0.512

REFERENCES

Annula," Book of ASTM Standard", Vol. 3.01 and 3.02 Philadelphia USA, 1988 .

Bolton w."Engineering Materials Technology",Butter worth Heineman,Oxford 1998 .

Current Location: Home>> steel grades > Carbon steel >>.

H.Visscher, M.B.de Rooij, P.H.Vroegop,D.J.Schipper,"The influence of laser line hardening of carbon steel AISI 1045 on the lubricated wear against steel AISI 52100",Wear 181-183, PP638-647,1994.

Hirogaki,T.,Nakagawa,H.,Hayamizu ,M.,Kita,Y.andKakino,Y.,"In-situ heat treatment system for die steels using Nd:YAG laser with amachining center", Journal of the international Societies for precision Engineering and Nanotechnology ,Vol.25,No.3,pp.212-217,2001.

JanuszLubas," Tribologicalcharacteristics of the surface layer of steel modified with Boron under mixed friction conditions", Journal of KONES. Power- train and Tran sport,Vol.18,No.2,pp 271-278,2011.

Khalid Osman Sharaf, " The influence of laser surface heat treatment on mechanical properties and wear resistance of high carbon- low alloy steel", Damascus University journal, vol.(27), No.(2), 2011.

Kuang,J,H.,Hung ,T.P., Lai, K., Hsu, C.M and Lin ,A.D," The surface Absorption Coefficient of S304L stainless steel by Nd :YAG Micro-pulse laser", Advanced Materials research,472,pp2531-2534,2012.

L.F.Garcia,H.Danninger ,H.Ponemayr,"Laser cladding of Low Alloy steel Substrates with carbon-Free Tool steels Fe-Co-Mo/W", Powder Metallurgy Progress,Vol.13,No.1,pp 11-20, 2013.

Mitra Radmanesh, Amirkianoosh Kiani, "ND: YAG loser pulses Ablation Threshold of stainless steel 304",Materials Sciences and Application ,vol. 6, pp 634-645, 2015.

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

Olga TURCAN, Octavian DONTU, Jose OCANA MORENO, Ionelia VOIULESCU ,Ion Mihai VASILE ,"Aspects Recharging the possibility of Increasing Hardness on alow carbon steel ST37-2 by surface treatment with CO_2 laser", U.P.B, Science. Bull .Series B,Vol.76,ISS.2,PP 225-232,2014.

Purushothaman Dinesh Babu, Gengus amynaidu Buvanashe Karan. R.Balasubramanian, "Expermental studies on the microstructure and hardenss of laser transformation hardening of low alloy Engineering, Vol. 36, No.3, pp. 241- 257,2012 .

S .SathikBasha , V.M.Periasamy ,M.Kamaraj, "Slury Erosion Resistance of Laser-modified 16Cr-5Ni Stainless steel ",International Journal of chem. Tech Research, Vol.6,No.1,pp 691-704,2014.