Wear Performance of a Laser Surface Hardened ASTM 4118 Steel

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ABSTRACT

In this investigation ASTM 4118 steel was treated by using pulse Nd: YAG laser with wave length 1064nm and pulse duration 100ns. In order to assess the new tribological properties of laser surface hardened ASTM 4118 steel, the wear resistance between specimens treated with laser and those of conventionally hardened under dry sliding conditions was compared. The change of wear mechanisms in laser hardened 4118 steel resulted in distinct difference in wear rates.

The results showed that quenched zones not only had sufficient depth of hardening and higher hardness, but had more retained austenite and finer carbides because of a higher degree of carbide dissolution. Laser surface hardened ASTM 4118 steel specimens exhibited superior wear resistance to their conventionally hardened specimens due to the change in the microstructure hardening, high hardness. The wear mechanism for both the laser quenched layer and conventionally hardened layer was highly similar, generally involving adhesive wear mechanism , material transfer, wear induced oxidation and plowing. Also the results of hardness show that increases with increasing of laser energy by 70%.

Keywords: laser surface treatment, steel, Wear.

سلوك البليان للفولاذ ASTM 4118 المصلد سطحيا بالليزر

الخلاصة

في هذا البحث تمت معاملة الفولاذ ASTM 4118 بالليزر نيديميوم- ياك النبضي ذو الطول الموجي 1064nmوزمن النبضة 100ns ولتحديد الخواص الترايبولوجية الجديدة للفولاذ ASTM 4118. اجريت مقارنة مقاومة البلى للعينات المعاملة بالليزر والعينات المعاملة بالطريقة التقليدية تحت ظروف البلى ألانزلاقي الجاف. التغيير في آليات البلى للفولاذ ASTM 4118 المصلد بالليزر ينتج عن اختلاف واضح في معدلات البلى.

أظهرت النتائج ان المناطق المصلدة لا تمتلك فقط عمق معين من التصليد وصلادة اعلى, إنما تحتوي على كميةاكبر من الاوستنايت المتبقي وكاربيدات ناعمة وذلك لزيادة قابلية الذوبانية للكاربيدات .أظهرت عينات الفولاذ ASTM 4118 المصلدة بالليزر ان مقاومتها للبلى أفضل من العينات المصلدة بالطريقة التقليدية وذلك الفولاذ للتغيير في البنية المجهرية وزيادة الصلادة الناتجين

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عن التصليد. ان الية البلى للطبقة المصلدة تكون متشابهة الى حد كبير في التصليد بـالليزر والتصـليد بالطريقة التقليدية, والتي تتضمن الية البلى, الالتصاق، انتقال المادة مع حدوث أكسدة وإزالة للطبقات المتعرضة للبليان.

INTRODUCTION

While the contact surfaces are subjected to repeated heavy stress, they still must maintain high precision and rotational accuracy. Thus, the contact surfaces must be made of material that has high hardness and good dimensional stability and is resistant to fatigue and wear [1-5].To achieve these goals common surface modification processes, which often simultaneously increase the surface resistant to wear, are based on heat treating such as laser hardening [6,7].To diminish wear in tribological systems it is not always necessary to provide the entire surface with a wear resistant layer. Depending on the application it is sufficient to harden locally the load carrying areas which are subjected to wear. Such areas can be treated properly by laser, either totally or partially [8,9].Laser surface hardening is a relatively new and promising process for the thermal hardening of steel. It is widely used in many enterprises because of its technical and economical advantages [10].Rapid heating and cooling are the key characteristics of laser quenching heat enable the formation of a novel microstructure and thereby improve the hardness and wear resistance. Development of this kind of favorable microstructure should give rise to different wear behaviors of laser hardened steel with respect to conventionally hardening steel [11-16].

Previous studies [17,18], demonstrated that under the dry sliding wear conditions, laser surface hardened specimens of ferrous alloys (L.C.S & M.C.S) exhibited enhanced wear resistance than conventionally hardened specimens. Wear behavior of laser surface hardened specimens was found to be largely similar to those of quenched and tempered specimens, while the wear mechanism of materials and the morphologies of wear surfaces were different.

The aim of this work is to investigate the dry sliding wear behaviors of laser surface hardened ASTM 4118 steel specimens and to compare the result for laser transformation hardening with those of conventionally quenched and tempered. Moreover ,the wear properties of the ASTM 4118 steel and its corresponding wear mechanisms under dry test conditions were also studied.

EXPERIMENTAL PROCEDURE

Materia

The material used in this work is ASTM 4118 steel. The chemical composition of this alloy is shown in Table (1).The microstructure of this alloy is examined by using optical microscopic which indicated that the steel contain well-distributed mixture of ferrite and pearlite as shown in Figure (1).Table(2) shows the mechanical properties of ASTM 4118 steel[19]. While the practically stress - strain curve of this alloy is shown in Figure (2).

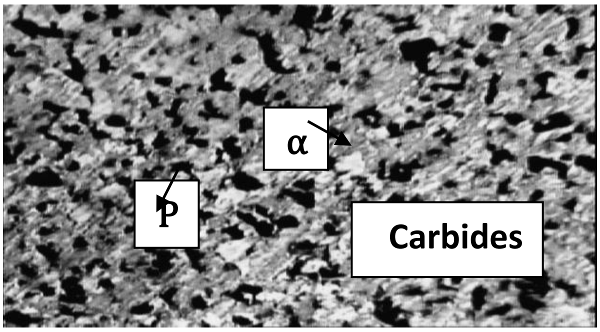


Figure (1) Specimen as-received (250X).

Table (1) Chemical composition of ASTM 4118 steel alloy[19].

Element%	C ≤	Si ≤	Mn≤	P ≤	S ≤	Cr	Mo
Standard value	0.18-0.23	0.15-0.35	0.7-0.9	0.035	0.04	0.4-0.6	0.08-0.15
Actual value	0.2	0.16	0.75	0.028	0.031	0.45	0.068

Table (2) Mechanical Properties of ASTM 4118 steel alloy [19].

Properties		**Conditions**	
		T (°C)	Treatment
Density (×1000 kg/m^3)	7.7-8.03	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	190-210	25	
Tensile Strength (Mpa)	1158	25	Oil quenched, fine grained, tempered at 425°C
Yield Strength (Mpa)	1034		
Elongation (%)	15		
Reduction in Area (%)	53		
Hardness (HV)	350	25	Oil quenched, fine grained, tempered at 425°

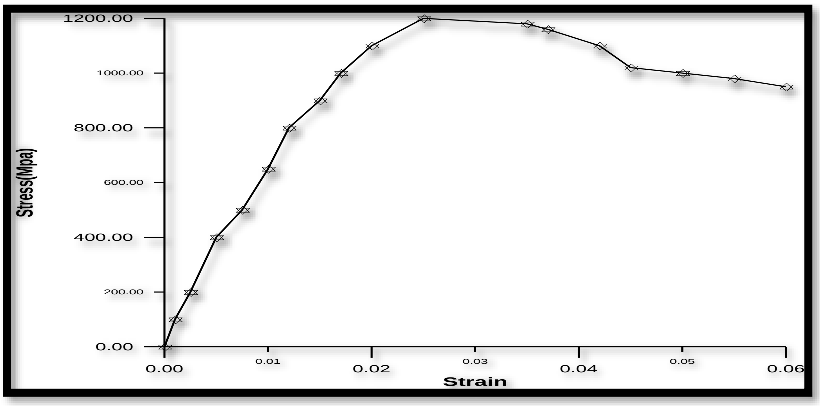


Figure (2) Relationship between stress- strain curves of ASTM 4118 steel alloy.

Heat Treatments

The specimens were firstly treated by conventional heat treatment and then with laser respectively. Conventional heat treatment for the specimens of ASTM 4118 steel was carried out as follows: Heating at 850C^{o} for 1hr
frequency of laser system is 1-6 HZ with wave length 1064 nm and pulse duration 100ns.The laser treatment was performed at 1 (J) .The hardness profile along the depth of the cross section in the hardened surface layer was measured by using (Hensddt Wetzlar No.23298) type Vickers microhardness tester with a testing load of 250gm and a holding time of 15 seconds. The specimens were characterized by Optical Microscopy (OM).Figuere (3) shows the laser apparatus.

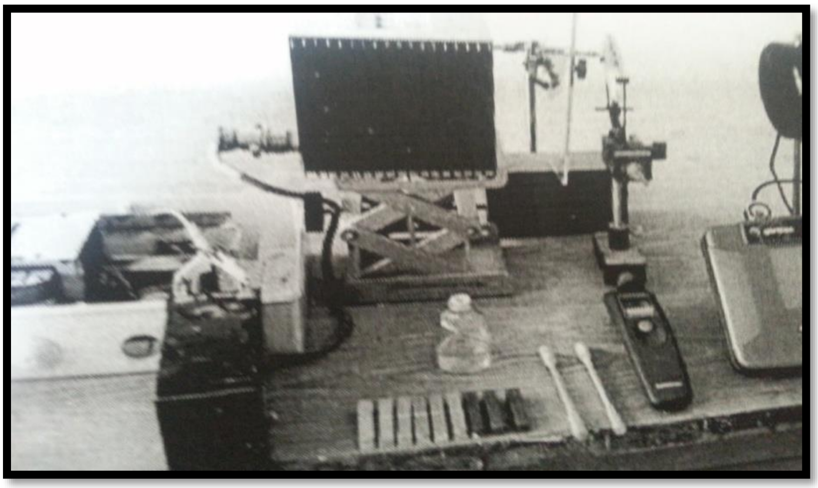


Figure (3) Nd:YAG laser system .

Wear test

The wear test of ASTM 4118 steel was carried out by using pin-on-disc machine to compute the rate of wear of the specimens before and after each one the treatments which were used in this work. Figure(4) shows the pin-on-disk machine.

Figure (4) wear machine .

The test sample with 1cm diameter and 2cm in length was pressed against hardened rotating disc (with an average hardness of 45HRC) at 720 rpm. Wear test was performed by changing applied loads (5,10,15,20,25 N),and changing sliding time (5,10,15,20,25,30 min) respectively.

Before and after the wear test, the specimens weight was separately measured to calculate the weight loss during the test. An analytical balance with accuracy of 0.1 mg (Type Mettler AE 60 _ China) was used to measure the weight of the sample before and after each test. Its specific wear rate was calculated by the following equation:

$$\text{Wear rate} = \Delta w / S_D \quad \text{gm/cm} \qquad \dots (1)$$

$$\Delta w = w1 - w2 \qquad \dots (2)$$

Where

Δw: The changing in weight (gm).

W1, w2: The weight of the specimen before and after test (gm).

$$S_D = 2\pi . r . n . t. \qquad \dots (3)$$

Where

S_D: sliding distance (cm).

r:radius from the center of the specimen to the centre of the disc (cm).

n: number of rotating disc (r. p. m).

t: time of test (min).

Roughness test

A roughness instrument type Talysurf - 4 products by English Taylor-Hobson Company, was used to measure the average roughness (Ra) for the samples before and after treatment .Table (3) shows readings of the average of surface roughness for the alloy treated by laser surface treatment and conventionally treatment respectively under sliding wear test conditions.

Table (3) The roughness values under sliding wear test conditions.

The Specimen	Load (N)	The average roughness values Ra (before wear test) µm.	The average roughness values Ra (after wear test) µm.
Laser surface treatment	5	0.018	0.010
	10	0.110	0.207
	15	0.119	0.258
	20	0.205	0.301
	25	0.287	0.322
Conventionally heat treatment	5	0.025	0.016
	10	0.129	0.107
	15	0.145	0.123
	20	0.276	0.257
	25	0.302	0.201

Results and discussion

Metallographic analysis

The specimen surface was heated above the austenization temperature by laser heat treatment. Subsequent rapid cooling due to self-quenching led to the formation of a hardened surface layer with carbides in a matrix of austenite and martensite as shown in Figure (5).

(a) (b)

Figure (5) Specimens after heat treatments (250X).
(a) :Conventional treatment.
(b) : Laser surface treatment.

While the hardness distribution along the depth of the laser-treated layer is shown in Figure (6).

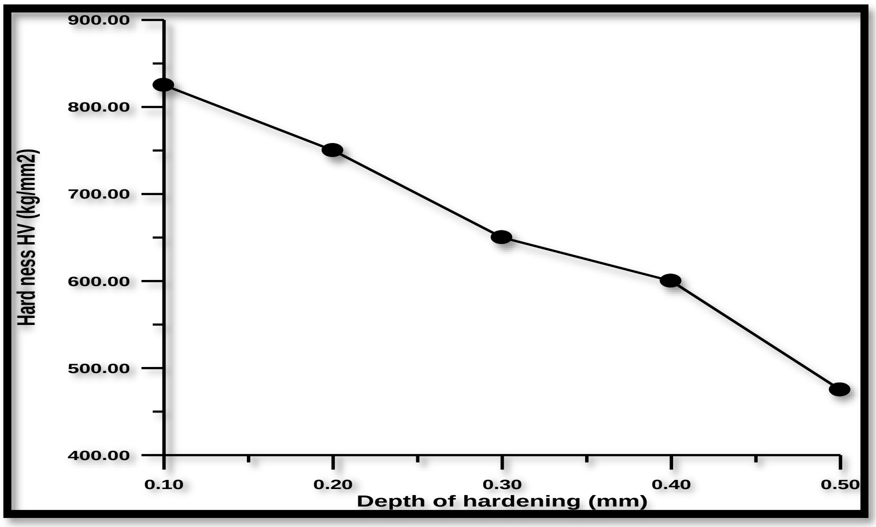


Figure (6) Hardness distribution curve along hardening depth of the laser treated specimen.

The hardness of the quenched layer is substantially greater than that of conventionally quenched and tempered (with an average hardness 300HV). In the hardened layer the hardness gradient showing a gradual decrease in hardness is attributed to the dissolution of carbide due to the temperature gradient in the depth direction.Compared with conventionally heat-treated specimens, the laser treated specimens contain more retained austenite and un dissolved carbides. The conventionally treated specimen contains mainly with tempered martensite and un dissolved carbides plus little retained austenite as the light microscopy indicate. Because of the very short time involved in the austenization during laser heat treatment, the finer austenite grain size resulting in the formation of unusually fine martensitic structure was obtained.

It is well known that the wear resistance of the materials could be better related to the hardness of the surface. Although martensite is hard, the presence of retained austenite has been reported to enhance the toughness, which implies that a proper combination of these phases would result in higher wear resistance

Effect of the applied loads and time on wear behaviors

At the steady state in all contact pressure rang, the laser treated specimens presented a lower wear rate than those of quenched and tempered specimens. As a result for all loads and time, the quenched and tempered specimens presented a higher wear rate, and it increased with increasing applied loads and time. While the very high hardness of the specimens makes laser surface quenched layer very difficult to be plastically deformed with little adhesive features, the surface of the quenched and tempered ones is soft, having much adhesive features. Therefore, the laser treated specimens presents a lower wear rate than those of the quenched and tempered specimens.

The fluctuation of the wear rate caused by material transfer and oxidation occurred in the wear process. These oxide films could act as solid lubricant and avoid direct metallic contact with coupling counterpart with the advantage of diminishing the wear rate. The friction heat produced during the sliding friction resulted in the formation of oxide films on the contact surfaces. Furthermore, higher friction contact temperature may cause larger area of oxide films formed on the wear surfaces.Wear weight loss and wear track depth of the laser treated specimens were lower than those of the quenched and tempered ones.Compared with conventional heat treatment specimens, the laser treated specimens showed a lower wear rate at all loads, see Figure (7).

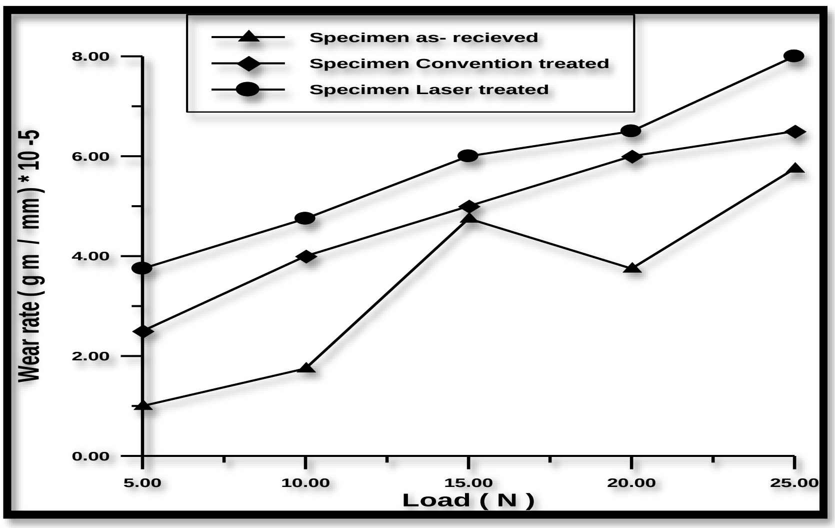


Figure (7) Relationship between applied load and wear rate for sliding time 15 min.

The conventionally hardened specimens tested at 25 N load exhibited very high wear rates (about $6.8*10^{-5}$gm/cm).Because the hardness of the specimens surface of laser treatment was bigger than that of the specimens treated conventionally, then the wear rates of the laser treated specimens were low.The wear rate is often used to evaluate wear resistance performance. It shows that the laser quenched layer is more resistant to wear than the specimens with conventionally heat treatment with excellent abrasive and adhesive wear resistance under sliding wear test conditions, because the surface strength and hardness of the specimens are significantly enhanced by laser.

The effect of time on wear mechanism and wear rate is the same of the effect of loads and for all the changing values as shown in Figure (8).

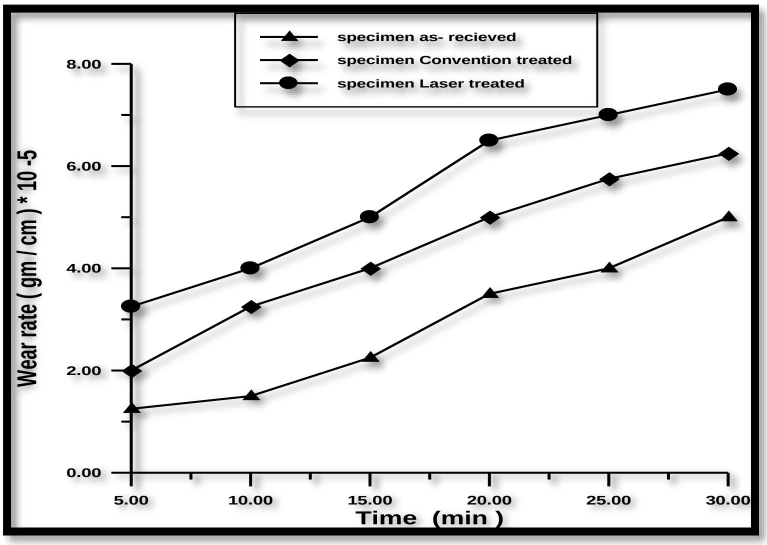
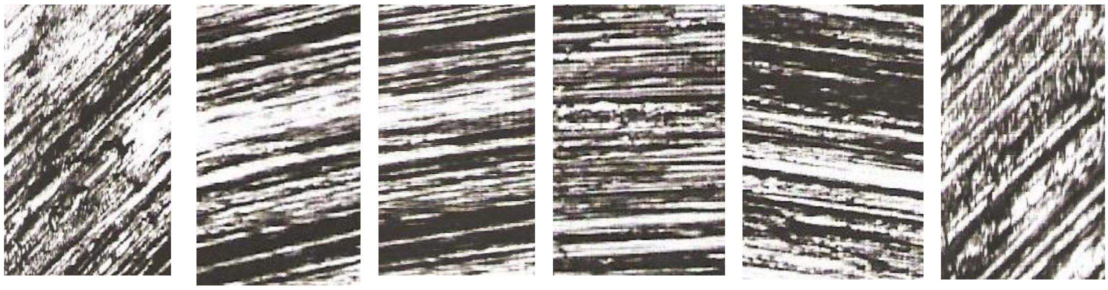


Figure (8) Relationship between sliding time and wear rate for loading 20 N.

Sliding wear mechanism

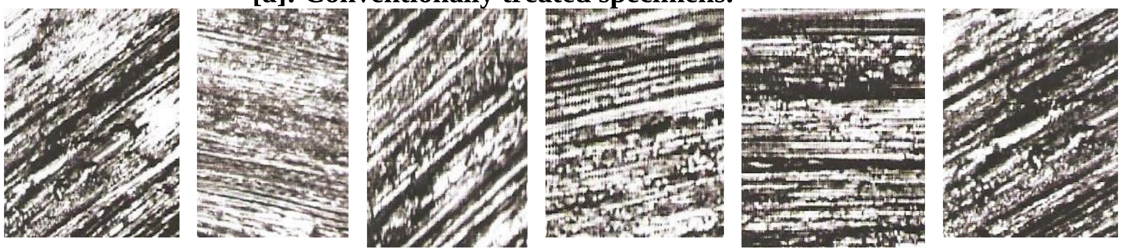
Figure (9) shows the micrographs of top view of the wear surface of the specimens with conventional heat treatment and laser surface treatment. It can be observed that the main wear mechanism for both the laser quenched layer and the conventionally heat treated layer are similar, generally involving adhesive , material transfer , wear –induced oxidation and plowing. Adhesion between the specimens and the rotating disc accompanied by material detachment and transfer to the rotating disc occurred during sliding process.

In the conventionally quenched and tempered specimens, the worn surface of the specimen is relatively smooth Figure (9.a) for the loads 5, 10,15,20,25 N respectively, the relatively smooth and slight micro-cutting worn surface without significant plastic deformation and deep parallel plowing grooves are visible. The worn surface shows fine wear debris, reaction products (oxides). Their counter surface is covered with large black oxide layer on the worn surface.In the laser treated specimens, the basic mechanism remains unchanged and only the grooves become slightly deeper Figure (9.b) for all loads 5,10,15,20,25N presents photomicrographs showing plowing marks on the worn surface as well as some very small debris ,reaction products (oxides). Their counter-surface exhibits no plowing marks, and is covered with thin black oxide lager on the worn surface.



As-received 5N 10N 15N 20N 25N

[a]: Conventionally treated specimens.



As-received 5N 10N 15N 20N 25N

[B]: Laser surface treated specimens.

Figure (9) Photomicrographs of the worn surface of all specimens.

CONCLUSIONS

1-Laser surface treatment lead to improve wear rate more than conventionally heat treatment.

2-Increasing load and time lead to increase wear rote for all the specimens .

3-Laser surface treatment lead to increase the hardness in the surface of the specimens by 70%.

4-Depth of hardening by laser decreasing far from the surface.

REFERENCES

[1]. Seyda Polat , Enbiya Turedi , S. Hakan Atapek , Merve Koseoglu, "Wear behavior of Heat Treated Din 100 Cr6 steel " , International iron & steel symposium , karabuk , Turkiye (2012) 181 -186 .

[2]. Navas ,C. A.Conde, M.Candenas and J.de Damborenea,"Tribological properties of laser clad satellite 6 Coatings on steel substrates",Surface engineening,Vol.22, No.1, (2006) 26 - 34.

[3]. I.Hileio C,"Wet and Dry Abrasion behavior of AISI 8620 Steel Boriding", Memorias Del XVI Congreso International Anual, Nuevo Leon. Mexico(2010)

[4]. Zhong Junwei Lu, Jin Zhong Lao, "Tribological Behaviors of Las Shock processing AISI 8620 Steel" Chinese Journal of lasers,(2012) 1-3.

[5]. Radziszewska, A. and J. Kusinski, "Laser alloying of the plain carbon steel surface layer", Archives of Foundry Engineeing,Vol.8 ,Issue(2008)175-179.

[6]. David k. Madok , Khalid A. Alogah , Mark D .Richard , John G. Speer, " Surface processing to Improve the Fatigue Resistance of- Advanced Bar Steels

for Automotive Applications " , Materials Research , Vol . 8 , NO.4 (2005) 453 - 459 .

[7]. Liu Qingbin and Liu Hong,"Experimental study of the laser quenching of 40 Cr NiMo A steel", Journal of Materials Processing Technology, Vol.88, Issues 1-3 (1999) 77 - 82.

[8].H. Visschers , M.B. de Rooij,P.H. Vroegop and D.J.Schipper,"The influences of laser line hardening of carbon steel A1S1 1045 on the lubricated wear against AISI 52100",Wear Vol.181-183, (1995) 638 - 647.

[9]. R.Bendikiene,S.Chodocinskas,E.Pupelis"The Strengthening of Surface Layer by the Impulse Laser Irradiation", Materials Science,Vol.9,No.4(2003) 338-341.

[10]. .S .R . yu, y.liu , L. Q Ren et al, "Development of laser-cladding layers Containing nano-Al_2O_3 Particles for Wear Resistance Material",Metallurgical and Material Transactions,(2006) 3639 - 3645.

[11]. Q.B.Liu, "Experimental study of laser Quenching of 40CrNiMo steel", Journal of Materials processing Technology ", (1999) 77 - 82.

[12]. Reti,T. " Prediction of as _ quenched hardness after Rapid Austenization and cooling of surface hardened steel ", Computational Materials Science, (1999) 111 -112.

[13]. K.H.Lou," Effect of Laser treatment on cavitation Erosion and corrosion of AISI 440C Martensitic stainless steel ", Materials letters, (2003) 88 - 93.

[14]. R.Kaul, "Characterisation of Dry Sliding Wear Resistance of laser surface hardened En 8 steel ", Journal of Materials Processing Technology,(2005) 83 - 90.

[15].Rakesh Kaul,P . Ganesh,Pragya Tiwari, R.v.Nandedkar and A.K.Nath,"Characterzation of dry sliding wear resistance of laser surface hardened En 8 Steel",Industrial carbon Dioxide Laser Section, Centre for Advanced Technology P.O. CAT, Indore(M.P)(2004).

[16]. Yan-qiu Xia, Wei-min Liu, Qun-ji Xue, "Comparative Study of the tribological properties of various modified mild steels under boundary lubrication condition", Tribology International 38(2005) 508-514.

[17]. Komonduri, R. "Influence of processing conditions on the Abrasive wear behavior of a laser surface Melted Tool Steel", Scripta Materials, (1999) 715 - 721.

[18]. Xia, Y.Q. "Comparative Study of the Tribological properties of various Modified Mild steels under Boundary Lubrication conditions," Tribology International, (2005) 508 - 514.

[19]. Current Location: Home>>steel grades >carbon steel>>AISI 4118.