Wear Behavior of An Aluminum Alloys Using Nd:YAG Laser Treatment

Dr. Khansaa Dwood Salman and Dr. Muhannad Zedain Khalifa
University of Technology- Electromechanical Engineering Department

Abstract

This research aims to study the effect of laser surface treatment on wear resistance of different aluminum alloys (٥٠٨٦H-٣٢،٦٠٦١T).The specimens were hardened by using pulse Nd:YAG laser with wave length١٠٦٤ nm and pulse duration١٠٠ ns with constant energy ١ J and spot size 1–5 mm.

Wear behavior of the specimens as – received and specimens treated by laser being studied by using pin-on-disc technique under dry sliding wear conditions at different applied loads and different sliding speeds.

This study shows that the wear rate increases by increasing values of applied loads and decreases with increasing sliding speed, and wear rate for ٦٠٦١-T6 alloy is less than 5086-H32 alloy. Also the results show that the micro hardness decreases by increasing hardening depth and the micro hardness values for 6061-T6 alloy more than 5086-H32 alloy at the same depth.

سلوك البليان لسبائك الألمنيوم باستخدام المعاملة السطحية بالليزر نيديميوم – ياك

الخلاصة

يهدف البحث لدراسة تأثير المعاملة السطحية بالليزر على مقاومة البلى لسبائك مختلفة من الألمنيوم (6061-T6, 5086-H32) تم تصليد العينات باستخدام ليزر نيديميوم – ياك النبضي ذو الطول ألموجي 1064 nm وزمن النبضة 100 ns عند طاقة ثابتة 1 J وقطر النبضة 5-1mm.

تمت دراسة سلوك البلى للعينات قبل وبعد المعاملة بالليزر باستخدام تقنية المسمار-على- القرص تحت تأثير ظروف البلى ألانزلاقي الجاف عند أحمال مختلفة وسرع انزلاق مختلفة. أظهرت النتائج بان معدل البلى يزداد بزيادة الحمل المسلط ويقل بزيادة سرعة الانزلاق، وان قيمة معدل البلى للسبيكة 6061-T6 اقل مما هو عليه للسبيكة 5086-H32 . كذلك اظهرت النتائج بأن الصلادة المايكروية تقل بزيادة عمق التصليد، وإن قيم الصلادة المايكروية للسبيكة 6061-T6 اكثر مما هو عليه للسبيكة 5086-H32 عند نفس العمق .

1- Introduction

Laser surface treatment for aluminum alloys have experienced extensive development in the past 10 years, aiming at modifying the shape ad properties of aluminum components, particularly in the aerospace industry [1]. Aluminum is widely used in industry due to its low density, light thermal conductivity and good resistance to the corrosion ambient at room temperature. However the tribological properties of aluminum surface are poor and need improvement used in wearing environment [2].

More recently there has been a growing interest to improve the corrosion and wear performance of aluminum alloys by laser technique similar to those used for steel. The techniques principally involved are laser surface melting (L5M) and laser surface alloying (LSA). Laser surface hardening offers many advantages over conventional techniques (physical vapor deposition, chemical vapor deposition, sputtering, Sol-gel), localized/ bulk surfaces with superior surface resistance properties (wear, fatigue, corrosion, fracture, erosion) can be obtained. Laser surface hardening is a non contact process that in turn provides a chemically inert and clean environment as well as flexible integration with operating systems. High volume of production with superior surface quality and reasonable manufacturing cost are the foremost advantages [3,4].

On the other hand, high power pulse energy irradiation can modify metal surface and its process can be expected to increase hardened layer and then to improve the resistance of aluminum alloys [5]. Depending on the intended application, laser surface treatment can either improve wear behavior enhance fatigue properties or increase corrosion resistance. In some case all three properties can be improved [6].

There are many investigations were published in this field. P.H. change et al [7], they studied the influence of overlapped regions on corrosion and wear behavior of laser melted aluminum 2014-T6 alloy. Laser melting was carried out using a 3KW CW Nd:YAG laser with a line beam profile. The work revealed enhancement of wear resistance and pitting potential by 170 mv compared with that of untreated alloy. While F. Fariant et al. [8] reported the excimer laser cementation process which is developed to enhance the mechanical and chemical properties of a aluminum alloys. Fretting test measurements exhibit an improvement of the surface mechanical behavior for some experimental conditions. Majid Hammed Ismaiel and Mohamed Abdul Wahhab [9], they studied the effect of laser parameters which includes the effect of the pulsed Nd: YAG laser energy and the effect of number of shots (pulse) on wear rate of [Al-Cu-Si], [Al-Si-Mg] and [Al-Zn-Mg].

The aim of this paper is studying the performance of the effect of laser surface treatment at cryogenic conditions on microstructure, microhardness and wear characteristics of casting alloys 5086-H32 and 6061-T6.

2. Experimental Procedure

2.1 Materials under Test

The starting materials were aluminum alloys (5086-H32 and 6061-T6). Alloy 5086-H32 is solid solution strengthen is not age hard enable, widely used in cold worked conditions. While alloy 6061-T6 is age hard enable and is often used in construction of air craft structures, such as wings and fuselages. The chemical compositions of these alloys were given in table (1), while table (2) shows the mechanical properties of theses alloys.

Table (1-a): Chemical Compositions of 5086-H32 Alloy.

Element	Mg	Mn	Cr	Cu	Si	Fe	Ti	Zn	Al
Actual value wt%	4-6	0.45	0.15	-	0.52	0.35	-	0.19	Rem
Standard value wt%	3.5-4.5	0.2-0.7	0.058-0.25	0.1	0.4	0.5	0.15	0.25	Rem

Table (1-b): Chemical Compositions of 6061-T6 Alloy.

Element	Mg	Mn	Cr	Cu	Si	Fe	Ti	Zn	Al
Actual value wt%	1.0	-	0.2	0.27	0.63	0.57	-	0.2	rem
Standard value wt%	0.8-1.2	0.15	0.04-0.35	0.15-0.4	0.4-0.8	0.7 max	0.15 max	0.25	rem

Table (2-a):The Mechanical Properties of 5086-H32 Alloy[10].

Yield Strength (MPa)	Ultimate Tensile strength (MPa)	Elongation (%)	Modulus of Elasticity (GPa)	Hardness Hv (Kgf/mm^2)	Poisson's Ratio
207	290	6-12	71.0	88	0.33

Table (2-b):The Mechanical Properties of 6061-T6 Alloy[11].

Yield Strength (MPa)	Ultimate Tensile strength (MPa)	Elongation (%)	Modulus of Elasticity (GPa)	Hardness Hv (Kgf/mm^2)	Poisson's Ratio
276	310	12	68.9	107	0.33

2.2 Laser Surface Treatment

The laser-shock experiments were performed with a pulse Nd:YAG laser system. The laser was operate in a pulsed mode with wave length 1064 nm and pulse duration 100 ns for constant energy 1 J and spot size 1.5 mm while the frequency of laser system (1-6 H_Z). The same conditions were done for the specimens of microhardness test.

2.3 Specimens Preparation

For microhardness test, the aluminum alloys samples have a diameter of 15 mm with 10 mm thickness, while in wear tests the samples have a diameter of 10 mm with 20 mm in height.

Before laser treatment, grinding and polishing were done to remove any foreign impurities, grinding was done by using emery papers 220, 500 and 1000 μ_m of Silicon Carbide to obtain smooth and uniform surfaces, and then the specimens were polished by using diamond paste for 1 μ_m in size.

2.3 Microhardness Test

Assessment of surface microhardness was done by using (Hensddt Wetzlar No. 23298) with applied load 300 gm. Microhardness calculates according to the following formula:

$$HV = 1.8544 \times \frac{F}{d_{ave}^2} \qquad (Kgf / mm^2) \qquad .....(1)$$

where:

F : applied load (Kgf)

d_{ave} : the mean diagonal of indentation (mm).

Case depth hardening is defined by three readings from the surface to the point at which the change in hardness, chemical composition or microstructure of the case and core can not be distinguished.

2.5 Microstructure Examination

A computerized optical microscopy was used to examine the microstructure of the specimens before and after surface treatment with Nd:YAG laser.

2.6 Wear Test

Wear test was done by using pin-on-disc machine. The instrument consists of an electric motor rotating at 750 r.p.m to a gear box and shaft where the specimen is mounted. Weight loss method was used to calculate the material that might be lost as a result of sliding wear. The specimen was mounted on its position in the instrument by direct contact with a very hard reference disc which has 45 HRC. Applied loads were changing by 2, 4, 6, 8, 10 N at the first stage with constant sliding speed equal to 1.5 m/s, while in the second stage the sliding speed was changing by 0.5, 1, 1.5, 2 m/s with constant load 6N for all aluminum specimens before and after laser surface treatment.

Wear rate can be calculated by the following equation [12].

$$W.R = \frac{w_1 - w_2}{S_D} \quad (gm/mm) \qquad .....(2)$$

where :

W.R: wear rate (gm/mm).

w_1: weight of the specimen before wear test (gm).

w_2: weight of the specimen after wear test (gm).

S_D: the distance of sliding (mm).

$$S_D = S \times t \qquad .....(3)$$

where :

S: the sliding speed (m/s).

t : the time for the sliding (min).

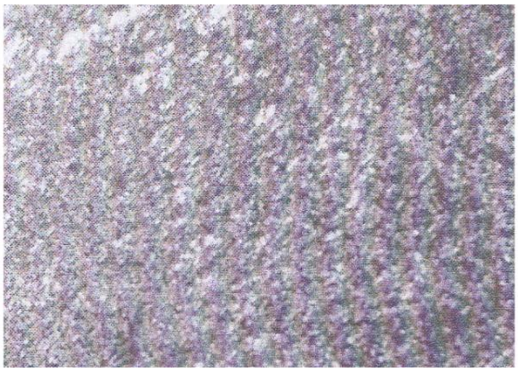
Before and after the wear test, the wear test, the specimens weight was separately measured to calculate the weight loss in the test by using an analytical balance with accuracy of 0.1 mg.

Note: In this study the time is constant = 20 min.

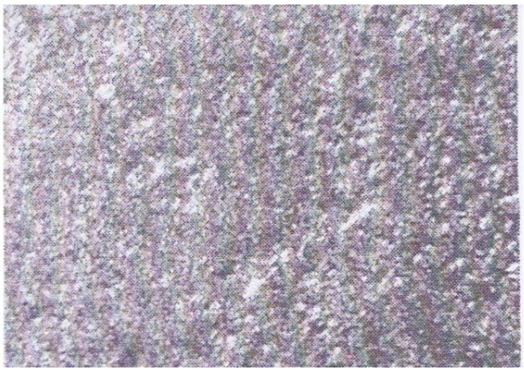
3. Results and Discussion

3.1 Metallographic Evaluation

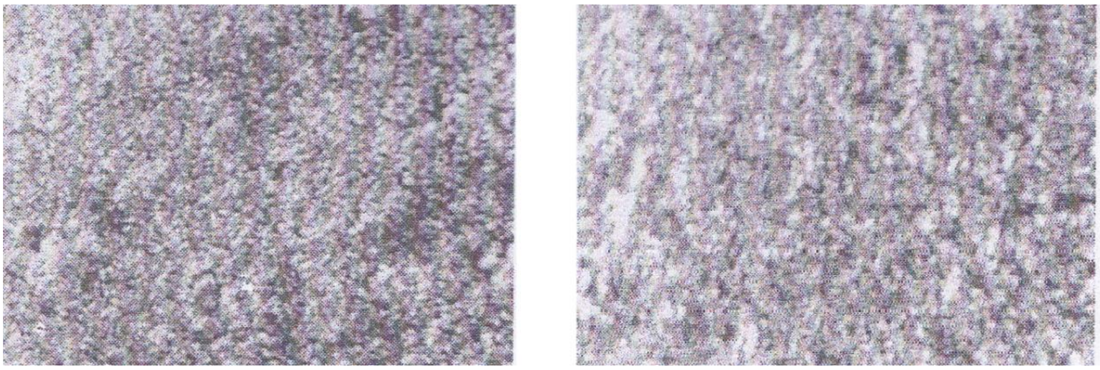
The specimens of aluminum alloys were heated by laser heat treatment. Subsequent rapid cooling led to the formation of a hardened surface layer. Because of the very short time involved during laser heat treatment, the finer grain size resulting in the formation of unusually fine structure was obtained. Figure (1) shows the microstructure of the specimens of Al alloys 5086-H32 and 6061-T6 before and after laser surface treatment.



5086-H32 specimen before laser surface treatment



5086-H32 specimen after laser surface treatment



6061-T6 specimen before laser surface treatment **6061-T6 specimen after laser surface treatment**

Figure(1): Photomicrographs of surface microstructure of the specimens before and after laser surface treatment with magnification (200x).

3.2 Microhardness Analysis

Figure (2) shows that the laser surface treatment leads to increase the microhardness of 6061-T6 alloy more than for 5086-H32 alloy, it is attributed to that the effects of high amplitude stress waves on the microhardness. These stress waves are often generated by explosive changes or impact between a project and target specimen. One of the most interesting effects is that the shock waves can develop significant plastic strains in the metal.

When the intense laser beam strikes the metal surface, the surface layer is instaneously vaporized. The rapidly expanding high temperature vapor exerts a pressure on the target surface which then propagates into the specimen as a stress wave. High surface pressures are obtained by placing on the target surface an overlay transparent to the laser beam for 6061-T6 alloy more than 5086-H32 alloy, which confines the blow-off material between it and the specimen surface for duration of laser pulse.

Figure (2) shows that the microhardness decreases below the surface of the specimens toward the core of them, and the microhardness for 6061-T6 specimen more than 5086-H32.

3.3 Effect of The Applied Loads and Sliding Speeds on Wear Behavior

The wear rate is an important factor to be considered in surface treatments. At the steady state and in all contact pressure range, the friction of the 6061-T6 treated specimens presented a lower wear rate than 5086-H32.

As a result, for all loads, 6061-T6 specimen presented a lower wear rate (higher wear resistance) and the friction increased with increasing applied load. While the high hardness of the specimens makes laser surface layer very difficult to be plastically deformed with little adhesive features, the surface of the specimen 5086-H32 is soft, having much adhesive features. Therefore, the friction of the laser treated specimens 6061-T6 present a lower wear rate than the specimens 5086-H32.

The fluctuation of the friction caused by materials transfer and oxidation occurred in the wear process. These oxide films could act as solid lubricant and avoid direct metallic contact with the coupling counterpart with the advantage of diminishing the friction. The friction heat produced during the sliding friction test resulted in the formation of oxide films on the contact surfaces. Furthermore, higher friction contact temperature may cause larger areas of oxide films formed on the wear surfaces. Wear rate was measured to compare the weight losses of the specimens 6061-T6 and the specimens 5086-H32. Wear weight loss and wear track depth of the laser treated specimens 6061-T6 were lower than those of 5086-H32. Because the hardness of the specimens surfaces of 6061-T6 was higher than that of 5086-H32 and then the wear rates of them were low.

The wear rate is often used to evaluate wear resistance performances. It shows that the specimens of 6061-T6 are more resistant to wear than the specimens 5068-H32 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 treatment. Figure (3) shows that increasing applied loads lead to increase the wear rate, and the wear rate for the specimens 6061-T6 lower than for the specimens 5086-H32. While increasing the sliding speed lead to decrease the wear rate because of the strain hardening occurred in the specimens which lead to increasing strengthening, and for the specimens 6061-T6 lower than for the specimens 5086-H32. Figure (4) shows that increasing the sliding speed leads to decrease the wear rate, and the wear rate for the specimens 6061-T6 lower than for the specimens 5086-H32.

3.4 The Roughness Values Under Sliding Wear Test Conditions

The quantitative characterization of the worn specimen surface roughness in table (3) indicates that the wear processes in the specimen of 6061-T6 were dominated by polishing wear and the wear surface was relatively smooth and the roughness values decreased. An increased in the roughness values is observed in the surface of the specimen 5086-H32 after wear test.

The laser-hardened surface exhibited good wear resistance, the grooves of the laser-hardened surfaces are relatively shallow due to the higher hardness of the surface and the severity of micro ploughing is comparatively less pronounced on the worn surfaces of 6061-T6 hardened specimens. But the results of wear tests of 5086-H32 hardened specimens presents deeper grooves.

Table (3): The Roughness Values Of The Specimens Treated By Laser.

Specimen	The roughness values Ra (µm) before wear test	The roughness values Ra (µm) after wear test
5086-H32	0.089 0.111 0.204	0.185 0.376 0.823
6061-T6	0.075 0.098 0.125	0.086 0.115 0.277

Figure (5) shows the optical micrographs of the top view of the wear surface of the specimens 5086-H32 and 6061-T6, it can be observed that the main wear mechanism for each specimen treated by laser are similar, generally involving adhesive and material transfer and wear induced oxidation and plowing. Adhesive between the specimens and counter body according accompanied by material detachment and transfer to the counter body occurred during sliding processes. In the specimens of 6061-T6, the worn surface of the specimen is relatively smooth Fig (5-a), 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) Fig (5-b). Their counter surface is covered with large black oxide layer on the worn surface.

In the specimens of 5086-H32, the basic mechanism remains unchanged and only the grooves become slightly deeper. Fig(5-c) presents an optical micrograph showing plowing marks on the worn surface as well as some very small debris, reaction products (oxides). While as shown Fig (5-d), some rugged areas are visible on the cleaned worn surface. Their counter surface exhibits no plowing marks and is covered with thin black oxide layer on the worn surface.

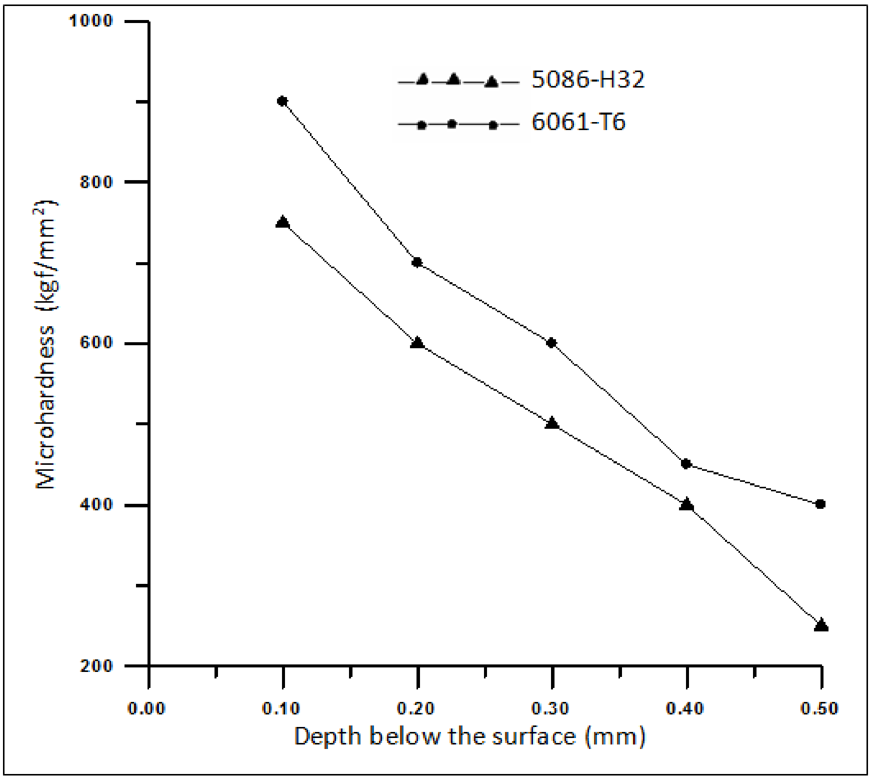


Figure (2): Hardness Distribution Curves Along Hardening Depth

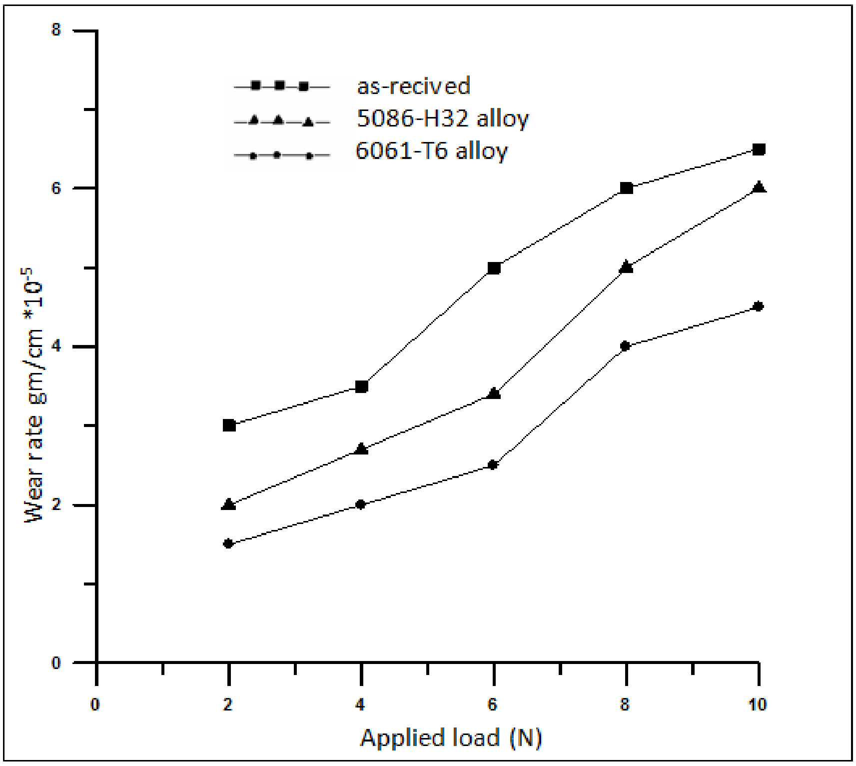


Figure (3): The Relationship Between Wear Rate And Applied Load With Constant Speed (1.5 M/S).

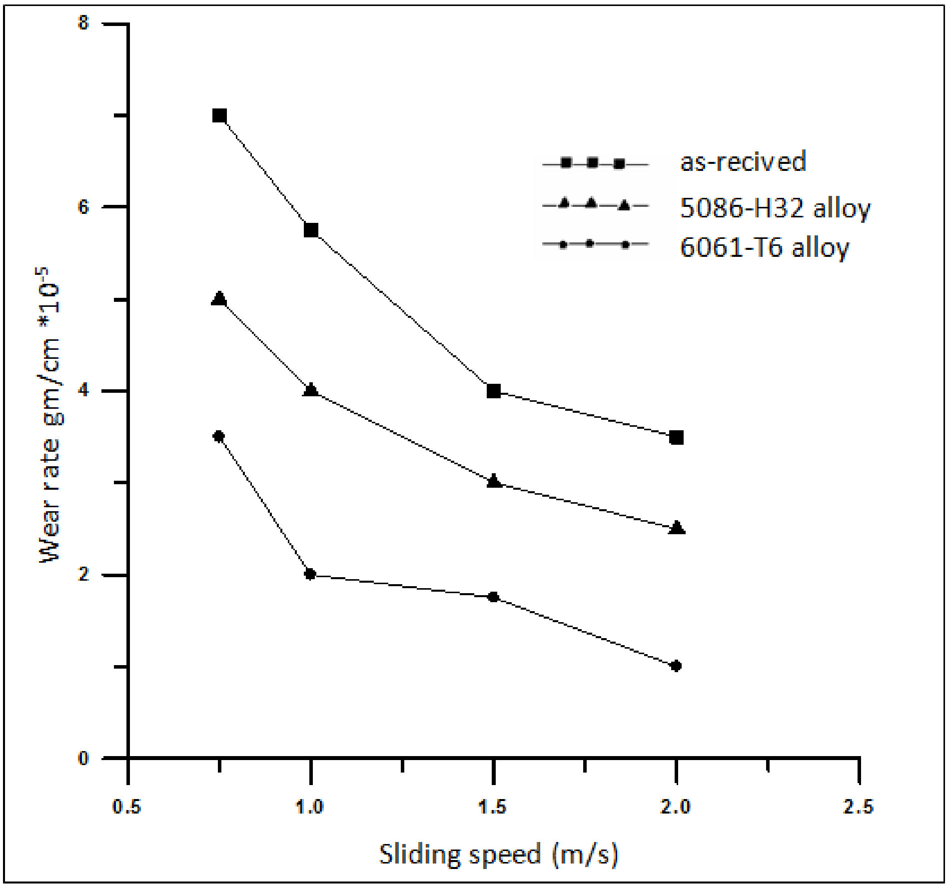
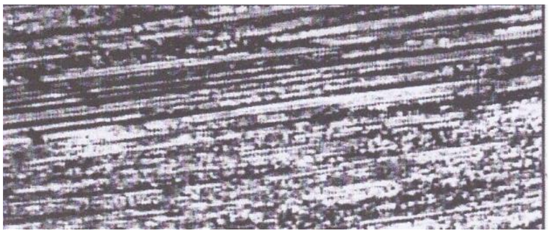
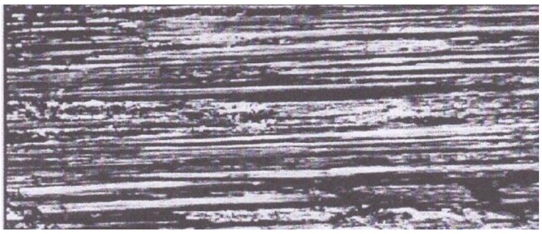
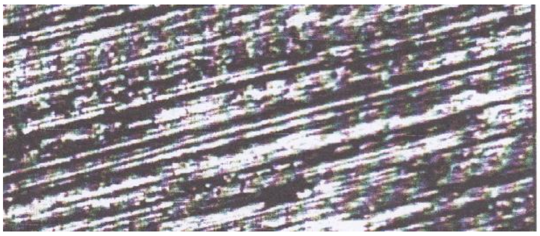
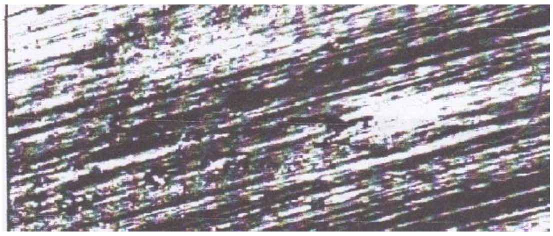


Figure (4): The Relationship Between Wear Rate And Sliding Speed With Constant Load (6 N).

5-a **5-b**

5-c **5-d**

Figure (5): Photomicrographs of Worn Surface of The Specimens.

4. Conclusions

1. **Laser surface treatment leads to improve wear resistance for two aluminum alloys (5086-H32, 6061-T6).**
2. The microhardness decreases by increasing the hardening depth and the microhardness values for 6061-T6 alloy more than 5086-H32 alloy at the same depth.
3. Increasing the applied loads leads to increase wear rate for the specimens 5086-H32 more than for the specimens 6061-T6 after laser treatment.
4. Increasing the sliding speeds leads to decrease the wear rate for the specimens 6061-T6 more than 5086-H32 after laser treatment.

References

[1]. G. Fribourg, A. Deschamps. Y. Brechet. G. Mylonas, G. Labeas, U. Heckenberger, M. Perez, " Microstructure Modifications Induced by a Laser Surface Treatment in an AA7449 Aluminum Alloys", Materials Science and Engineering A528,pp.2736-2747, 2011.

[2]. B.S. Yibas, A.F.M. Arif, C.Caratas and K. Raza, "Laser Treatment of Aluminum Surface : Analysis of Thermal Stress Field the Irradiated Region, Journal of Materials Processing Technology, Volume 209, Issue 1, pp.77–88,2009.

[3]. K.G. Wakins, M.A. Memahon and W. M steen, " Microstructure And Corrosion Properties of Laser Surface Processed Aluminum Alloys " , Materials Science and Engineering: A, Volume 231, Issues 1–2, pp. 55–61, 1997.

[4].Narendra B. Dahotre,"Laser Suface Hardening", ASM Handbook,Volume 4A, Steel Heat Treating Fundamentals and Processes, 2013.

[5]. Masatosgi Enomoto, Sadao Kokubo and Kazuhiro Nakata, " Surface Treatment of Aluminum Alloy with Laser Irradiation To Increase Wear Resistance ", Materials Science forum vols.(539-543), pp. 404-410, 2007.

[6]. H .W. Bergman, D. Muller, T. Endres, R. Damascheck, J. Domes and A. S. , “Industrial Applications of Surface Treatments with High Power Lasers”, Materials Science forum vols. (163-165), pp. 377-404, 1994.

[7]. P.H. Chong, Z. Liu, P. Skeldon and G.E. Thompson, " Large Area Laser Surface Treatment of Aluminium Alloys For Pitting Corrosion Protection" , Applied surface Science vols. (208-209), pp. 399-*404, 2003.*

[8]. F. Fariout, C. Boulmer-leborgn , E. Le Men, T. sauvage, C. Andeeazza, P. Andeeazza, . Langlade, " Surface Carburization Of Aluminum Alloys By Excimerlaser ", Proceedings of the 28th International Conference on Metallurgic Coatings and Thin Films, Vols. 146–147, pp. 324–330, 2001.

[9]. Majid Hammed Ismaiel and Mohamed Abdul wahhab, " Surface Treatment of Aluminum Alloys using Nd: YAG laser "En& .Tech. Journal, Vol .29 ‹No .14, pp. 3006-3018, 2011.

[10]. http://asm.matweb.com , 5086-H32 -ASM Material Property Data-Matweb.

[11]. http://asm.matweb.com ,Glemco, Aluminum 6061-T6 -ASM Material Property Data-Matweb.

[12].http://books.google.iq, Colin E. Webb‹Julian D. C. Jones, ” Handbook of Laser Technology and Applications: Laser Design And Laser Systems”, Volume II, ©IOP Publishing Ltd 2004.