University of Thi -Qar Journal for Engineering Sciences
http://www.doi.org/10.31663/tqujes.12.1.123(2022)
Vol 12.1 (April2022)

ISSN :2664- 5572 (online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@ utq.edu.iq

Comparison wear behavior of different Al-alloys under the effect of laser surface treatment

Anees Al-Tamimi†

†Electromechanical Engineering Department, University of Technology, Iraq, anees.f.saad@uotechnology.edu.iq.

Abstract

This paper investigates a comparison of wear behavior under laser surface hardening for two different kinds of aluminum alloys. Experimental investigations of wear processing were carried out under different load conditions 5, 10,15,20,25 N and with constant sliding speed 2.199 m/s for 15 min. Also changing sliding velocities 1.319, 2.199, 3.078, 3.958 m/s with constant load 20 N for 15 min. Wear machine operate with constant disc rotating at 750 r.p.m. Trails of laser hardening were performed by using pulse Nd:YAG laser with three level energies 500 , 750 , 1000 mJ. Different wear tests were made such as, measurement of depth of hardening, micro-hardness and microstructure examination. This work is shown that the highest amount of laser energy is affected on increasing the micro hardness of 2024 alloy, while it has little or no effect of laser treatment for 7075 alloy. Also wear rates were significantly decreased for 2024 alloy more than 7075 alloy. Photomicrographs show that refining of grains after laser treatment for 2024 alloy more than 7075 alloy.

Keywords: wear, micro-hardness, laser treatment, Photomicrographs, microstructure

1. Introduction

Among the various laser engineering LSE methods, laser surface hardening LSH is a modern modification technology. That meant the modification of the surface microstructural can be done without a change in composition **[1-5]**. Recently laser surface hardening by pulsed laser sources has become an increasingly selected method in the engineering industry and has opened up wider opportunities for the application of selective surface hardening **[6]**.

Victor et, al **[7]**, illustrated how laser can be used to reduce the effect of the wear in material, which is provided the surface with resistance to the wear by increasing the hardness of the load in the local area . in order to reduce the wear introduced that the laser can be treated the entire surface.

The use of laser beam is attractive because the hardening can be localized to the desired region is rapid, and can be easily adapted to numerical control **[8-10]**. Z. Taha, et. al, **[11]** , were studied wear behavior of two different material alloys (steel and aluminum) which were hardened by using pulsed Nd : glass laser. It was found that increasing in wear resistance for 40 ch alloy more than another alloys. K.Hamza et. al, **[12]**, was studied laser surface treatment by using CW Nd: YAG laser on mechanical properties of three different alloys low carbon steel, Al-Si, Al-Cu. The results reveal that improvement in yield strength, ultimate tensile strength and impact strength for L.C.S more than other alloys. Majid Hammed Ismail **[13]**, was studied the effect of laser surface treatment on wear rate of on Al alloys Al-Cu-Si , Al-Zn-Mg , Al-Si-Mg. It was noted that the amount of loss in weight of Al-Cu-Si alloy and Al-Zn-Mg is greater than the loss of weight for Al-Si-Mg alloy. Also the results showed that the amounts of loss are less than the amount of loss in those alloys before the treatment. H.Clauer et.al, **[14]**, were studied the influence of pulsed laser beam to shock harden weld zone in 5086-H32 and 6061-T2 aluminum sheet on mechanical properties.

They show that after laser shocking, the tensile yield strength of 5086-H32 was raised to the bulk level and the yield strength of 6061-T2 was raised midway between the welded and bulk level and the increase in ultimate tensile strength and hardness were smaller than the increase in the yield strength . W.Serbiniski, et. al, **[15]** , were studied the effect of laser on wear characteristics of AlSi13 Mg ICu Ni Alloy . The beneficial effect of laser treatment on the microstructure, microhardness and wear behavior of the cast aluminum alloy were observed.

The purpose of this work is to investigate the effect of the laser surface hardening for two different aluminum alloys (2024 and 7074) and study the effect of the laser on microhardness wear and microstructure.

2. Experimental Work

2.1 Metal used

In this work, A chemical compositions of aluminum 7075 and aluminum 2024 are showing in Tables 1 and 2, while the mechanical properties for these alloys are represented in Tables 3 and 4 **[16]** .

Table 1 The chemical compositions of Al 7075 **[16]**.

Al %	Cr %	Cu %	Fe %	Mg %	Mn %	Si. %	Ti %	Zn %
87.1	0.18	1.2	0.5	2.1	0.3	0.4	0.2	5.1

Table 2 The chemical compositions of Al 2024 **[16]**.

Al %	Cr %	Cu %	Fe %	Mg %	Mn %	Si. %	Ti %	Zn %
87.1	0.18	1.2	0.5	2.1	0.3	0.4	0.2	5.1

Table 3 The mechanical properties of Al 7075 **[16]**.

Mechanical Properties	Values
Yield Strength (Mpa)	503
Ultimate Tensile Strength	572
Poisson's ratio	0.33
Hardness (Hv)	175
Elastic modulus (Gpa)	71.7
Elongation (%)	11

Table 4 The mechanical properties of Al 2024 **[16]**.

Mechanical Properties	Values
Yield Strength (Mpa)	324
Ultimate Tensile Strength	469
Poisson's ratio	0.33
Hardness (Hv)	137
Elastic modulus (Gpa)	73.1
Elongation (%)	19

2.2 Laser surface treatment

The treatment of Laser surface was performed by using pulse Nd:YAG laser by wave length (1060 nm) and (1-6) Hz frequency of laser system, also by using three amount of energies (500 mJ, 750 mJ and 1000 mJ). The specimens of microhardness tests on both materials were considered all the above conditions. Also, the optical microscopic examination was used to estimate the microstructure of the specimens before and after laser treatment.

2.3 Tests of dry sliding wear

This experiment was conducted by using a pin on disc with dimensions is 10 mm in diameter and 20 mm in length. In this experimental different loads were considered (5N, 10N, 15N, 20N and 25N) at constant speed (2.199 m/s and 15 s). Also, various sliding speeds (1.319 m/s, 2.199 m/s, 3.078 m/s and 3.958 m/s) were used with fixing the load (20N) and time (15 s).

A small specimen (pin) is held stationary in the wear arm against a disc (45 HRC) which rotates (at 720 r.p.m) on the end of a motor output shaft . In this way the pin wears whilst the disc remains relatively unworn.

The wear test (pin on disk) was used in this work in order to find the effect of the laser treatment on the aluminum alloys (Al 2024 and Al 7074) with different value of the pluses (1 and 2). Also, the weighing method was demonstrated in this work, to calculate the wear rate. In this test, the samples of aluminum were scaling before and after starting the test by using digital scale (Mettler AE 160) with 0.0001 gm sensitively. The following equation used to calculate the wear rate:

$$rate\,of\;wear\,(gm\,/\,mm) = \Delta w\,/\,SD \qquad (1)$$

where Δw is the difference between the measuring weight before and after the test, and the sliding distance (SD) which is can be determine from the following equation

$$SD = 2\pi rnt \qquad (2)$$

where r (mm) is the distance in between center of the disc and center of the sample, n (r. p. m) is the number of the rotating of disc and t (s) is the time at the end of the test.

In this test, the photomicrographes were capture for each sample to show the topography of the surfaces of the specimens before and after laser treatment.

2.4 Microhardness test

Hensddt Wetzlar No.23298 used to assessment of surface microhardness, with applying load 500 gm. Microhardness calculates by the following equation:

$$Hv = 1.8544\ f/d_2\ (ave)\ (kgf/mm2) \qquad (3)$$

Where f is the applied force (kgf) and d2 is the main diagonal. The hardness method was used to measure the depth of hardening for the specimens of Al 7075 alloy and Al 2024 alloy was measured after the laser surface treatment by three level of energies 500mJ , 750mJ and 1000 mJ with different pulse values (1 and 2). The relation between the hardening depth and number is shown in Figure 1. The result shows that the microhardness with laser 100 mJ and 2 pluses is biggest than other energies (500 mJ and 750mJ). This is due to the highest in gradient of the temperature for the samples materials which are varying from the melting temperature of the aluminum alloys at the surface towards the subsurface .Also rapid self-quenching occur at the surface for energy 1000 mJ more than energies 500 mJ , 750 mJ which in turn lead to increase the microhardness.

2.5 Roughness test

This test was conducted by using roughness tools where the average roughness (Ra) for the Al 2024 and Al 7075 was calculated the after and before the effect of the laser treatment on the samples. The results of the average of surface roughness for the different aluminum samples which are treated by using one pulse and two pulses laser with three different energies is shown in Table 5.

Table 5 The average roughness (Ra) for Al 2024 and Al 7075), with (500mJ, 750 mJ and 1000mJ) and 1 and 2 pluses

Laser energy(mJ)	Surface roughness (Ra) (µm) with 1 pulse		Surface roughness (Ra) (µm) with 2 pulses	
	Al 7075	Al 2024	Al 7075	Al 2024
500	0.272	0.348	0.158	0.248
	0.301	0.472	0.194	0.397
	0.374	0.524	0.224	0.478
	0.411	0.569	0.278	0.509
750	0.341	0.429	0.312	0.328
	0.403	0.491	0.379	0.457
	0.476	0.562	0.448	0.518
	0.513	0.583	0.505	0.556
1000	0.394	0.481	0.933	0.421
	0.482	0.573	0.417	0.498
	0.561	0.597	0.492	0.537
	0.593	0.613	0.553	0.599

Note: the average roughness for Al 7075 alloy is 0.199 and for Al 2024 alloy is 0.158.

3 Results and discussions

3.1 The results and discussion of wear behaviour

The experimental results for the depth hardening and hardening value for Al 2024 and Al 7075which are treated by one or two pulse are depicted in Figure 1. Laser surface treatment with two pulses induced more dislocations in substrate than for one pulse which lead to increasing in microhardness. The morphology of 7075 alloy and 2024 alloy before and after laser surface treatment at cryogenic conditions are compared at microscopic scale and for three depths from the surface.

Figures 2 and 3 are showing the refining of the grains for 2024 alloy, while it is not distinct refining of the grains for 7075 alloy because of it is less response to laser treatment than for 2024 alloy. Wear measurements that made through different loads and different velocities as shown in Figures 4-7, which were measurements the wear rate with one pulse and two pulses respectively. The results show that the load has significant effect on the wear rate for samples made from Al 2024 and Al 7075 in three different places (mild, transition and severe wear). This problem can be solved by using a laser treatment (one pulse and two pulses) which leads to reduce the wear rate.

The laser hardening observed in Al 2024 and Al 7075 is originated from the dislocation substructure produced in the specimens by the shock waves. The microstructure near the surface is expected to have higher dislocation densities because the post-shock hardness and plastic strain is higher near the surface.

The relation between the wear rate for Al 2024 and Al 7075 and applied load and sliding speed are shown in Figures 8 and 9, respectively. It is clear evidence from the results that the aluminum 7075 has no change in wear rate and microhardness after laser surface treatment. This is due to that the response of the 7075 alloy was less than that of 2024 alloy. The effect of laser hardening and wear in dislocation substructure for Al 2024 and Al 7075 should be created due to the effect of the shock wave which it has a significant influence on the plastic strain. Moreover, it is increasing the density of dislocation of material properties for the two samples **[14]**.

Also, from these results it can be found that the laser energy has a significant effect on samples made from Al 2024 and Al 7075, where a lower wear rate can be calculated when using a laser surface with 1000 mJ and higher rate of wear when using the other energies 500 mJ and 750 mJ. These attributed to that under the high pressure at the localized points of contact, elastic, and plastic deformations occur until the areas of contact junction are large enough to support the load **[17]**.

The topographies of the wear surfaces for the Al 2024 and Al 7075 for the three different energies 500 mJ, 750 mJ and 1000 mJ are presented in Figures 5 and 6, respectively. It clear from the results that when using the laser treatment to hardening the surfaces the grooves in these surfaces are less than surfaces without laser treatment. Also, the microploughing is clear on the damage surfaces at 1000 mJ. Moreover, the cracks are shown in samples this is because the residual stress in the sample.

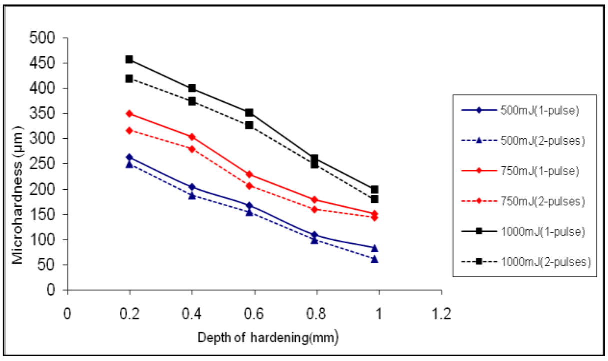
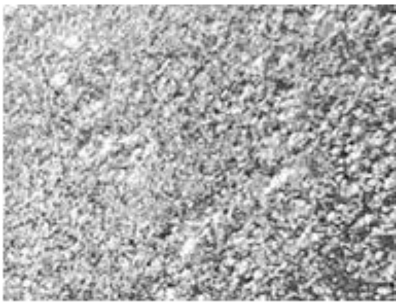
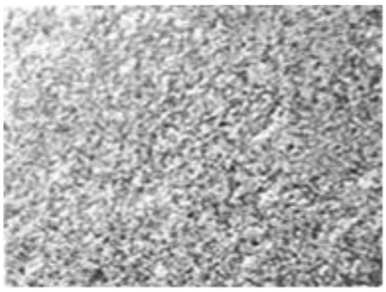


Fig. 1 Microhardness-depth of hardening with laser surface treatment (1 pulse and 2 pulses)

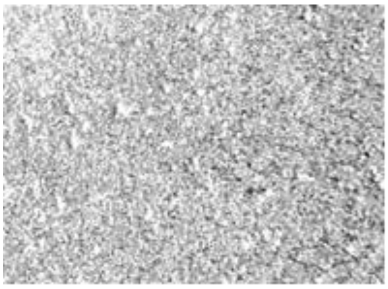
(a) Al 7075 without laser heat treatment (depth =100 µm)



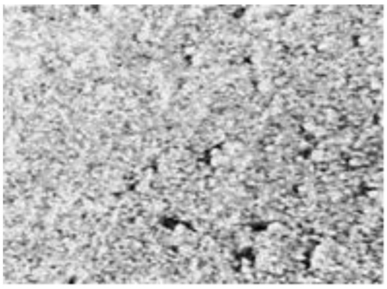
(b) Al 7075 without laser heat treatment (depth =300 µm)



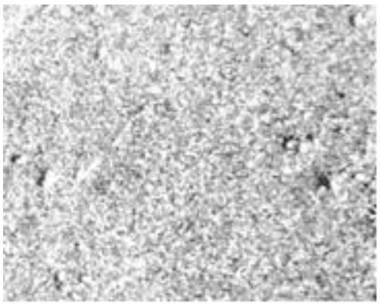
(c) Al 7075 without laser heat treatment (depth =500 µm)



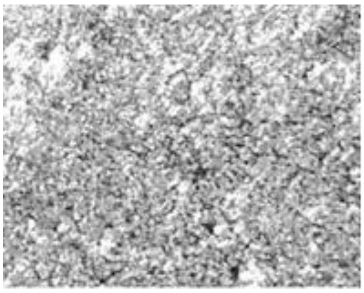
(d) Al 7075 laser heat treatment
(depth =100 µm) , 500 mJ



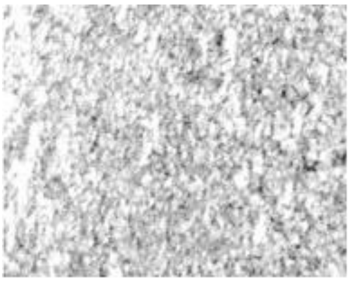
(e) Al 7075 laser heat treatment
(depth =300 µm) , 500 mJ



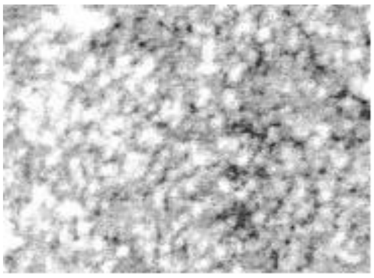
(f) Al 7075 laser heat treatment
(depth =500 µm) , 500 mJ



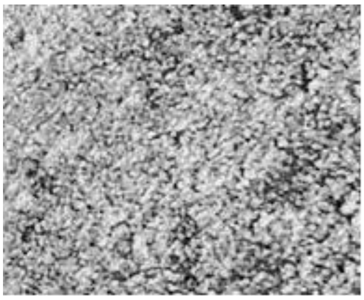
(g) Al 7075 laser heat treatment
(depth =100 µm),750 mJ



(h) Al 7075 laser heat treatment
(depth =300 µm),750 mJ

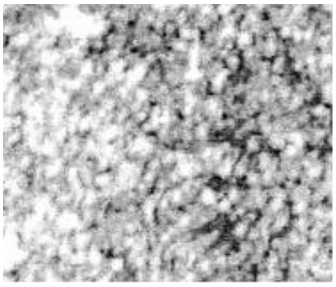


(i) Al 7075 laser heat treatment
depth =500 µm),750 mJ



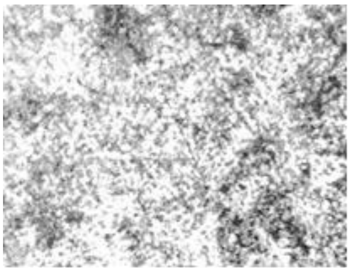
(j) Al 7075 laser heat treatment
(depth =100 µm),1000 mJ

(k) Al 7075 laser heat treatment
(depth =300 µm),1000 mJ

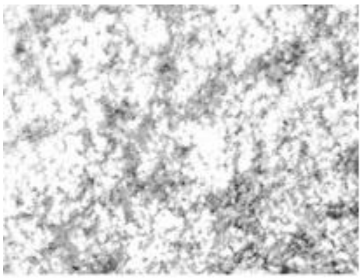


(l) Al 7075 laser heat treatment (depth =500 µm) , 1000 mJ

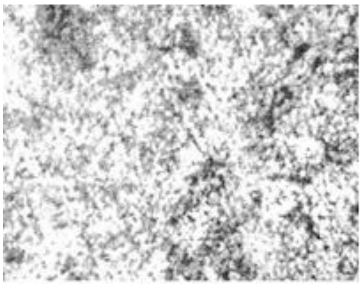
Fig. 2 Photomicrographs of Al 7075 alloy before and after laser treatment for three depths (100 µm, 300 µm and 500 µm) with three energies (500 mJ, 750 mJ, and 1000 mJ)



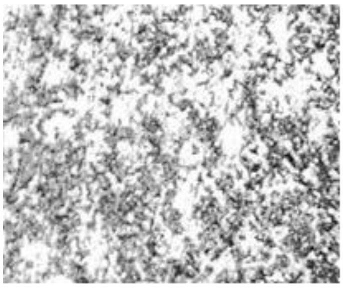
(a) without laser heat treatment (depth =100 µm) for Al 2024



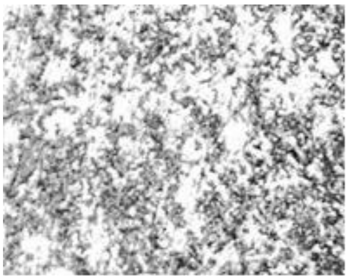
(b) without laser heat treatment (depth =300 µm) for Al 2024



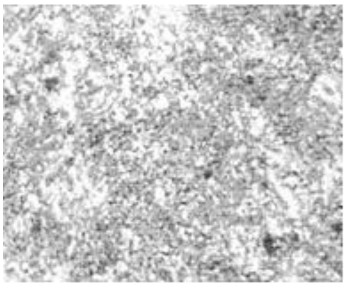
(c) without laser heat treatment (depth =500 µm) for Al 2024



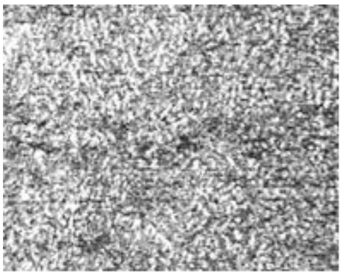
(d) Laser heat treatment for Al 2024 (depth =100 µm),500 mJ



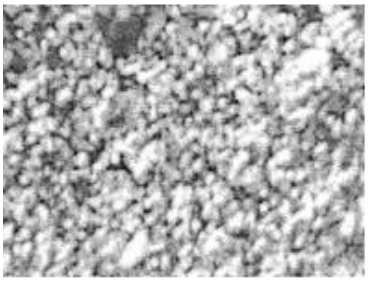
(e) Laser heat treatment for Al 2024 (depth =300 µm),500 mJ



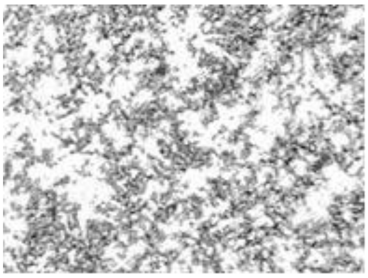
(f) Laser heat treatment for Al 2024 (depth =500 µm),500 mJ



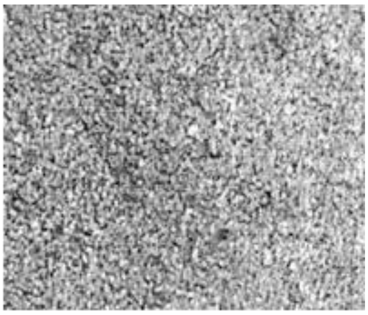
(g) Laser heat treatment for Al 2024 (depth =100 µm),750 mJ



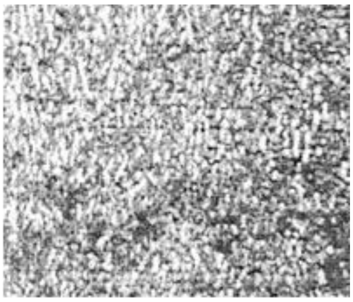
(h) Laser heat treatment for Al 2024 (depth =300 µm),750 mJ



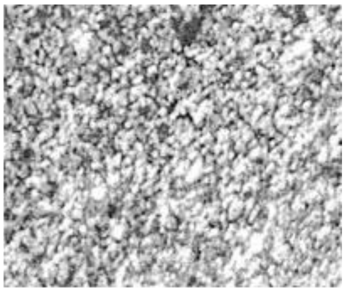
(i) Laser heat treatment for Al 2024 (depth =500 µm),750 mJ



(j) Laser heat treatment for Al 2024 (depth =100 µm),1000 mJ



(k) Laser heat treatment for Al 2024 (depth =300 µm),1000 mJ



(l) Laser heat treatment for Al 2024 (depth =500 µm),1000 mJ

Fig.3 Photomicrographs of Al 2024 alloy before and after laser treatment for three depths (100 µm, 300 µm and 500 µm) with three energies (500 mJ, 750 mJ and 1000 mJ)

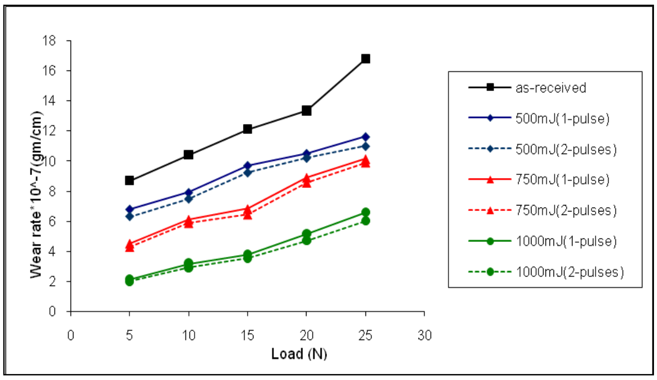


Fig. 4 wear rate- load for Al 7075 with sliding speed 2.199 m/s

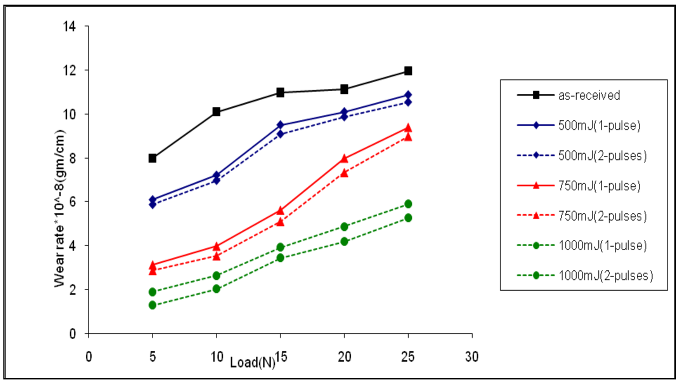


Fig. 5 wear rate- load for Al 2024 with sliding speed 2.199 m/s

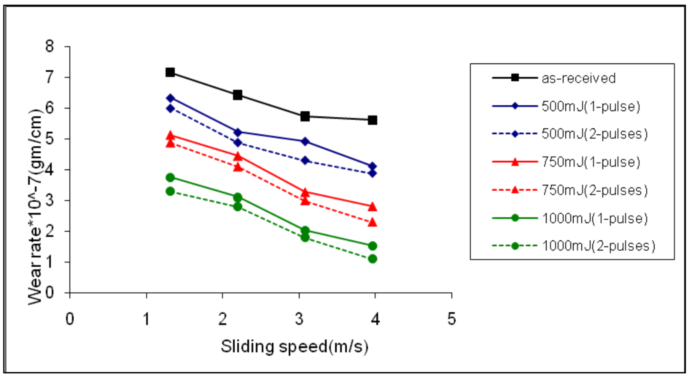


Fig. 6 wear rate-sliding speed with for Al 7075 with applied load (20N)

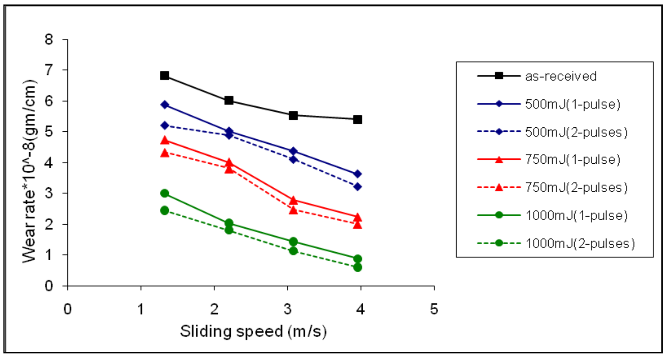
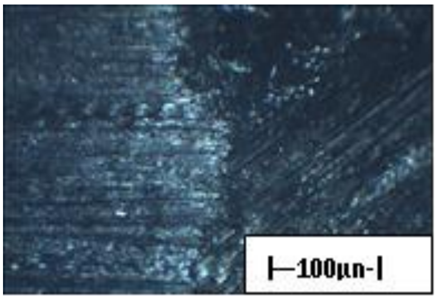
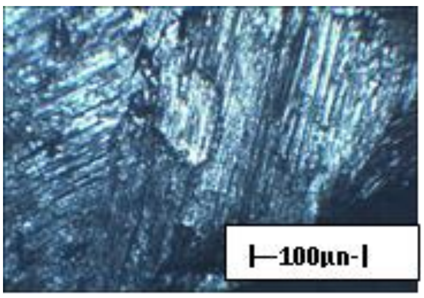


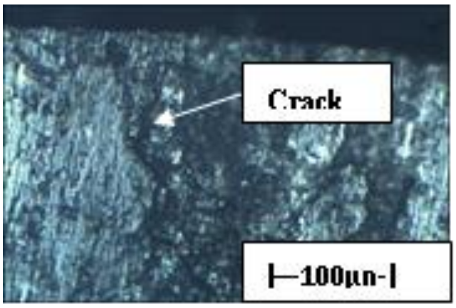
Fig. 7 wear rate-sliding speed for Al 2024 with applied load (20N)



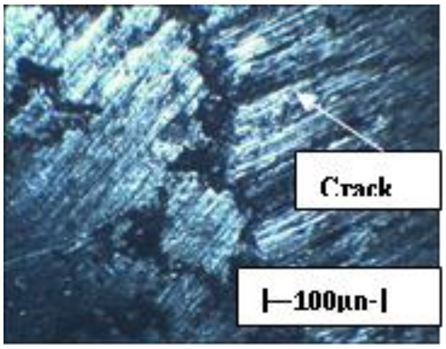
(a) as-received (250 x)



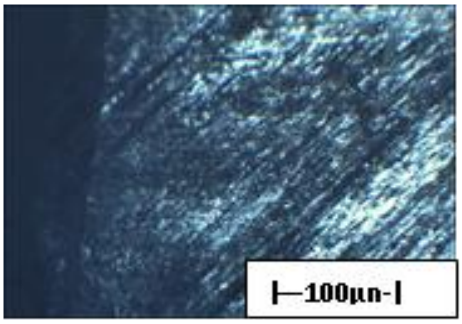
(b) Laser surface treatment with one pulse and 500 mJ



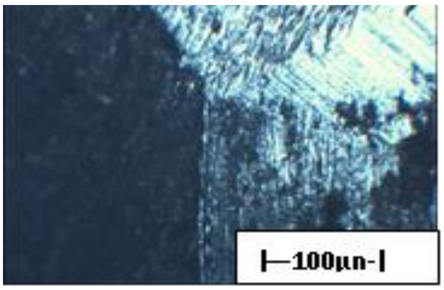
(c) Laser surface treatment with two pulses and 500 mJ



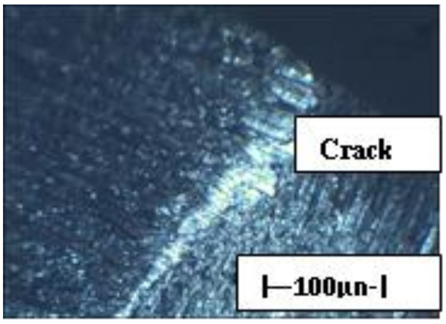
(d) Laser surface treatment with one pulses and 750 mJ



(e) Laser surface treatment with two pulses and 750 mJ

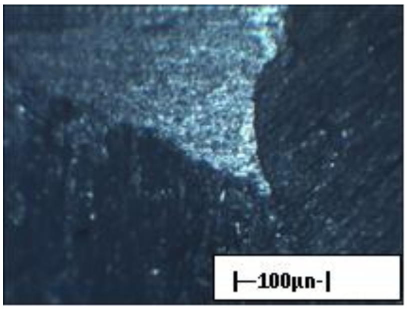


(f) Laser surface treatment with one pulse and 1000 mJ

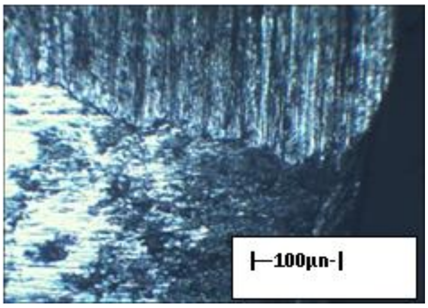


(g) Laser surface treatment with two pulses and 1000 mJ

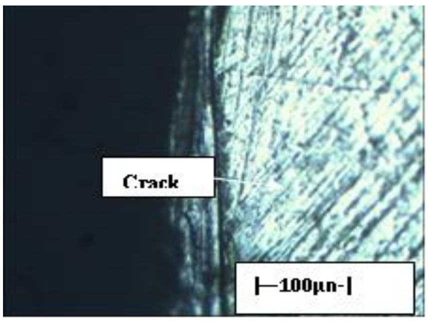
Fig. 8 Micrographs of wear surfaces for Al 7075 for various energies (500 mJ, 750 mJ and 1000 mJ) with laser surface treatment (1 and 2 pulses)



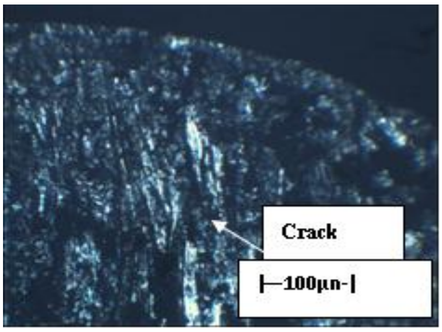
(a) as-received (250 x)



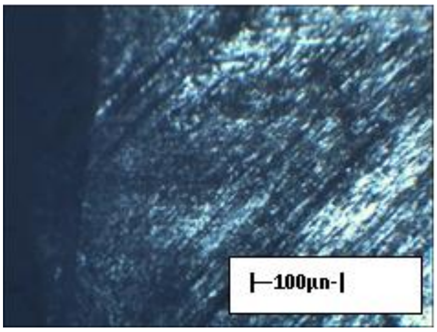
(b) Laser surface treatment with one pulse and 500 mJ



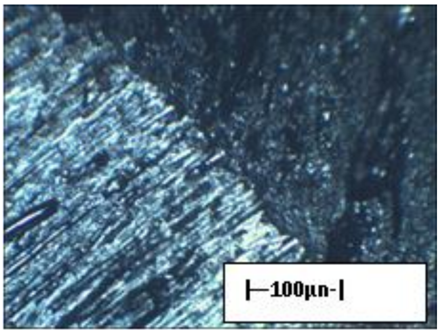
(c) Laser surface treatment with two pulses and 500 mJ



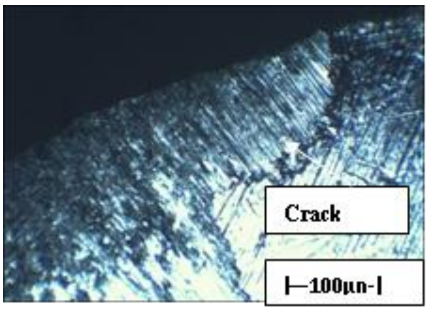
(d) Laser surface treatment with one pulse and 750



(e) Laser surface treatment with two pulses and 750



(f) Laser surface treatment with one pulse and 1000



(g) Laser surface treatment with two pulses and 1000

Fig. 9 Micrographs of wear surfaces for Al 2024 for various energies (500 mJ, 750 mJ and 1000 mJ) with laser surface treatment (1 and 2 pulses)

Conclusions

In this work, the experimental investigation of wear behaviour of the two aluminum alloys under the effect of the laser surface hardening. The following conclusions can be found from the presented work:

1. Increasing laser energy lead to increase the wear resistance.
2. Aluminum 7075 alloy less response to laser treatment than the Aluminum 2024 alloy.
3. Laser surface treatment with two pulses induced increasing in microhardness, Wear resistance, refining of grains more than one pulse.

References

[1] J.DUTTA MAJUMDAR and MANNA, "laser processing of materials", Sadhand, 2003, 495.
[2] C.NAVAS, A.conde , M.cadenas and j.de Damborenea , " Tribological properties of laser clad satellite 6 coating on steel substrate" , *J. surface engineering* , 2006 ,22, 26.
[3] S.p.gadag, M.N.srinivasm, "Surface properties of laser processed ductile iron", *J.Applied physics A*, 1996, 63,409.
[4] S.ALTSHULIN, J.ZAHAVI, A.ROSEN, S.NADIV. "The interaction between a pulsed laser beam and a steel surface*", J. of materials science* 25, 1990 , 25, 2259 .
[5] MIOKOVIC T.SCHULZE V.VOHRINGER O.LOHE D. "Influence of cyclic temperature changes on the microstructure of AISI 4140 after laser hardening", *J. Acta materialia*, 2007, 55 , 589.
[6] H.visscher , M.B.de ROOIJ , P.H.vroegop and D.J schipper , " The influence of laser line hardening of carbon steel AISI 1045 on lubricated wear against steel AISI 52100" , *wear* , 1995, 181, 638.
[7] Victor G. ,"Laser Heat Treatment in laser material processing" , Bass M(Ed) , 1983, 3 ,138.
[8] Cros,"laser surface hardness", *Journal of optoelectronics and Advanced materials*, 2004, 6, 325.
[9] Fairand AH, Clauer BP. Interaction of laser-induced stress waves with metals. *In Proceedings of the ASM Conference Applications of Lasers in Materials Processing*, Washington, DC, USA ,1979, 18.

[10] Watkins, K.G., McMahon, M.A. and Steen, W.M., 1997. Microstructure and corrosion properties of laser surface processed aluminium alloys: a review. *J. Materials Science and Engineering*, 1997, 231, 55.
[11] Zyad Aeyad Taha , "Laser surface heat treatment for steel and aluminum alloys", University of Baghdad, thesis for the degree of Master science in Mechanical engineering, (1988).
[12] Asaad K.Hamza , "A Computer Training Program to Study the Effect of Surface Heat Treatment on Mechanical Properties for Different Metal Alloys" , University of Technology, thesis for the degree of Master science in Mechanical engineering, (2008).
[13] Majid Hammed Ismaiel, "Surface Treatment of Aluminum Alloys using Nd ; YAG laser' , University of Technology, thesis for the degree of Master science in Mechanical engineering, (2010).
[14] Clauer, A.H., Fairand, B.P. and Wilcox, B.A., " Laser shock hardening of weld zones in aluminum alloys". *J.Metallurgical Transactions A*, 1977, 12),1871.
[15] W.Sebiniski ,J.I.Lubiniski , K.Druet , "Microstructure and wear of cast Aluminum alloys with Laser Modified surface layer" , *Advanced in Materials Science* , 2003, 1,71.
[16] Meyers MA. Dynamic behavior of materials. John wiley & sons; 1994 , 28.
[17] J.L.ELLIS , "Wear Resistance alloy bonded carbides produced by PM" , *J.Powder Metallurgy*,1984, 16, 53 .