Surface Treatment of Aluminum Alloys Using Nd:YAG Laser

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Received on: 3/1/2011
Accepted on: 21/7/2011

Abstract

In this research, a pulsed Nd:YAG laser with wavelength (1064nm) and (532 nm) and pulse duration (100 ns) for different energies [250 mJ,500 mJ,750 mJ,1000 mJ] and spot size (1.5mm) was used.

Laser surface treatment is the most important way in industrial application because of its ability to improve the surface properties of metal and alloys.

The alloys used were [Al-Cu-Si], [Al-Si-Mg] and [AL-Zn-Mg].The essential aim for this work includes study the effect of laser parameters on aluminum alloys. In laser surface engineering the mirohardness and wear tests will be studied after laser treatment.

The effect of laser parameters includes:

1- The effect of the pulsed Nd: YAG laser energy.
2- The effect of the number of shots (pulse).

Keywords: Surface Treatment by Nd: YAG Laser, Treatment of Aluminum Alloys Using Nd:YAG Laser .

المعالجة السطحية لسبائك الألمنيوم بأستخدام ليزر نديميوم ياك (Nd:YAG)

الخلاصة

في هذا البحث أستخدم ليزر نبضي ليزر النديميوم ياك Nd:YAG مع طول موجي (1064 nm) و(532 nm) مع أمد نبضة (100 ns) مع طاقات مختلفــة(250mJ , 500mJ ,750mJ ,1000mJ) ومع قطر حزمة (1.5 mm) .

المعالجة السطحية بالليزر من أهم الطرق المستخدمة في التطبيقات الصناعية بسبب قدرة الليزر على تحسين المواصفات السطحية للمعادن و للسبائك.

السبائك المستخدمة كانت:{ [Al-Cu-Si], [Al-Si-Mg], [AL-Zn-Mg] }

أن الهدف الضروري لهذا العمل يَتضمّنُ دراسة تأثيرَ متغيرات الليزر على سبائكِ الألمنيوم. فـــي المعالجة السطحية بالليزر فحص الصلادة المجهرية وفحص البلى ستدرس بعد المعالجة بالليزر .

تأثير متغيرات الليزر تشمل :

- تأثير طاقة الليزر النبضية.
- تأثير عدد النبضات.

1 Introduction

The twentieth century has witnessed many inventions and discoveries; the mankind was unable through its long centuries to reach these inventions and Discoveries. One of the most

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important inventions among these inventions is the laser radiation invention. Laser radiation has great importance in many applications, such as the scientific and industrial applications. The invention of laser has led to a scientific and technological revolution which included the conventional and modern industries, laser helped in bring about tremendous developments for many sciences and application fields and has become one of the modern science achievements [1].

Laser material processing is an advanced and highly efficient manufacturing method. It has been applied into almost all fields of engineering, military, industry, and communication [2].

1-1 Laser Beam Parameters:

The energy from a laser is in the form of a beam of electromagnetic radiation. It has the properties of wavelength, pulse duration, coherence and divergence, energy and peak power, mode structure and beam focusing. Some of them are discussed in the following sections **[3]** .

1-2 Wavelength:

The wavelength of laser radiation is given by the active environment. It is situated invisible for (ruby, He-Ne) either in infra-red (YAG, CO2).

1-3 Pulse Duration of Laser:

Ultra fast pulses offer significant potential advantages over conventional sources for micromachining. The key benefit of an ultra short pulse lies in its ability to deposit energy into a material in a very short time period, before thermal diffusion can occur. Following linear or multi photon absorption of the laser energy, electron temperatures can exceed many thousands of degrees Kelvin. With energy transfer from the electrons to the atomic lattice, material removal, ablation, and plasma formation occur [4].

1-4 Coherence and Divergence of a Beam:

A laser beam is highly coherent and has a small divergence [5] .

1-5 Energy and Peak Power:

Laser power: May be continuous or pulsed [6] :

1– Continuous (CW):

Important parameter is the power in Watts between 100W and 20kW for materials processing

2– Pulsed:

Important parameters are Joules per Pulse and number of Pulses per Second

a – Energy per pulse**:** 1mJ -1kJ,

b–Pulse length: 1ms -1ns,and

c–Pulse repetition rate: 0.1 Hz to 1000 Hz.

1-6 Mode Structure:

The photon oscillating from end of the resonator to the other constitutes an electromagnetic energy which forms an intense electromagnetic field. The shape of this field is critically dependent not only on the photon wave length, but also on the mirror alignment, curvature, spacing, and on bore diameter of the laser tube [7] .

1-7 Beam Focusing:

The entire beam of coherent light from a laser can be imaged at a point in space by focusing a lens. Intensity of the light at the image point **(**relative to the intensity at the source) is proportional to the solid angle included by the lens, making the imaged spot much more intense than the unfocussed beam [7].

2 Material Parameters:

Material parameters that affect laser processing are discussed below.

2-1 Reflection.

2-2 Absorbsivity.

2-3 Thermal Conductivity.

2-4 Thermal Diffusivity (N th).

3 Wear:

Surface dependent degradation by wear, oxidation, and corrosion is as much a problem in nonferrous metals and alloys as that in ferrous alloys. Thus, LSE (Laser Surface Engineering) is widely applied to Al, Ti, and Cu, Mg and other important nonferrous metals and alloys to extend the service life of components subjected to severe conditions of wear, oxidation, and corrosion. In this section, the scope and current status of understanding regarding the application of LSE (Laser Surface Engineering) to enhance surface dependent properties of non-ferrous alloys will be reviewed [2] .

A directed energy electron beam is capable of intense heating and melting the surface of the most refractory metals and ceramics [2]. Figure (2-1) presents a brief classification of different LSE (Laser Surface Engineering) [2] .

4 Experimental Work and Procedures:

4-1 Laser System:

Pulsed Nd:YAG Laser of different laser energy was used in this work (See Fig. (1-2)). The wavelength of the system is 1064 nm and the pulsed energy can be used from 100 mJ to 1000 mJ. The pulsed duration was 100 ns with spot size (1.5 mm).

4-2 Materials Under Test:

Aluminum alloys (Al-Cu-Si), (Al-Si-Mg) and (Al-Zn-Mg) with their chemical compositions illustrated in tables (1-1), (1-2), and (1-3) the results were agreement with ASM [American Standard of Materials]. For microhardness test, the treated aluminum alloy samples have a diameter of 15mm with 10mm thickness as shown in Fig. (1-3). While in wear tests the dimensions for diameter is 10mm and 40 mm for thickness as shown in Fig.(1- 4). Before laser treatment, grinding and polishing were done to remove any foreign materials.

4-3 Specimens Preparation:

Grinding was done using silicon carbide papers 320, 500 and 1000. Grinding was established to obtain smooth and uniform surface. Then, a certain area on the circumference of specimen was polished to be irradiated with laser.

4-4 Microhardness Test:

The digital microhardness Vickers Hardness Tester TH714 form the Time Group Inc of Beijing Time High Technology LTD, is shown in Fig. (1-5) for mechanical industries, and it was used to determine the microhardness magnitudes of the substrate material (see Fig. (1-6)). In all microhardness tests, the load was fixed to (1.961 N about 200 gf). At least three readings of the microhardness magnitude were

4-5 Wear Tests:

The wear test system shown in Fig. (1-7) was used to compute the wear rate. The instrument consists of an electric motor rotating at (950 r.p.m) to a gearbox and shaft where the specimen is mounted. Pin

– on – Disk principle was satisfied to measure the wear rate. Weight loss method was also 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 with direct contact with a very hard reference disk rotating at (277.4 r.p.m). A light load of (500 g), was applied, and the test interval was (75 min) for all aluminum alloys.

The specimen was weighed each (5 min). Wear rate can be calculated by the following relation[7]:

$$W.R. = \frac{W_1 - W_2}{S.D} \quad \dots (gm/mm) \dots 3-1$$

S.D. = S×t … (mm)… 3-2

S = 12000 (cm / min)

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

$W1$: The specimen mass before the wear test (gm).

$W2$: The specimen mass after the wear test (gm).

ΔW = (W 1- W 2), the change of weight before and after the treatment.

$S.D.$:The distance of sliding wear (mm).

S : The speed of the sliding (mm/min).

t : The time of the sliding (min).

5 Results and Discussion :

5-1 The effect of the laser energy and the number of shots:

Figures (1-8, 1-9, and 1-10) represent the relationship between the microhardness and laser energy of different values (250mJ, 500mJ, 750mJ, 1000mJ). It can be seen that with increasing laser energy, the value of the hardness of (Al-Si-Mg) alloy increased as in Fig. (1-9) while the values of the microhardness of, (Al-Cu-Si) and aluminum (Al-Zn-Mg) alloys decreased as in Figs. [(1-8), (1-10)].

5-2 The wear rate before and after laser treatment:

Figures (1-11, 1-12, 1-13) represent the relationship between rate of wear and examination time of alloys used in this thesis. Figs [1-11, 1-12], shows the relationship between the rate of wear and time of testing for (Al-Cu-Si) and (Al-Zn-Mg) alloys. This figure explains also that the treatment by laser did not improve the wear resistance of the alloy, which leads the wear to be at the higher value and, it is almost invariable due to the loss of regular weight with the observation that the wear rate at the beginning of testing is at a high value and then tends to be uniform because the surface of the process becomes soft as a result of laser treatment. The untreated alloy showed an improvement in the mechanical properties, the wear rate in addition to being a regular; it would be small as compared with the laser treated alloy.

For the (Al-Si-Mg) alloy as shown in Fig. (1-13), the case is completely different since the laser treatment improved the mechanical properties and a clear increase in the value of hardness is observed. So, the wear rate of the alloy after the laser treatment is minimal. This means that the rate of wear after laser treatment is less than that in the alloy before the treatment, which recorded the highest rate of wear. **Conclusions:**

1 - The results show that when the laser energy is increased, in the aforementioned range the hardness is increased in (Al-Si-Mg), while a decrease in the hardness for (Al-Cu-

Si) and (Al-Zn-Mg) alloys is observed.

2 - The results exhibit that the microhardness values are decreased for (Al-Si-Mg) with the distance away from the center of the impact and increased for (Al-Cu-Si) and (Al-Zn-Mg).

3 - The treatment by laser in the aforementioned laser parameter leads to decrease the wear rate and increase in microhardness for (Al-Si-Mg) alloy.

4 - The treatment by laser in the aforementioned laser parameter leads to increase the wear rate and decrease in microhardness for (Al-Cu-Si) and (Al-Zn-Mg) alloys.

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[7] I. Coherent, " Laser Operation, Equipment, Application, and Design, "The Engineering Staff of Coherent Inc., California, 1980, pp.73-76.

Table (1-1):Chemical composition for (Al-Cu-Si) alloy.

Al	Si	Fe	Cu	Mn	Mg	Zn	Ni
92.8	0.96	0.54	4.96	0.02	0.477	0.019	0.199

Table (1-2):Chemical composition for (Al-Si-Mg) alloy.

Al	Si	Fe	Cu	Mn	Mg	Zn	Ni
96.8	1.48	0.404	0.603	0.05	0.760	0.18	0.132

Table (1-3):Chemical composition for (Al-Zn-Mg) alloy.

Al	Si	Fe	Cu	Mn	Mg	Zn	Ni
90.48	0.58	0.54	1.74	0.018	1.89	4.75	0.0

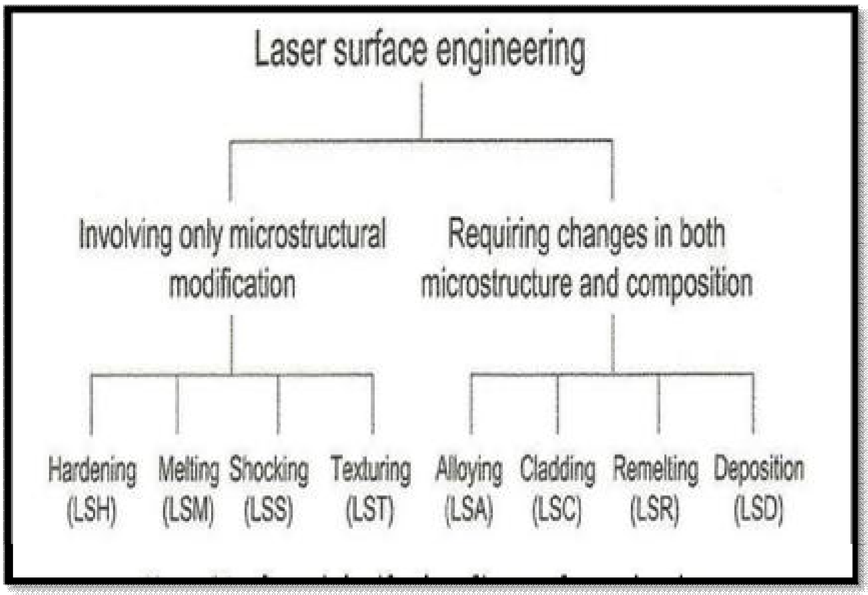


Figure (1-1) General classification of laser surface engineering [2].

Figure (1-2) Laser system used

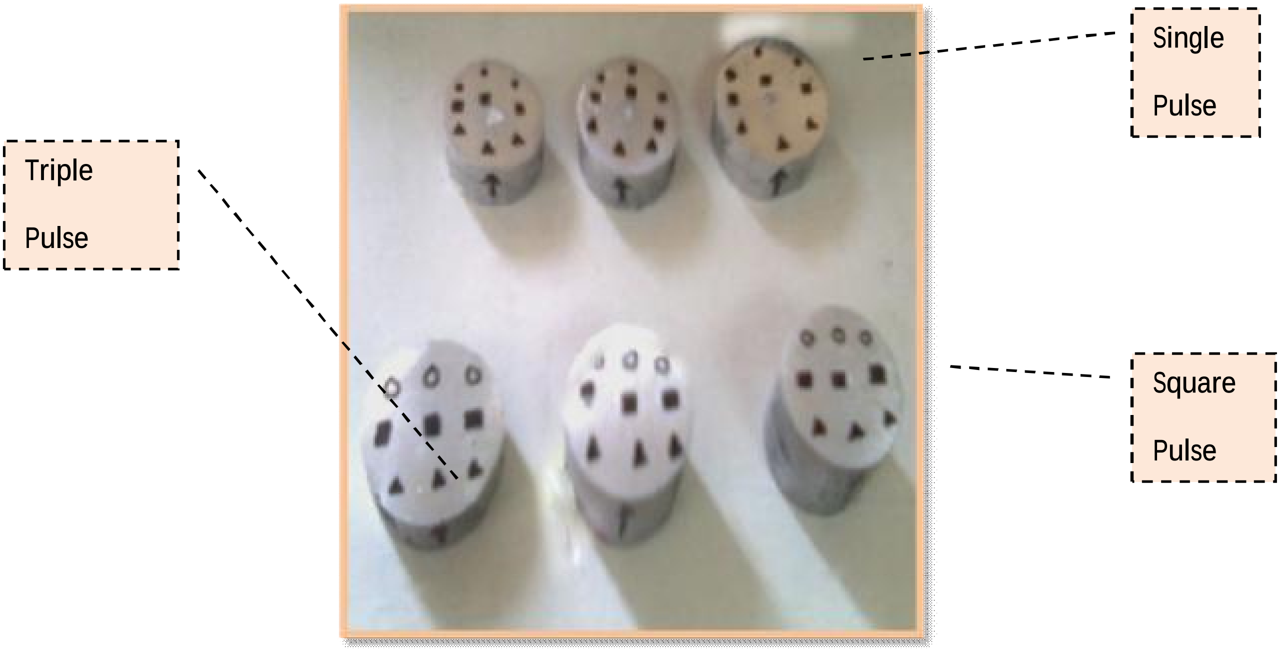


Figure (1-3) Aluminum alloys used in microhardness tests.

Figure (1-4) Aluminum alloys used in wear test taken for each specimen.

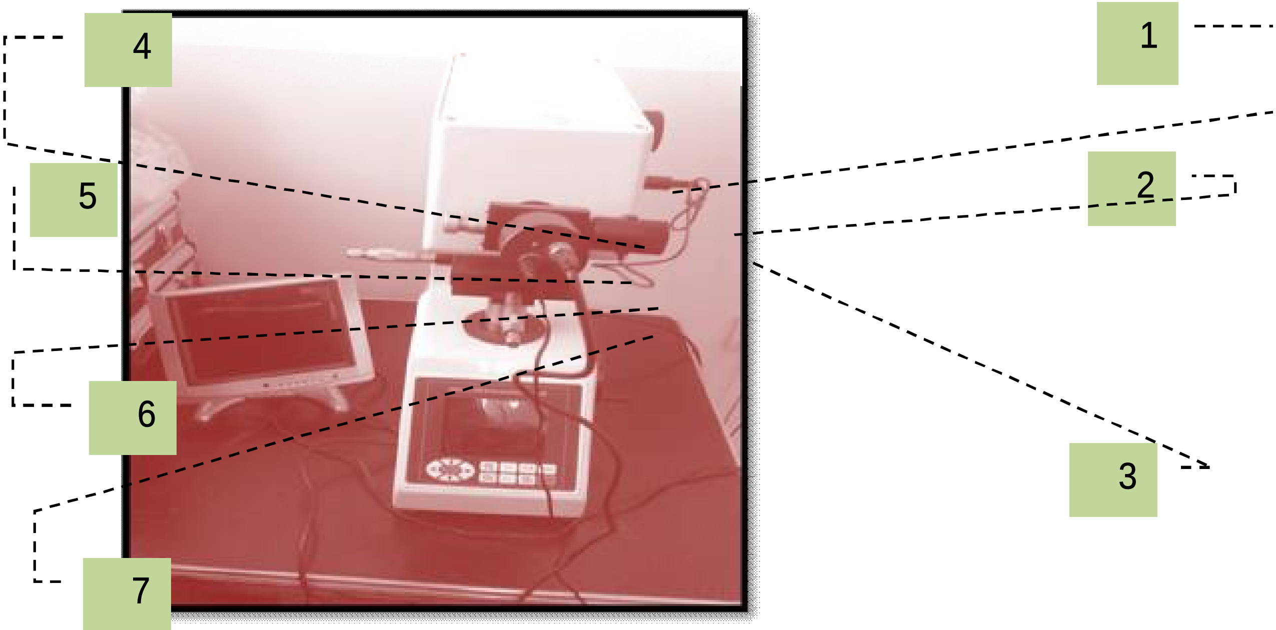


Figure (1-5) The digital microhardness tester (1. Upper Cover, 2.Microscope, 3. Rotating Board,4. Indenter, 5. Testing Table, 6. Up-Lifting Filament Pole, 7. Screw).

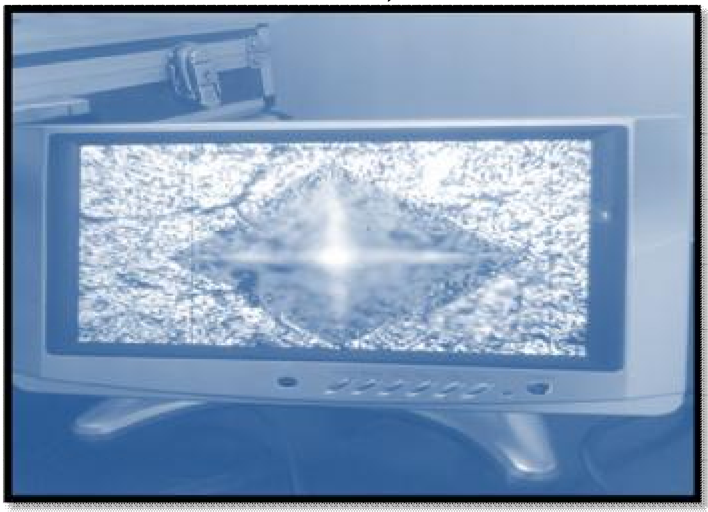


Figure (1-6) Tracks of microhardness indenter of laser in (Al-Zn-Mg).

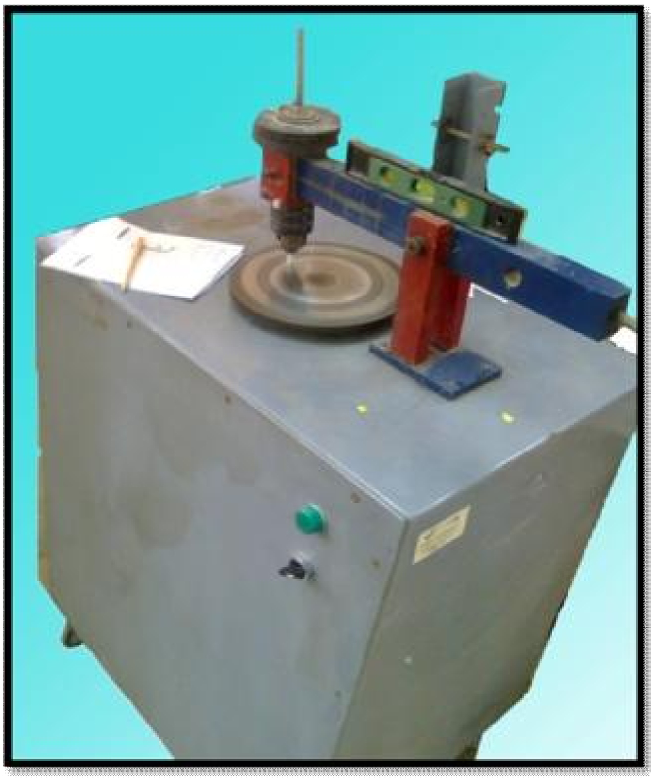


Figure (1-7) Wear test system

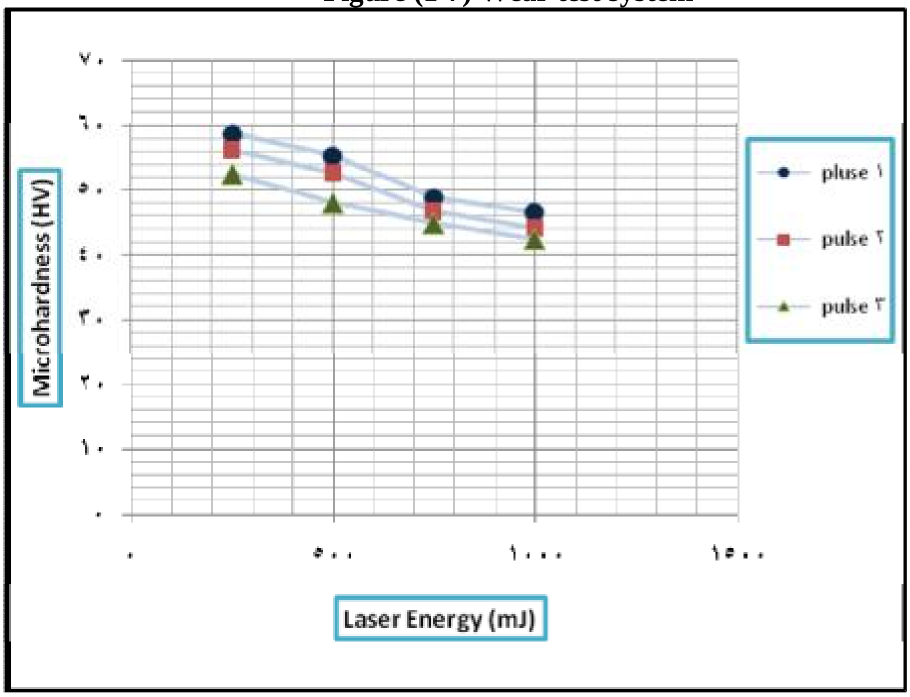
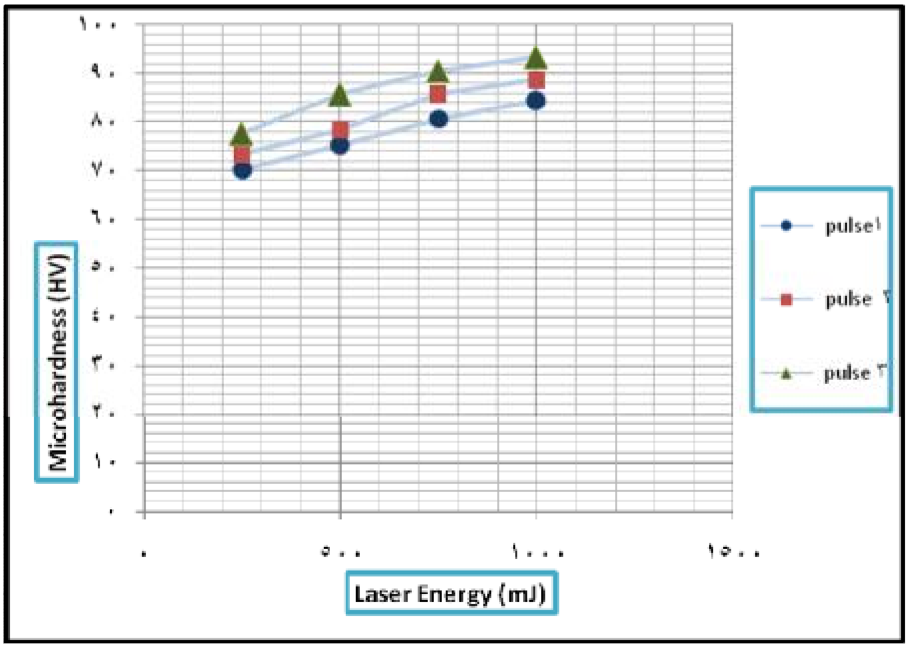
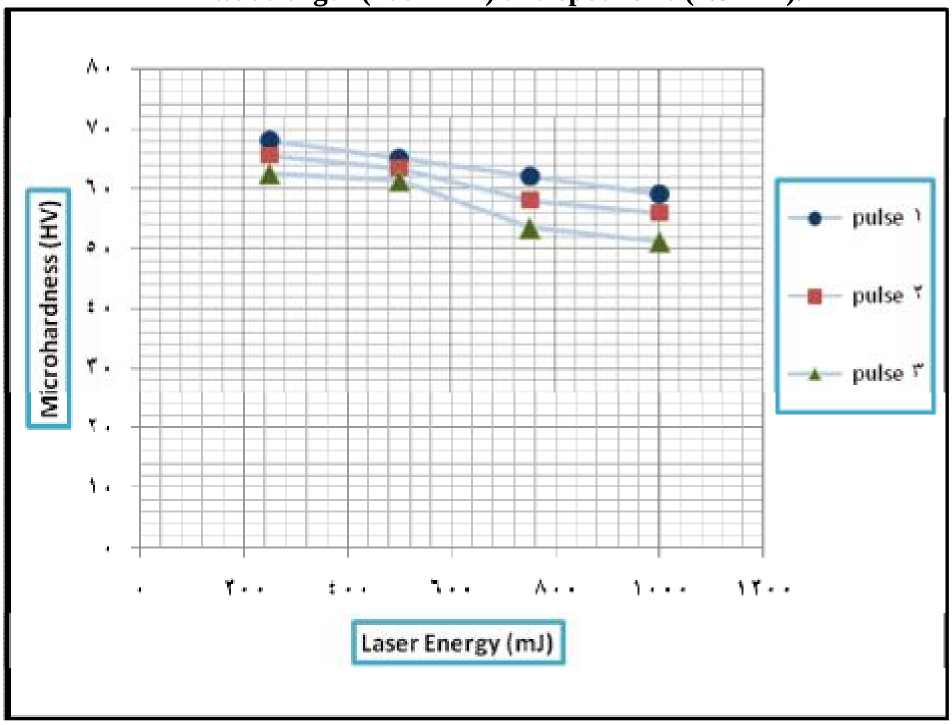


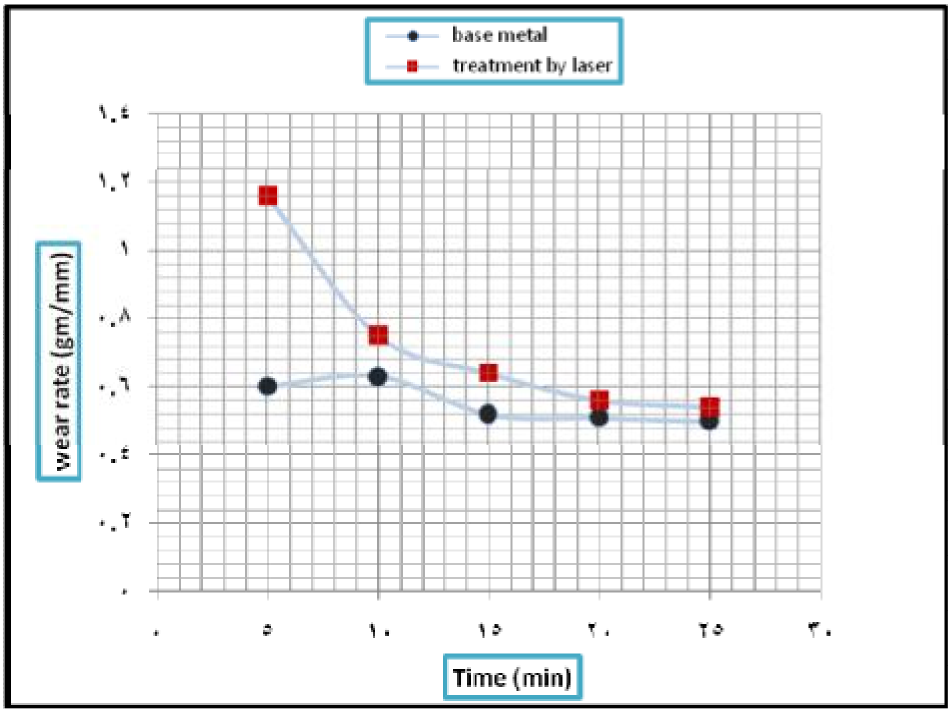
Figure (1-8) The effect of the laser energy and the number of shots(pulses) on the microhardness for samples (no.1) (Al-Cu-Si) at focal length (f=12cm) and wavelength (1064nm) and spot size (1.5 mm).



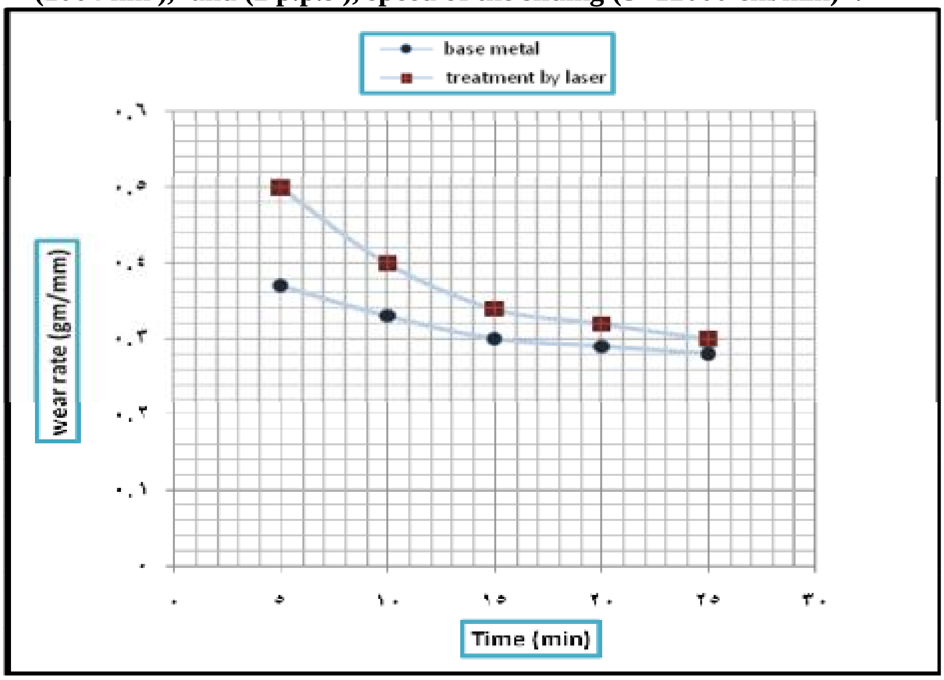
Figurer(1-9) The effect of the Laser energy and the number of shots (pulses) on the microhardness for samples (no.2) (Al-Si-Mg) at focal length (*f*=12 cm) and wavelength (1064 nm) and spot size (1.5 mm).



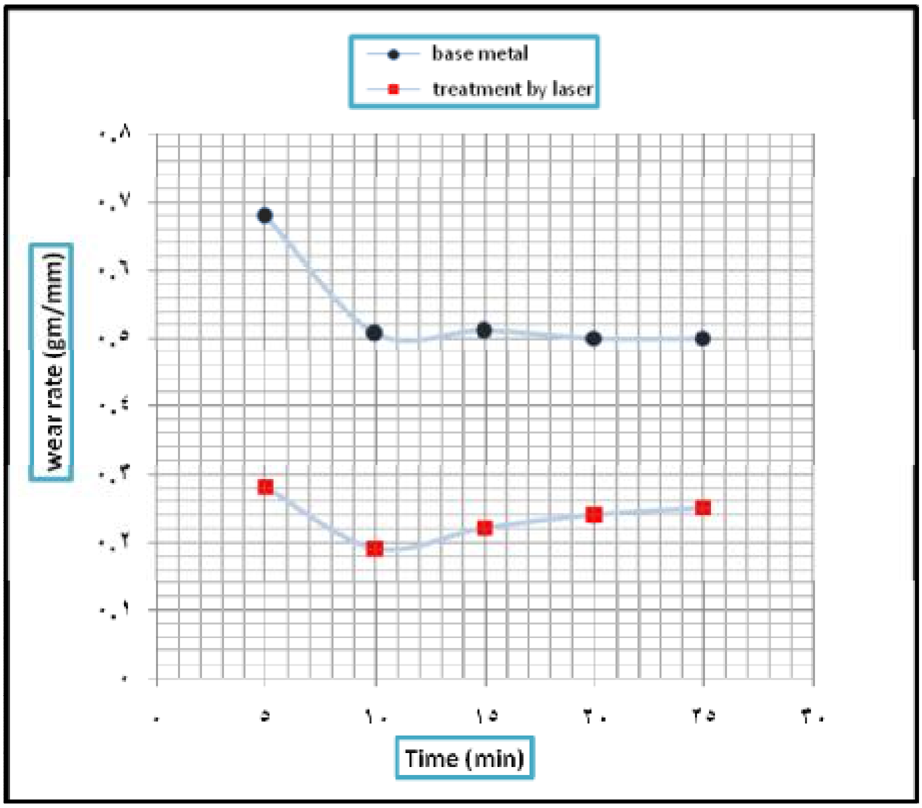
Figure(1-10) the effect of the Laser energy and the number of shots (pulses) on the microhardness for samples (no.3) (Al-Zn-Mg) at focal length (*f*=12 cm) and wavelength (1064 nm) and spot size (1.5 mm).



Figure(1-11) The relation between the wear rate and the time before and after laser treatment for (Al-Cu-Si) at laser energy (1000 mJ), (f=12 cm), wavelength (1064 nm), and (2 p.p.s), speed of the sliding (S=12000 cm/min) .



Figure(1-12) The relation between the wear rate and the time before and after laser treatment for (Al-Zn-Mg) at laser energy (1000 mJ),(f=12cm) ,wavelength (1064 nm), and (2 p.p.s), speed of the sliding (S=12000 cm/min) .



Figure(1-13) The relation between the wear rate and the time before and after laser treatment for (Al-Si-Mg) at laser energy (1000 mJ) , (*f*=12 cm) ,wavelength (1064 nm), and (2 p.p.s), speed of the sliding (S=12000 cm/min) .