

## Enhancement of Surface Properties for C11000 and 6063Al Alloys by Using Laser Shock Wave Process

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### Abstract

The use of a laser to modified the surfaces of various materials engineering is a important topics in the present time. Two types of alloys were used in this investigation; 6063Al and C11000 alloys. Samples were prepared by cutting into disc shape of radius 12 mm and then cleaning and polishing process to produce same surface roughness for all samples . Surface roughness and micro hardness were measured for all samples before and after laser shock wave treatment . different laser parameters effect on alloys surface properties were studied such as laser energy , confinement layer( different depth of DDDW ),and number of laser pulses . The results reveal that the surface roughness are increased by 200% for 6063Al alloy and by 120% for C11000 alloy when we used laser energy of 400mj , number of laser pulses of 100 and confinement layer 5mm . While the microhardness increase by 80% for the two kinds of alloys and at the same conditions . Different measurements were carried out for all samples such as XRF, EDX, SEM , and different mechanical tests For precise and accurate results.

**Keywords:** Laser shock wave , Microhardness , Surface roughness

### تحسين خصائص السطح لسبائك C11000 و 6063Al باستخدام عملية الصدمة بموجات الليزر

#### الخلاصة

استخدام الليزر لتحسين اسطح المواد الهندسية المختلفة يعد من المواضيع المهمة في الوقت الحاضر وقد استخدم نوعين من السبائك استخدمت في هذا العمل وهي C11000 و 6063Al . تم تحضير النماذج وذلك بتقطيعها على شكل قرص بقطر 12 ملم وتنظيفها و اجراء عملية التنعيم للحصول على خشونة متاوية لجميع العينات. تم قياس درجة الخشونة والصلادة المجهرية لجميع العينات قبل وبعد اجراء عملية الصدمة بالليزر المؤثرة. تم دراسة تأثير مختلف عوامل الليزر على النماذج مثل طاقة نبضة اللزر وسمك طبقة الحصر وعدد نبضات الليزر . اظهرت النتائج زيادة الخشونة بنسبة 200% بالنسبة للسبيكة 6063Al و بنسبة 120% لسبيكة C11000 عند زيادة طاقة الليزر الى 400mj وعدد النبضات 100 وسمك طبقة الحصر 5mm ، بينما ازدادت الصلادة بنسبة 80% لكلا النوعين وتحت نفس الظروف . ولقد اجريت مختلف القياسات اجريت مثل XRD و XRF و EDX و SEM للحصول على ادق وافضل النتائج .

**الكلمات المفتاحية :** الصدمة بالليزر ، خشونة السطح ، الصلادة المجهرية

## INTRODUCTION

Among the wide mixture of surface treatment explored for enhancing properties of materials, laser surface treatment was created around 35 years back in the USA with specific application to improve some mechanical properties[1]. All the more as of late, surface treatment advancements have turned out to be more vital in industry to cut expenses and keep away from the requirement for extravagant materials [2]. In the field of surface treatment, with the coming of high-power lasers, laser shock processing (LSP) has risen as another and extremely encouraging system to build the resistance of metals and fatigue, wear and corrosion[3,4]. Unlike other laser applications, LSP is not a thermal rather a mechanical process for treating materials [5]. The LSP process parameters that may be varied include the power density or fluence and height of transparent layer. In order to obtain the required pressure, a transparent overlay is used to confine the plasma expansion; in this work water is used. Water tends to confine the energy and increases the [ 6,7]. LSP is based on plasma generation at the moment of the interaction of laser light with a specimen, which produces shock waves and plastic shifts of atomic planes in the material[8].

pulse pressure intensity against the base metal. Some researchers have been studied the effect of LSP on the mechanical properties such as In Zhen and et al [9] investigated the effect of LSP on brass. Micro hardness, roughness, microstructure, wear resistance and friction coefficient evolution for different parameters of LSP. Their results show that the roughness increases after LSP; no ablation was observed; the microstructure has no remarkable change; hardness and the wear resistance increase as the pulse density increases . Haitham T. Hussein,1 Abdulhadi Kadhim and et al [10] were studied the Influence of laser treatment on mechanical properties, wear resistance, and Vickers hardness of aluminum alloy was studied. The specimens were treated by using Nd:YAG laser of energy 780mj, wavelength 512 nm, and duration time 8 ns. And other researchers [7,11,12]also were investigated the increase of microhardness and surface roughness with the increase of laser pulse energy and the influence of the thickness of the confining layer on microhardness and surface roughness for different alloys .

### **Experimental procedure:**

#### **Sample preparation:**

The samples were manufactured from copper and aluminum alloys types C11000 . and 6063Al respectively . The samples were cutting into a rectangular shape with dimensions of 12×12×3 mm<sup>3</sup> Mechanical properties of these alloys are shown in Tables1. Before laser treatment the samples were polished with metallographic paper with different grades of roughness ranging from 400#,600#,and 800# and then polished by diamond paste with lubricated liquid on cloth paper, followed by washing by deionized water (DDDW) and ethanol .

**Table (1) : The mechanical properties of copper C11000 and 6063Al alloy**

Alloy	Yield limit (MPa)	Ultimate tensile strength (MPa)	Elastic modulus (MPa)	Elongation (%)
C11000	273	290	149800	12.8
6063Al	160	215	70500	10

**Chemical composition analysis :**

The chemical composition analysis were carried out for all samples by using X-ray fluorescence (XRF) model (TSMJ) made in Germany to determine the elemental composition of samples and the results were tabulated in tables 2 and 3 as follows:

**Table(2) Chemical composition of alloy type C11000**

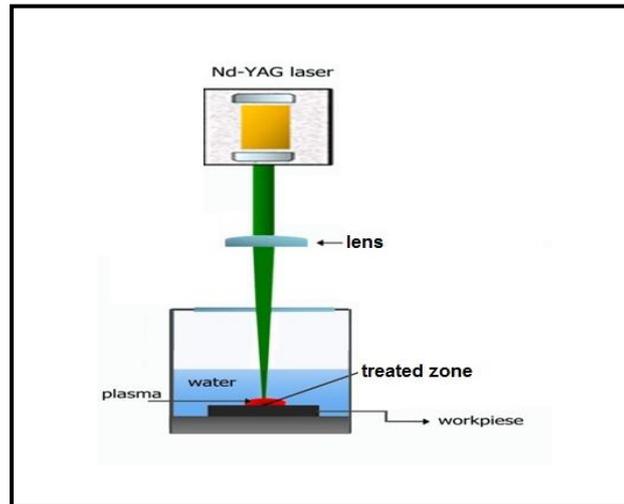
Element	Zn	Pb	Sn	Fe	Sb	Al	Cu
%	0.015	0.001	0.002	0.021	0.006	0.004	99.9

**Table(3) Chemical composition of aluminum alloy type 6063Al**

Element	Si	Fe	Mg	Mn	Cu	Zn	Ti	Cr	Al	other
%	0.32	0.35	0.1	0.1	0.09	0.1	0.09	0.1	97.15	0.15

**Experimental setup:**

The shock waves were induced by a Q-switched Nd-YAG laser , repetition-rate 1 Hz laser with a wavelength of 1064 nm, a pulse duration of about 10 ns , number of pulse 20 and the confinement layer is 2mm. The laser spot size about 0.8 mm , the laser energy was varied from 400 mJ to 600mJ. The experimental setup as shown in figure 1.



**Figure(1) The experimental setup**

**Measurements of Microhardness:**

The micro-hardness was measured before and after Laser treatment . Vickers hardness method with " Digital Micro Vickers Hardness Tester ESEWEY" Model EW422-DAT.2012-UK production was used to measured the microhardness of all

samples . The measurements were made with 200 g load and 15 sec as a hold time. Three measurements were taken at the impact center of laser spot and averaged to one value .

#### **Measurements of Surface Roughness:**

Surface roughness measurements of the different specimens were performed by using " Digital Surface Roughness Tester TR-220". A summary of arithmetic mean roughness measurements, Ra, with different laser pulse energies. Surface roughness measurement was conducted for specimens with and without LSP treatment. Three measurements were taken at the center of laser spot and averaged to one .

#### **Morphology analysis**

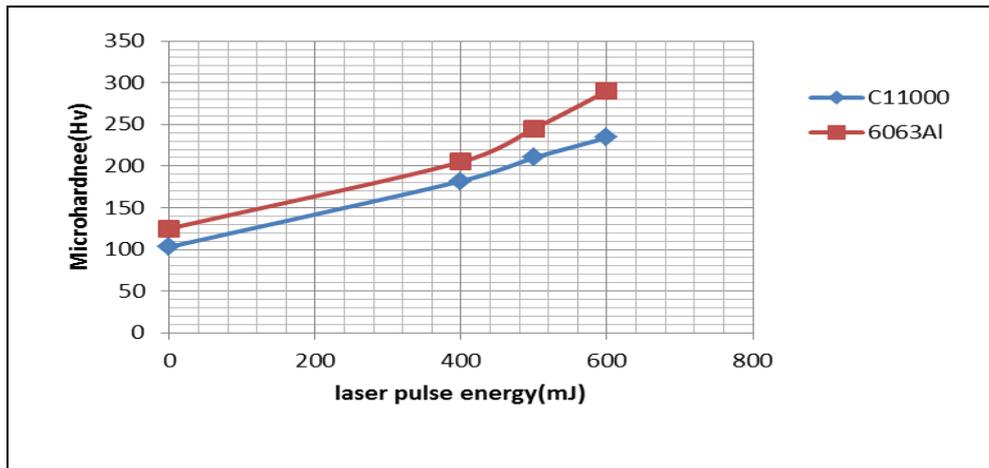
Scanning Electron Microscope (SEM) type (FESEM, SUPRA TM 55vp Zeiss, England product) was used to analyze surface morphology of all specimens before and after LSP treatment and all mechanical tests.

#### **Results and Discussion:**

##### **The effect of laser energy:**

##### **Micro-hardness v.s laser energy results:**

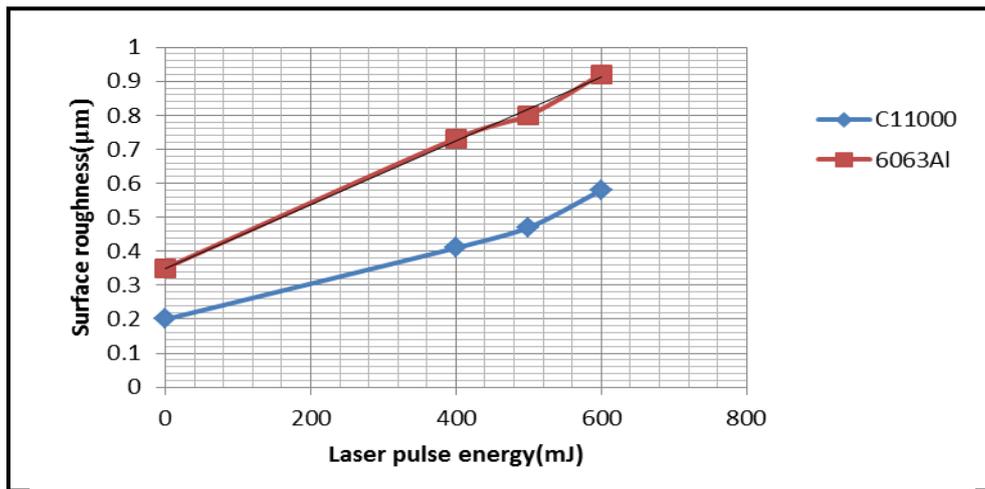
Vickers hardness method was used to measured the micro-hardness for all samples before and after laser treatment . The average micro-hardness value before laser treatment about 103 Hv and 125 Hv for C11000 and 6063Al respectively .The measurements after laser processing were varied from 182 Hv to 234 for C11000 and from 205Hv to 290Hv for 6063Al according to laser pulse energy as shown in figure 2 . The increasing of laser shock processing pulse energy leads to further refined grain. Therefore, after LSP, the surface microhardness increases mainly due to dislocation strengthening and grain refinement.



**Figure (2) The micro-hardness as a function of laser pulse energy**

**Surface roughness v.s laser energy results:**

Surface roughness was measured for all samples before and after laser shock wave treatment . The average Surface roughness value before laser treatment for C11000 and 6063Al samples are 0.20 and 0.351  $\mu\text{m}$  respectively and the measurements for same samples after laser shock wave processing were varied from 0.41  $\mu\text{m}$  to 0.58  $\mu\text{m}$  for C11000 and varied from 0.732  $\mu\text{m}$  to 0.921 $\mu\text{m}$  for 6063Al according to laser pulse energy as shown in figure 3 . This behavior due to the ablation processes which are associated with laser shock wave processing at the samples surface caused by the increasing of laser pulse energy increase.

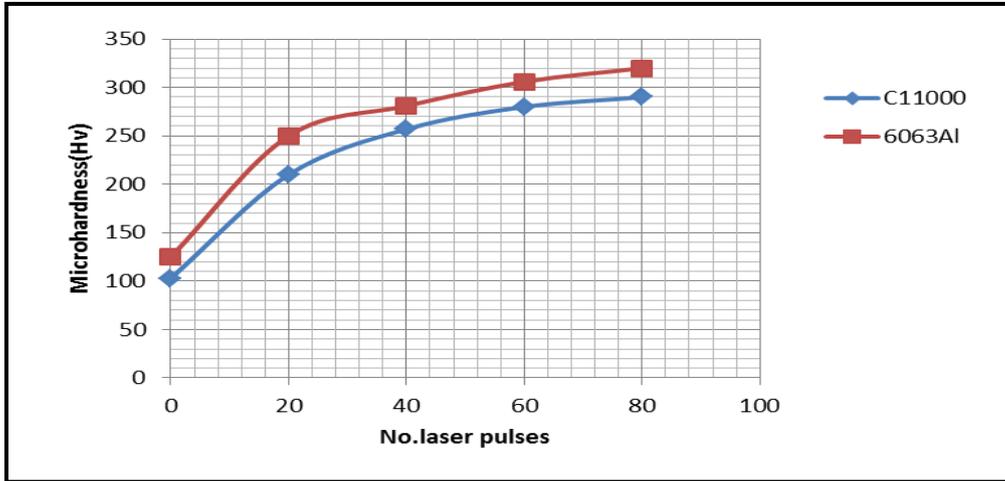


**Figure (3) Surface roughness as a function of laser pulse energy**

**Effect of number of laser pulses:**

**Microhardness v.s No.pulses results:**

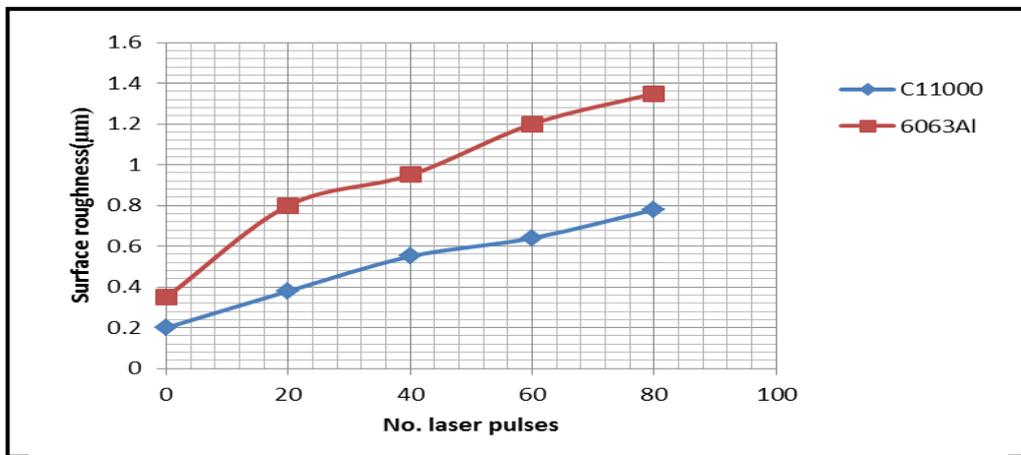
Laser shock processing was carried out at the fixed conditions such as laser energy of 500mj , laser wavelength of 1064nm and confinement layer depth of 2mm. Figure 4 shows the relation between the microhardness and the number of lase pulses and can be shown the increasing of microhardness results for C11000 samples from 103 Hv before laser shock processing (LSP) up to 290Hv after laser shock wave processing and at the same time the microhardness for 6063Al samples from 125 Hv before laser shock processing (LSP) up to (320Hv) after laser treatment because of the pressure of induced plasma on sample surface increased when the number of pulses increased and this lead to increasing in microhardness.



**Figure (4): Microhadness as a function of laser pulses number**

**Surface roughness v.s No. pulses results:**

The increasing of laser pulses led to increase of surface roughness as shown in figure 5 . This behavior may be due to the increase of sample surface ablation by laser pulses . The values of surface roughness of C11000 samples were doubled approximately three times in the range of (0-80 pulses). While the values of surface roughness of 6063Al samples were increased by four times when the number of laser pulses increased from 0 to 80 pulses.



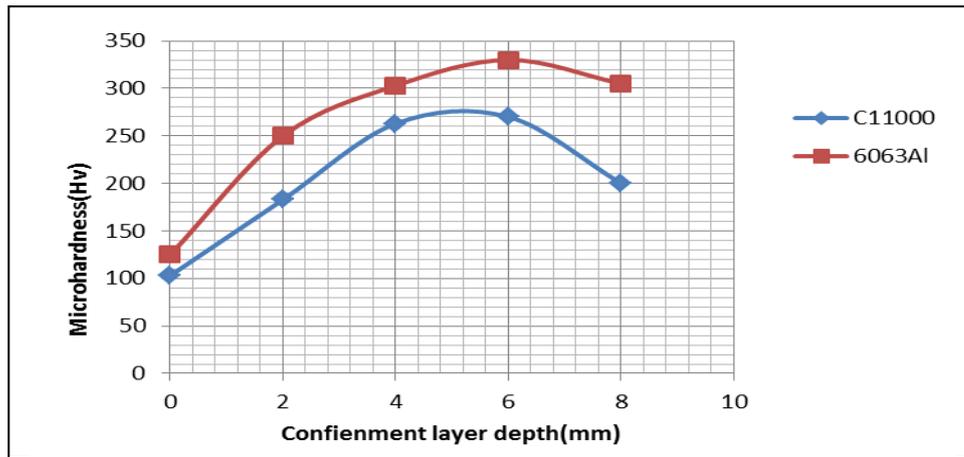
**Figure (5) Surface roughness as a function of number of laser pulses**

**Effect of depth of confinement layer:**

**Micro hardness v.s layer depth results:**

The experiment of this section was carried out at the fixed conditions such as laser energy of 500mj , laser wavelength of 1064nm and number of laser pulses are 20 pulses. Figure 6 shows the relation between the microhardness and the depth of confinement layer (depth of DDDW) and can be shown the increasing of

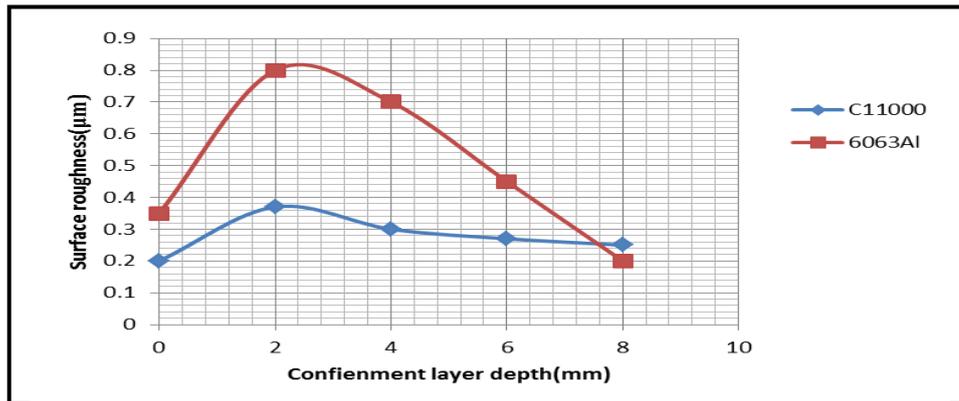
microhardness results of C11000 samples from 183 Hv at the confinement layer depth of 2mm to 270Hv at confinement layer depth of 6mm . The increasing of microhardness results of 6063Al samples from 250 Hv when the confinement layer depth of 2mm to 330Hv at confinement layer depth of 6mm because , this behavior may be due to the pressure of induced plasma on sample surface increased at this depth , but the value of microhardness reduce to 200Hv and to 305Hv for C11000 and 6063Al respectively when the layer depth increased to 8mm , because of the laser energy is absorbed by DDDW .



**Figure (6) Microhardness as a function of confinement layer depth (mm)**

**Surface roughness v.s. layer depth results:**

The increase of confinement layer depth from 0mm (direct ablation) to 8mm led to decrease of the average surface roughness because of confinement layer (DDDW depth) reducing material ablation and melting as shown in figure 7 . The values of average surface roughness arrive to minimum value at depth layer of 8mm .

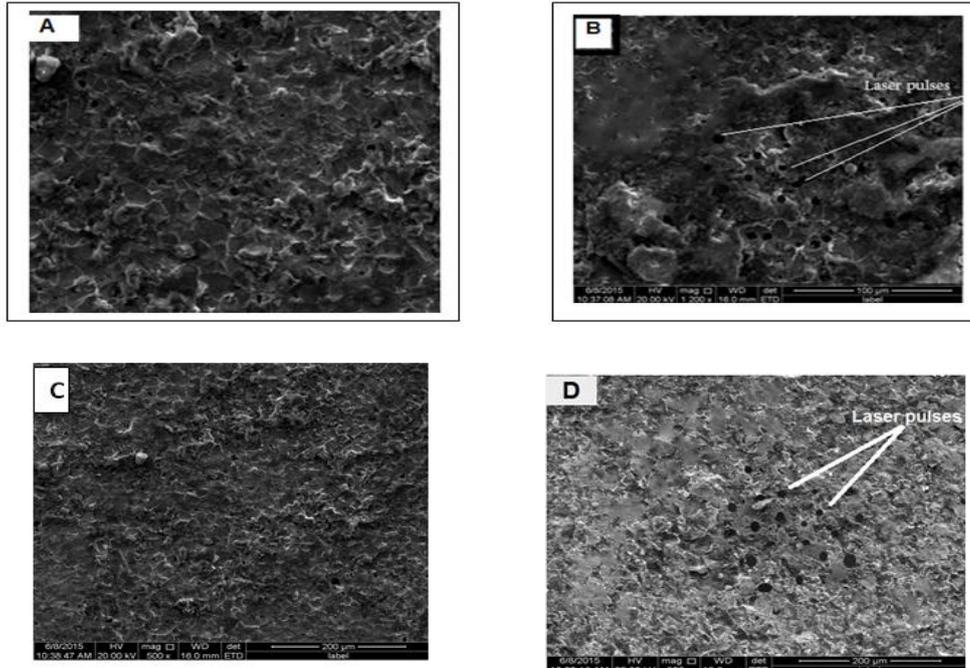


**Figure (7) Surface roughness versus against depth of confinement layer**

**Scanning Electron Microscopy (SEM) results:**

Samples surface suffer from laser pulses, which was initially clean and smooth before laser treatment for C11000 and 6063Al as shown in figure 8A and C, got to be

rough after carried out laser treatment as shown in figure 8B and D. The roughness was carried out by 20 laser pulses , 500mj and 2mm as a confinement layer. From Figure 8B and D can be demonstrated that the indentation of laser pulses and the laser ablation effect of alloy samples .



**Figure ( 8) SEM micrographs for C11000 and 6063Al ( A and C before laser treatment , B and D after laser treatment).**

**Conclusions :**

- The microhardness increased by 103% and 132% for C11000 and 6063Al samples respectively when the laser energy increased from 0mJ( without laser treatment) to 600mj and the effect of laser energy was clear on the surface roughness that increased of surface roughness from 0.2 $\mu$ m to 0.58  $\mu$ m for C11000 samples and from 0.35 $\mu$ m to 0.93  $\mu$ m for 6063Al .
- The microhardness of C11000 and 6063Al samples are increased by 38% and 28% respectively when the number of laser pulses increased from 20 to 80 pulse and the surface roughness rate of C11000 increased by 40% and when the number of laser pulses increased from 20 to 80 pulse . While the surface roughness rate of 6063Al samples were increased by 69% when the number of laser pulses increased from 20 to 80 pulse.
- The microhardness of C11000 and 6063Al samples are increase by 47% and by 32% respectively when the confinement layer depth increase from 2mm to 6mm and the surface roughness rate for same samples are decreased by 32% and by 75% when the confinement layer depth increased from 2 to 8 mm.

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