Iraqi J. Laser, Issue 2, Vol.18, pp.35-40 (2019)

IRAQI JOURNAL OF LASER

# Effect of High Energy Nd:Glass Laser on the Drilled in the 5052 Al-Mg Alloy

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(Received 17 December 2017; accepted 16 January 2018)

**Abstract:** This study presents the effect of laser energy on burning loss of magnesium from the holes' drilled in aluminum alloy 5052. High energy free running pulsed Nd:Glass laser of 300 µs pulse duration has been used to perform the experiments. The laser energy was varied from 1.0 to 8.0 Joules, The drilling processes have been carried out under atmospheric pressure and vacuum inside a specially designed chamber. Microhardness of the blind drilled holes has been investigated .The results indicated that the magnesium loss could be manipulated by adjusting the focusing conditions of the laser beam. Almost, the obtained holes were free of cracks with low taper and low sputter deposition. .The holes performed under atmospheric conditions have higher depth compared to the holes drilled under vacuum.

**Key words:** Al-Mg alloy, Nd:Glass Laser.

## Introduction

The potential of laser materials interaction can be attributed to several advantages like fast processing speed, possibility of complete automation, noncontact processing, elimination of post finishing operation, reasonable processing or operational cost, increasing product quality, extending the material utilization, and small heat affected zone [1–3].

Laser drilling was one of the early and successful applications since the laser invention. Laser drilling process includes surface rapid heating, melting and vaporization. When the surface reaches its boiling point, laser begins to penetrate deep inside the surface. At reasonable laser intensity of about $10^6$ W/cm$^2$ [4] or so, depending on the exact conditions of irradiation, laser drilling process will start. In this region, the laser light penetrates deeply inside the surface along with significant absorption at the vaporized surface. Hence, a large fraction of the material is expelled out as a liquid and droplets.

If the laser intensity increases to higher values, other physical phenomena may become operative [4]. The vaporized material absorbs part of the incident laser light and becomes heated and ionized forming a new phase called plasma [5]. This plasma which forms near the irradiated surface will propagate back toward the laser, along the laser beam direction. This phenomenon is called in other literatures, laser supported absorption (LSA) wave. It propagates to a position where the laser intensity is not sufficient to sustain the (LSA) wave. Thus the (LSA) wave has the appearance of a glowing fireball, which is initiated at the surface, and moving towards laser beam.

Magnesium and magnesium alloys are being increasingly used in various areas of industries due to their low densities and high specific strength. These alloys have the advantages of high strength-to-weight ratio, reasonable corrosion resistance, and good thermal and electrical performance, so aluminum alloy has been widely used for many applications in automobile industry, aerospace, railway, and pressure vessel [6,7]. Because the boiling point of Mg (1380 K) is much lower than that of Al (2723 K) and just little higher than the melting point of Al (933 K), a large amount of magnesium and the alloying element are subjected to vaporization. Therefore, a special set up is needed when this alloy is considered to be laser processed. Welding of aluminum alloy has recently attracted a lot of interest [8-11]. Drilling of these alloys still a challenge since there is large difference in the boiling points of the base metal and the alloying element .

In this work, laser hole drilling in Al-Mg alloy has been performed using high energy Nd:Glass laser. A special chamber has been used to control the drilling process.

**Experimental Procedure:**

Aluminum alloy investigated in this research is Al-Mg with a thickness of 3 mm. These alloys known as (5xxx) series according to ASM (American Society of Metals) [Table1]. Magnesium is one of the effective and widely used alloying elements for aluminum, when it is used as a major alloying element or with manganese, the result is of moderate to high strength non-heat treatable alloy.

**Table (1):** American Society Metal (ASM) Designation for Wrought Al- Alloy Groups: [12]

| | | **Alloy No.** |
|---|---|---|
| **Aluminum - 99.0% minimum and greater** | | 1xxx |
| Aluminum Alloys Grouped by Alloying Elements | Major Alloying element | |
| | Copper | 2xxx |
| | Manganese | 3xxx |
| | Silicon | 4xxx |
| | Magnesium | 5xxx |
| | Magnesium and Silicon | 6xxx |
| | Zinc | 7xxx |
| | Other Elements | 8xxx |
| Unused Series | | 9xxx |

It is equivalent to Al-alloy 5052 according to ASM (American Society of Metals designation). Its chemical composition is shown in Table (2). The analysis was carried out at the specialist institute of engineering industries Baghdad (Iraq).

**Table (2):** The chemical composition of the used Al-Mg alloy.

| Material | Percent |
|---|---|
| **Si** | 0.0936 |
| **Fe** | 0.1650 |
| **Cu** | 0.3280 |
| **Mn** | 0.0427 |
| **Mg** | 2.6500 |
| **Cr** | 0.1459 |
| **Ni** | 0.0000 |
| **Zn** | 0.0148 |
| **Ti** | 0.0205 |

The experiments have been carried out using Nd:Glass (homemade) laser(1.06µm) , 300 µs pulse duration and 6 cm focal length lens to focus the laser beam on the aluminum target. The laser energy was changed from 1-8 Joules. Figure (l) shows the essential features of the Nd:Glass laser being used to perform the drilling process.

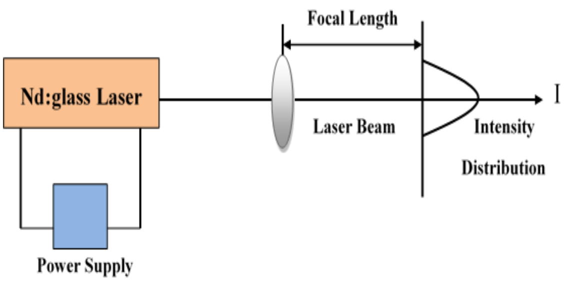


**Fig. (1):** The essential features of Nd:Glass laser.

The first part of the experiments was performed under atmospheric pressure, while the second part was carried out under vacuum. Figure (2) shows the experimental set up.

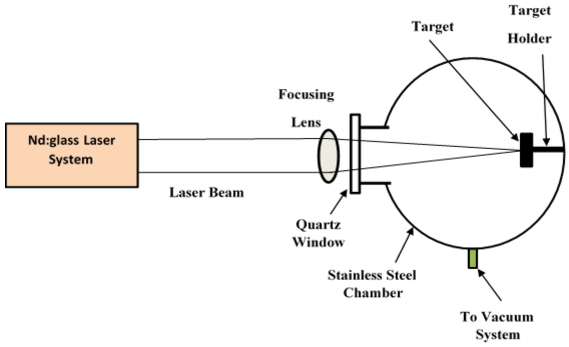


**Fig. (2):** The experimental set up.

The Al-Mg alloy target was located inside a vacuum chamber of about 225 $cm^3$ in volume and is made of stainless steel. It has many openings and these openings can facilitate the entrance of the laser beam through an optical window. While one of the openings is used to allow fixing a leadthrough to carry and move the sample being processed from outside. This chamber was connected to a rotary vacuum pump (Leybold –Heraus), to reduce the pressure substantially.

For the first set of experiments ,the pressure inside the chamber reaches around 5 $x10^{-2}$ mbar .The drilled samples were examined, and the hole depth and diameter were measured by using a calibrated optical microscope. The microhardness was measured for the drilled holes as well- by using Vickers microhardness apparatus with a load of 200 g, where the measurements have been done near the rim and the bottom of the holes.

## Results and Discussion

### Effect of Laser Energy on Hole Parameters

Under the specified conditions of beam focusing, the final dimensions of holes largely depend on the energy contained in the laser pulse. The variation of the hole depth (h) and diameter (d) with laser energy (E) is one of the main factors which deserves particular consideration. The experimental plots of h and d as a function of pulse energy (E) under atmospheric pressure and under vacuum are shown in Figure (3). The focal length of the lens used to focus the beam on the target surface is equal to 60 mm. Figure (3) shows the linear increase of the hole depth with laser energy at 100 µm spot size of the laser. This increment is not always valid for all laser energies.

When the laser beam interacts with the metal surface, and after overcoming the reflectivity, the laser energy will be absorbed within a thin layer of the surface. Within the range of energies of the laser system used in the present work, the blow off materials will start and a crater will form.

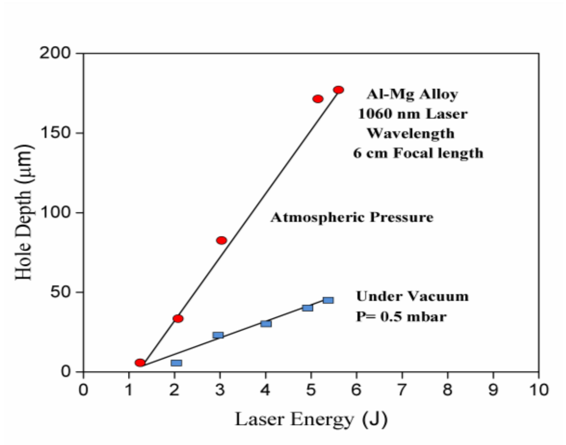


**Fig. (3):** The hole depth as a function of laser energy at atmospheric pressure and under vacuum.

The depth of the formed h depends mainly on the laser energy reached the hole. The liquid phase that is formed inside the crater might cause recoil force during its ejection outside the crater. The amount of the recoil force must be greater than the surface tension force plus gravitational force. When the sum of the surface tension plus gravitational force is greater than the recoil force, the molten material resoldified again. The molten material tends to move up the walls, and some resoldifies on the hole rim to form the lips around the hole and some is blown out to form a thin, recast rim on the metal surface. This is shown in Figure (4).

**Fig. (4):** The resoldified metal on the rims of the laser-drilled hole under atmospheric pressure (X200).

## Laser Drilling Under Vacuum

When the material evaporated in a vacuum, the vapor freely expands and the flow of particles to the surface is insignificant. In this case, there is no distinct boundary between the stage of heating and the stage of material removal by vaporization.

Figure (5) shows the change in the hole diameters drilled by Nd:glass laser with the change of laser energy.

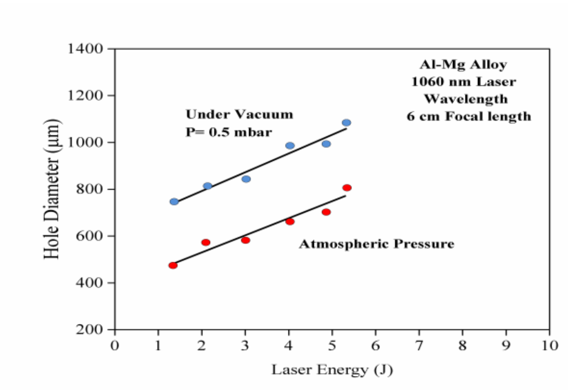


**Fig (5):** The hole diameter as a function of laser energy at atmospheric pressure and under vacuum.

## Microhardness Measurements

The change of surface microhardness in the zone of interaction of laser beam with Al-Mg alloy is shown in Figures 6 and 7. The microhardness value of the untreated Al-Mg alloy is 70 HV. The displayed result was for the measurements on holes drilled under atmospheric pressure and under vacuum. Figure 6 depicts the microhardness variation with laser energy near the rim of the hole, while Figure 7 is for measurements at the bottom of the hole.

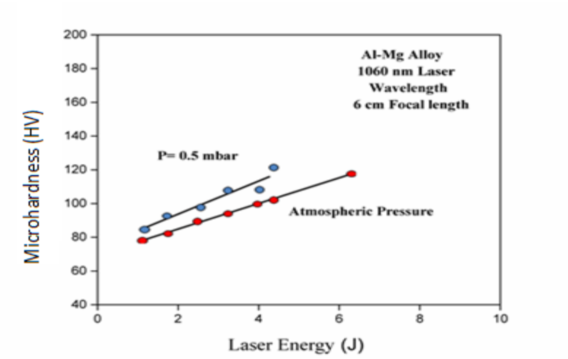


**Fig. (6):** Microhardness variation versus laser energy (Near the hole rim).

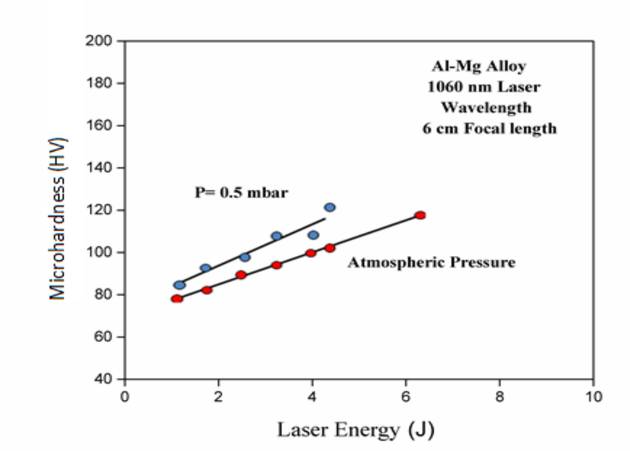


**Fig. (7):** Microhardness variation versus laser energy (At the bottom of the hole).

## Discussion

Leo et al. [13] found that the magnesium content of the fused zone decreased as the laser power is increased. The content of magnesium influenced the hardness of the drilled alloy.

The laser pulse width being used in this study was 300 µs. This short time will not allow the heat to be conducted to far layers of the material. When the materials evaporated in vacuum, a fraction of incident laser radiation does not reach the surface, but is absorbed and scattered by the blow off material. The vapor of the plume absorbs laser energy most strongly. This is considered a weakly ionized plasma whose temperature and density determine its transparency to the laser beam. The focusing conditions of the laser beam were adjusted. Consequently the intensity reaches the aluminum alloy target and the hardness could be manipulated accordingly.

The results show that the holes drilled under atmospheric pressure have greater depth than the holes drilled under vacuum. The change in the surface microhardness can be accounted for the structure modification due to high rates of heating and cooling of the surface layers. The results show that the value of microhardness has a little increase under vacuum than that under atmospheric pressure, this might be due to surface nitriding.

## Conclusions

The drilling processes have been carried out under atmospheric pressure and inside a specially designed vacuum chamber. The laser focusing conditions were adjusted externally to ensure minimum intensity to drill the holes .The intensity control was used to minimize the amount of magnesium element loss in the Al-mg alloy under investigation .The microhardness of the drilled holes have been studied. The hole depth and diameter were measured by using a calibrated optical microscope. The microhardness test was done by using Vickers microhardness apparatus. The results showed an increase of the hole depth under atmospheric pressure with increasing laser energy in comparison with hole drilled under vacuum due to plasma formation. The process was almost ideal where there is no cracks formation.

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# تأثير الطاقة العالية لليزر Nd:Glass في تثقيب سبيكة Al-Mg 5052

**خالد مطشر الجنابي**

هندسة المواد ، جامعة بابل ، بابل ، العراق

**الخلاصة** : تم في هذا البحث دراسة تأثير طاقة الليزر على مقدار فقدان المغنيسيوم من الثقوب المحفورة في سبيكةالمنيوم-مغنيسيوم 5052 .تم استخدام ليزر نديميوم- زجاج عالي الطاقة ذي عرض النبضة 300 مايكروثانية لاجراء التجارب .تم تغيير طاقة الليزر من( 1- 8 ) جول. جرت عملية التثقيب تحت الضغط الجوي الاعتيادي وفي الفراغ في غرفة فراغ مصنعة لهذا الغرض .استخدم جهاز فيكرز لقياس الصلادة المجهرية **.** اظهرت النتائج امكانية السيطرة على مقدار الفقد للمغنيسيوم من خلال السيطرة على ظروف تبئير حزمة الليزر وطاقته. لم يظهر اية شقوق مجهرية مصاحبة للثقوب.وجد ان الثقوب المحفورة تحت ظروف الضغط الجوي لها عمق اكبر من الثقوب المشغلة في ظروف الفراغ**.**