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Study the Effect of Many Parameters on the Speed of Drilling Materials by Laser Beam

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Abstract

The speed of drilling depends on different parameters such as power, material, time, distance between drilling tool and the material, the drilling tool, etc. In this paper; the laser beam was used as drilling tool. Two types of lasers were used; CO_2 laser (10.6µm & 25W) and pulse Nd:YAG laser (1^{st} harmonic 1064nm & 2^{nd} harmonic 532nm, 1J). Two different materials were used; pure silver (0.4mm thickness) and beech wood (3mm thickness). The distance between laser beam and the material was 10cm for CO_2 laser and 6.5cm for Nd:YAG laser. Theoretically the melting point of wood is 9345.8 °C. But when reaching the temperature of 300 °C, the auto ignition property will ignite the wood, even in a vacuum. The melting point of pure silver is 961^oC. Nor CO_2 laser neither Nd:YAG laser could not drill silver even at maximum power for them, but its surface was affected by Nd:YAG laser, where the affected zone color changed. Different powers for CO_2 laser were used for different intervals, increasing power increasing drilling speed, zone width and depth. The affected zone of wood by 2^{nd} harmonic Nd:YAG was clear more than that affected by CO_2, the CO_2 laser would burn it. Many figures which representing the relations between laser power, hole width, hole depth and drilling speed were obtained by using Matlab 2008 software program.

Keywords: Drilling materials, Laser beam, Speed of drilling.

دراسة تأثير عدة عوامل على سرعة حفر المواد باستخدام شعاع الليزر

الخلاصة

سرعة الحفر تعتمد على معاملات مختلفة مثل، القدرة، المادة، الوقت، المسافة بين اداة الحفر والمادة، اداة الحفر... الخ. في هذا البحث; استخدم شعاع الليزر كأداة حفر. تم استخدام نوعين من الليزر; CO_2 ليزر (10.6µm & 25W) وNd:YAG ليزر النبضي (التوافق الاول 1064nm & التوافق الثاني 532nm، 1J). وتم استخدام نوعين من المواد المختلفة; الفضة النقية (سمك 0.4mm) وخشب الزان (سمك 3mm). المسافة بين شعاع الليزر والمادة 10cm لــ CO_2 ليزر و6.5cm لــ Nd:YAG ليزر. نظرياً درجة ذوبان الخشب هي 9345.8 ^oC. لكن عند الوصول الى درجة حرارة 300 ^oC ، خاصية الايقاد الطبيعية ستوقد الخشب، حتى في الفضاء. درجة ذوبان الفضة النقية هو 961 ^oC. لم يتمكن الــ CO_2 ليزر ولا الــ Nd:YAG ليزر من حفر الفضة حتى عند اقصى القدرة المستخدمة، ولكن سطح الفضة تأثر بالــ Nd:YAG ليزر، حيث ان لون المنطقة المتأثرة تغير. تم استخدام قدرات مختلفة للــ CO_2 ليزر لفترات زمنية مختلفة ، ان

زيادة القدرة تزيد من سرعة الحفر، عرض وعمق المنطقة. منطقة الخشب المتأثرة بالـــ Nd:YAG التوافق الثاني واضحة اكثر من تلك المتأثرة بالـــ CO_2، CO_2 ليزر قد حرق المنطقة. تم استخدام برنامج Matlab 2008 للحصول على رسوم تمثل العلاقات بين قدرة الليزر، عرضس الحفرة، عمق الحفرة، سرعة الحفـر.

INTRODUCTION

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole in solid materials. The drill bit is a multipoint, end cutting tool. It cuts by applying pressure and rotation to the workpiece, which forms chips at the cutting edge. Drilled holes are characterized by their sharp edge on the entrance side and the presence of burrs on the exit side (unless they have been removed). Also, the inside of the hole usually has helical feed marks. [1]

Drilling may affect the mechanical properties of the workpiece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the workpiece to become more susceptible to corrosion at the stressed surface. [2]

Drilling with solid state lasers is a thermal removal process. Due to the strong focused laser beam with high energy density, material is melted and evaporated. As a result of the evaporation and assist gas pressure, the material is thrown out of the hole.

One of the very first industrial uses of the laser was reported in 1965 when a diamond die was drilling using pulse ruby laser. A hole 4.7mm in diameter & 2mm deep was made in about 15 minutes; using a mechanical process this had previously taken 24 hours. [3]

Laser drilling can be used to produce micro-holes in almost materials and can be performed to precise positional tolerances using 7-axis moving beam system. Small and large holes can be drilled on formed 3-dimensional parts made out of a variety of high-temperature alloys.

The laser has been designed to offer outstanding peak power levels, maximum pulse energy and an improved beam quality. The beam is capable of producing high quality hole profiles, while the high intensity laser spots allow for fast laser drilling. A new resonator design provides a much wider operating window than previous drilling lasers, allowing users a more flexible approach to manufacturing parameters and shorter times to optimise a new process.

The energy required to remove material by melting is about 25% of that needed to vaporize the same volume, so a process that removes material by melting is generally favored. Whether melting or vaporization is more dominant in a laser drilling process depends on many factors, with laser pulse duration and energy playing an important role. Generally speaking, ablation dominates when a Q-switched Nd:YAG laser is used. A Q-switched Nd:YAG laser normally has pulse duration in the order of nanoseconds, peak power on the order of ten to hundreds of MW/cm^2, and a material removal rate of a few micrometres per pulse. [4]

Penetration speed was studied during CO_2 laser cutting of stainless steel; the main purpose of this study was to clear that the laser cutting quality depends upon the proper selection of laser and workpiece parameters. Laser cut quality drops considerably when the size of the surface plasma increases. This plasma affects the speed of penetration, which in turn affects the cut quality. This study examined the measurement of the penetration speed during CO_2 laser cutting of stainless steel workpieces. It was concluded that the cut quality improves when penetration speed is at a maximum. [5]

An exact solution of the long rod penetration equations was found. This analytical solution allows a faster and easier solution of the penetration equations, since stability considerations associated with any numerically integrated solutions are avoided. Additionally, an analytical solution provides greater insight into the penetration mechanism than a comparable numerically integrated solution. [5]

WOOD DRILLING

Wood being softer than most metals, drilling in wood is considerably easier and faster than drilling in metal. The main issue in drilling wood is assuring clean entry and exit holes and preventing burning. Drill bits can tear out chips of wood around the top and bottom of the hole and this is undesirable in fine woodworking applications.

The ubiquitous twist drill bits used in metalworking also work well in wood, but they tend to chip wood out at the entry and exit of the hole. In some cases, as in rough holes for carpentry, the quality of the hole does not matter, and a number of bits for fast cutting in wood exist, including spade bits and self-feeding auger bits. Chipping on exit can be minimized by using a piece of wood as backing behind the work piece, and the same technique is sometimes used to keep the hole entry neat. [6]

Drilling is the normal area for YAG lasers but CO_2 lasers can also be used on many of these applications. The advantage of the laser is that it can drill holes at an angle to the surface. It is fast and accurate; mechanical drilling is slow and causes extrusions at both ends of the hole which have to be cleaned; mechanical punching is fast but is limited to holes greater than 3mm diameter. Electron beam drilling is fast at 0.125s/hole but needs a vacuum chamber and is more expensive than a YAG laser. A YAG laser took 4s/ hole. The holes were made by trepanning the required size over a range of sizes. [7]

CALCULATION OF THE SPEED OF PENETRATION

When the laser beam is focused on the material, the speed of penetration will be [3][4]:

$$V_P = \frac{H}{r\left(CT_V + L_V\right)} \qquad (1)$$

Where

V_P is the penetration speed (mm/s)

H is the heat flow or intensity (W/m^2)

r is the density of material (kg/m^3)

C is the specific heat capacity ($J.kg^{-1}K^{-1}$)

T_V is boiling point (K)

L_V is the latent heat of vaporization ($J.kg^{-1}$)

The heat flow or intensity can be found from the following equation [4]:

$$H = \frac{P}{A} = \frac{P}{pr^2} \qquad (2)$$

Where

P is the laser power (W)

A is the area of the hole (mm^2)

r is the hole radius (mm)

Energy in general is defined as the capacity for doing work. Power is the rate of doing work or the rate of using energy:

$$P=Work/t=Energy/t \qquad (3)$$

$$t=1/f \qquad (4)$$

where

t is time in (s)

f is frequency in (Hz).

$$\text{Aspect ratio}=\text{Depth/Width} \qquad (5)$$

Tables (1) & (2) show the parameters which were used to calculate the drilling speed for silver and wood respectively using equations (1), (2) and (3). [8][9][10][11]

EXPERIMENTAL SETUP

Using pulse Nd:YAG laser

This setup is shown in figure (1) which is used in 1st and 2nd harmonic to drill silver and wood, this setup consists of 1J Q-switched Nd:YAG laser with repetition rate of 6Hz, pulse duration of 100ns and beam diameter of 1.5mm.

(a) Pulse Nd:YAG laser

(b) Nd:YAG laser characteristic

(c) Silver place

Figure (1) Setup used for silver drilling

The figure (1-b) shows the characteristic of the pulse Nd:YAG laser and figure (1-c) shows the place of the specimen. The distance between the laser beam and the material is 6.5cm.

Using 25W CO_2 laser

Figure (2) shows another setup for drilling wood using CO_2 laser. This setup consists of:

- A power supply
- 25W CO_2 laser with repetition rate of 5 kHz, pulse duration of 100μs and beam diameter of 10mm.
- Beam delivery system: the laser beam will be focused through this system so that laser beam diameter that reaches the material will be 5mm.

- CNC positioning system was used to position and rotate the specimen under the laser during welding.
- Powermeter to select the required power.

Figure (2) Setup used for wood drilling

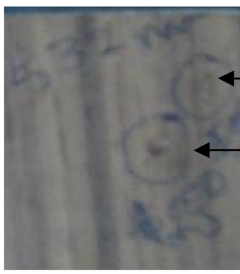
The distance between the laser beam and the material is 10cm.

Practical part and results

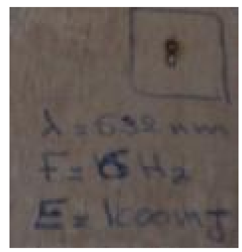
Figure (3) shows the zones in silver that affected by Nd:YAG laser beam at 1064nm laser (1^{st} harmonic) and energy 1J, the drilling speed in this case is about 0.027mm/s, it is clear in this figure that the laser beam can't evaporate layer of silver so there is no depth which means that this laser with its low energy couldn't drill silver. Figure (4) shows the zones in wood that affected by Nd:YAG laser beam, figure (4-a) shows the affected zones for wood at 1064nm laser (1^{st} harmonic) and two energies 500mJ &1000mJ, there is no depth in this figure also which means there is no drilling. In figure (4-b) the wood affected by 532nm laser (2^{nd} harmonic) and two energies 500mJ & 1000mJ for few pulses, here a small effect will be noticed. But in figure (4-c) the hole in wood is clear for 1J energy and 40 pulses; here the depth reaches to 0.9mm because in this case the energy is high, Nd:YAG is in 2^{nd} harmonic and the pulses is more than the other cases. So it could evaporate multi layers of wood and make a hole.
Table (3) shows the measured parameters for drilling silver and wood using Nd:YAG laser.

Figure (3) Silver drilled by 1064nm 1^{st} harmonic Nd:YAG laser at 1J

(a) At 500mJ, 1000mJ
& 1st harmonic (1064nm)



(b) At 500mJ, 1000mJ
& 2nd harmonic (532nm)



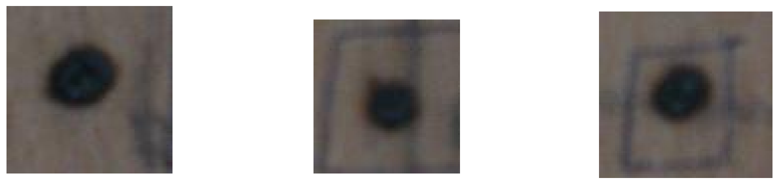
(c) At 1J, 40 pulses
& 2nd harmonic (532nm)

Figure (4) Wood drilled by Nd:YAG laser

Figure (5) shows the wood specimens after drilling by CO_2 laser, figure (5-a) shows the hole drilled at 5W power for 5s interval with 1.1mm depth & 5mm width, figure (5-b) shows the hole drilled at 2.4W which is the minimum power for CO_2 laser and for 5s interval with 1mm depth & 3mm width and the last figure (5-c) shows the hole drilled at 2.4W for 10s interval with 1.1mm depth & 4mm width. It seemed that the hole in figure (5-a) has the most depth and width because it has the largest drilling interval which makes it able to evaporate multi layers and makes a deep hole.

From the above results, drilling speed for wood using 2nd harmonic Nd:YAG 1J is the greatest value of drilling speed which is 1.64mm/s, because the drilling interval lasts for 40 pulses so the surface exposure to the laser beam for long time enough to evaporate the surface.

Table (4) shows the measured parameters for drilling wood using Nd:YAG laser and CO_2 laser.



(a) At 5W drilling interval 5s (b) At 2.4W drilling interval 5s (c) At 2.4W drilling interval 10s

Figure (5) Wood drilled by CO_2 laser

Figures (6 to 9) show the relations between measured parameters for wood, figure (6) illustrates that increasing laser power increasing drilling speed for CO_2 laser using all power values , for increasing laser power the hole width will increased too in a linear relationship as shown in figure (7) and equation 2, this figure used all power values for CO_2 laser. All above relations were direct proportional to each other parameters but in figure (8), the inverse proportion was found between drilling speed and hole width for all power values of CO_2 laser, decreasing drilling speed increasing hole width as illustrated in equations 1 & 2. Figure (9) shows that the drilling speed is proportional to the aspect ratio (hole depth divided by hole width) which is less than 1 until the drilling speed reaches 1mm/s then the aspect ratio began to decrease for increasing drilling speed, this figure used all power values of CO_2 laser. CO_2 laser couldn't evaporate silver surface but Nd:YAG laser could change the affected zone's color without making a hole, so figures (6 to 9) discuss the wood drilling only.

Also it appeared from these figures that the drilling speed depends on laser type, laser power, hole area, drilling interval and material type (intensity, material density, specific heat capacity, boiling point and latent heat of vaporization) as shown in equations 1 & 2.

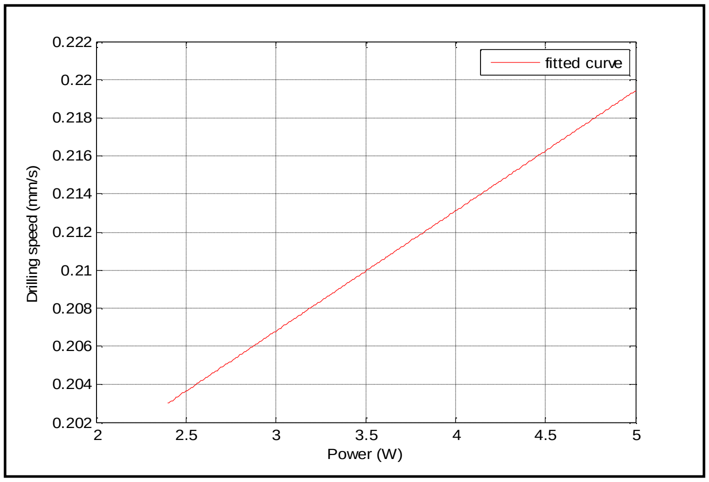


Figure (6) The relation between laser power and drilling speed for wood using CO_2 laser

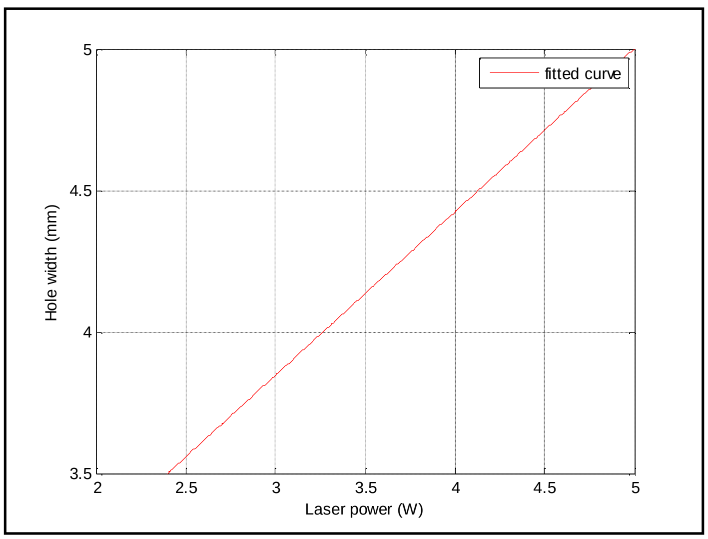


Figure (7) The relation between laser power and hole width for wood using CO_2 laser

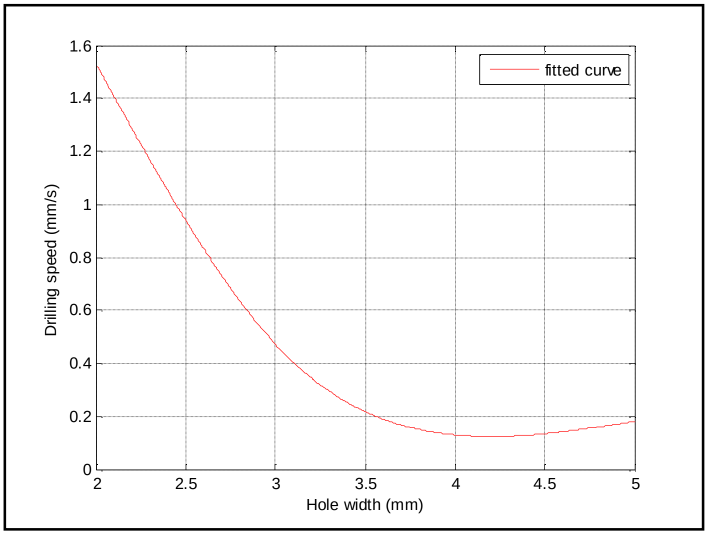


Figure (8) The relation between hole width and drilling speed for wood using CO_2 laser

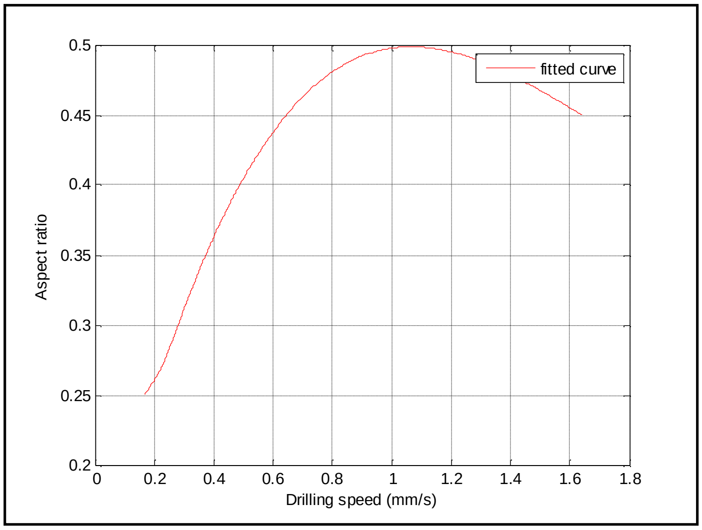


Figure (9) The relation between drilling speed and aspect ratio for wood using CO_2 laser

CONCLUSIONS

The following points can be concluded from this paper:

1- 2^{nd} harmonic Nd:YAG laser and CO_2 laser for many powers could drill the beech wood and made holes with different depths and widths.

2- Second harmonic Nd:YAG with wavelength 532nm is better in wood drilling than first harmonic Nd:YAG with wavelength 1064nm as shown in figure (4).

3- For drilling; CO_2, Nd:YAG and ruby laser can be used either in the pulsing mode or in the CW.

4- Nd:YAG laser is better than CO_2 laser for wood drilling in hole shape purity, but CO_2 laser is better in hole depth and width as observed in figures and tables.

5- The melting point or boiling point of wood is less than that of silver.

Table (1) Silver parameters and calculated drilling speed using Nd:YAG laser.

Parameters	Silver
H (W/mm^2)	0.8488
ρ (g/cm^3)	10.5
C (J/kg.K)	236.5
T_V (K)	2485.15
L_V (kJ/kg)	2356
V_P (mm/s)	0.027

Table (2) Wood parameters and calculated drilling speed using Nd:YAG laser and CO_2 laser.

Parameter	Wood			
	Nd:YAG laser	CO_2 laser		
Laser wavelength (μm)	0.532	10.6	10.6	10.6
Laser power (W)	1J	5	2.4	2.4
Drilling interval (s)	40 pulses	5	5	10
H (W/mm^2)	1.9098	0.2546	0.3395	0.19098
ρ (kg/m^3)	720.83	720.83	720.83	720.83
C (J/kg.C)	1700	1700	1700	1700
T_V (C)	300	300	300	300
L_V (kJ/kg)	1100	1100	1100	1100
V_P (mm/s)	1.64	0.2194	0.292	0.164

Table (3) Measured parameters for silver drilling using Nd:YAG laser.

Parameter \ Material	Silver
Laser wavelength (nm)	1064
Laser energy (J)	1
Hole depth (mm)	0
Hole width (mm)	2-3
Thickness (mm)	0.4

Table (4) Measured parameters for wood drilling using Nd:YAG laser and CO_2 laser.

Parameter \ Material	Wood			
	Nd:YAG laser	CO_2 laser	CO_2 laser	CO_2 laser
Laser wavelength (μm)	532	10.6	10.6	10.6
Laser power (W)	1J	5	2.4	2.4
Drilling interval (s)	40 pulses	5	5	10
Hole depth (mm)	0.9	1.1	1	1.1
Hole width (mm)	2	5	3	4

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