EFFECT OF PULSE DURATION ON HOLE QUALITY OF UNDERWATERGLASS DRILLING USING CO\textsubscript{2} LASER

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Abstract

Laser drilling is one of the earliest applications of lasers in materials processing. Less than 0.25mm in diameter is difficult to drill mechanically. Laser drilling offers good choices for small hole drilling, especially for hard and brittle materials, such as ceramics, but cracks appearance is one of the most difficulties that appears in this drilling. Therefore, this paper aims to study the effect of exposure time on the drilling of soda lime glass (SLG) using under water laser drilling technique. A 1.15 mm thickness SLG sheets were immersed 1mm below the water surface, then irradiated with CW CO\textsubscript{2} laser. The laser parameters used were (24, 25 and 26) W power, (5, 7.5 and 10) sec exposure time and (1, 2 and 3) pulses.

The drilled points were investigated under optical transmission microscope. Then the upper diameter, lower diameter, crack length and taper angle for these drilled holes were measured by analyzing the OM images using Image J software. Clearly appeared that hole diameter and the crack lengths could be controlled by the laser power and exposure time. When power or time were increased, the hole diameter increased. While the length of cracks is increased with increasing time and power. The good results found at laser power 24 W, five sec. and one pulse for hole diameter, while the minimum crack length was found at three pulses, five sec. and 24 W power.

Keywords: Laser Drilling, Soda Lime Glass, Brittle Materials Drilling, Under Water Laser Process, CO\textsubscript{2} Laser.

I. Introduction

The laser technology gets generally utilized for holes drilling, yet, while a pulsed laser drilling procedure, drilling performance, and hole quality are essentially defined by material extraction mechanism (melt expulsion and/or surface vaporization). Usually, a recast film happens throughout non cylindrical hole
sidewall, and some random nanoscale or microscale structures, debris/residue, and deficient melt expulsion regularly dwell on the sidewall surface of the hole, lead to dis uniform micro structures and stress concentration, crystal grains, and micro cracks for hole wall, hence reducing hole drilling goodness. Recast films and hole walls micro cracks are the key deficiencies for laser holes drilled [XIII]. On other hand, there are numerous benefits of this method contact less with the machine, low heat affected zone, high accuracy, flexibility, versatility, high speed and easy automation and computer control, as well as low cost and low processing times [VI], [I]. Laser hole drilling in materials like ceramic, polymer, copper, nickel, aluminum, brass, borosilicate glass, rubber, quartz, soda-lime glass, and composite materials grant great repeatability and accuracy for the medical equipment industry, nanotechnology and semiconductor fabrication, support systems [III], [X]. In laser drilling, there are a number of parameters like exposure time, power, laser ablation regards to the photon sputtering method, the explosive removal of material from a specimen under the radiance of an intensive laser pulse or constant wave [IV], [VII]. In the laser disposal of solid material, a CW laser is utilized to heat a solid surface and a small amount of material evaporated. During additional photon absorption, the removed material is heated up till it ionizes and increases in size from specimen surface as a plasma cloud. Recently, Yoshida et al. (2003) [VII] compared three applications in glass substrates, soda lime glass, synthetic quartz and Pyrex glass for single laser pulse drilling. Although the drilling speeds for each glass, there is a difference in the occurrence of the pileup around the hole, and they determined that synthetic quartz is excellent for laser processing. Moreover, they examined hole processing of synthetic quartz by single and multiple-laser pulse (MLP) drilling. As a result, MLP hole-shaping technique can control the taper angle of a through hole, and decrease the height coefficient of the pileup around the hole in synthetic quartz, which is not possible in SLP drilling. Furthermore, Tsai et al. (2009). [XI] Investigated the date with water laser drilling methods for brittle material. A CO₂ laser was applied to drill holes into LCD glass and alumina. They discovered that the underwater laser drilling feature for these materials is greatly well than from laser drilling in air. And the underwater laser drilling minimized phenomena of micro-cracking and reduced the size of the area affected by heat from the laser. In (2015) Benghalem. et al. [II] study details drilling method on glass via CO₂ laser. The research factors studied in these analyses are created on laser beam energy of range 30 to 80 present of 25 W plus time period for drilling 2 to 8 second. The measured widths of holes via optical methods are concerning 300 to 800 µm. The outcomes achieved by optical investigations recommend that regular and mineral glasses cannot resist a touch of the laser beam and crack throughout the development of the drilling hole. The least energy are the best parameters for drilling the organic glass, we recognize no cracks found, and repeatedly we notice that the ends of the holes have a great surface condition with a great aspect ratio. In 2017 Yoshiki. [XII] Used high aspect laser drilling method for glass substrate supported by supercritical CO₂ rather than water. Supercritical CO₂ has superior fluidity and solubility, which promotes effective elimination of ablated debris to the outside of the drilled hole. Therefore, laser drilling employing supercritical CO₂ results in deeper, thinner holes than these drilled employing water and air. In tests carried, glass slab was installed in an enclosure
loaded with CO$_2$ throughout the critical area. Finally, a sub picosecond pulsed laser focused and scanned on the specimen produced thinner and deeper holes with aspect ratios higher than one hundred. In 2018 Sun et al. [IX] investigated and analyze the influence of laser pulse number and pulse power on the morphology of the holes, to reduce the incident bubbles while the liquid supported laser machining and use ultrasound assisted under water femtosecond laser drilling on stainless steel. It has been observed that ultrasound not just has an extraordinary function of creating a hole with a clean and plane bottom but additionally decreases debris re-deposition about the processing point. This process enhances the machining quality. And it further enhances the depth/diameter ratio of the hole around twenty percent. In 2019 Feng et al. [V]. Offer multi scan laser machining method on a copper model sunk under running water with a tenable top surface. The results reveal that channels with lesser heat affected zone (HAZ), less minimal burr and debris recast can be produced by this method. Via utilizing multi scan machining, channels with depth up to 275.00 µm, taper angle of 13° to 22° and roughness of 1.30 to 6.95 µm Sa created. Furthermore, empirical models linking the procedure parameters to channels features were determined employing polynomial regression (PR) examination and AI algorithm, Gaussian process regression (GPR), afterward which their performances in the forecast of channels properties were confirmed.

II. Experimental Work

PiMicos CA-1500 CO$_2$ laser work station with 100W maximum power was used to drill 1.15mm thick sheet of soda lime glass. This target was placed in stainless steel path of (90x90x30) mm$^3$ immersed in deionized water of 1 mm above the sheet (Fig. 1)

![Fig. 1: The schematic diagram of liquid assisted laser processing for drilling soda Lima glass.](image-url)
After many pilot experiments the 10.6µm laser parameters were set to be (24, 25 and 26) Watt laser power, with exposure time of (5, 7.5 and 10) seconds and (1, 2 and 3) pulses. The laser beam diameter was 14 mm and was focused on the sheet surface.

The characterizations were done by capturing the holes using Genex LCD8 optical microscope, then measuring the average length surrounded cracks, the upper and lower diameters of the drilled hole, and its taper angle. These measurements were conducted using Image J 1.52a free software from Wayne Rasband, national Institutes of Health, and USA.

III. Results and Discussion

All samples were illuminated by different laser working powers (24, 25, 26) W and multi pulses (1, 2, 3) at different exposure time periods (5, 7.5, 10) sec. The most important parameters which indicate the good quality of the drilled holes by laser beam are the entrance diameter, exit diameter and crack length.

Effect of Time on Crack Length

From figure (2 to 4) shows the plot diagram for the different values of time versus the resultant crack length for each pulse and power. The hole is created, however the truth that the thickness of the glass is a tiny large compared to the applied power block the laser beam to go in bottom. The influence of time on crack length when the time increases the crack length increase for all powers. Since glass material is characterized by low thermal expansion coefficient and low thermal conductivity, hence its ability to expand during any thermal process will be limited as in this study leading to initiating the residual thermal stresses that causes micro crakes at high laser power and exposure time periods. The drilling process consumes the whole exposure time periods in executing the hole and increasing the heat content in the HAZ that initiate the residual thermal stresses and creating the micro cracks. As the power increases the cracks appear again because power will be consumed in increasing the heat content in the HAZ.

Fig. 2: The effect of Time (5, 7.5, 10) on Crack length at Power (24) W.
Fig. 3: The effect of Time (5, 7.5, 10) on Crack length at Power (25) W.

Effect of Time on Entrance Diameter

From figure (5 to 6) shows the plot diagram for the different values of time versus the entrance diameter for each pulse and time. We observe well the effect of drilling period on the drilling SLG glass, the interval was changed from 5 to 10 seconds for different working powers, the drilling period has an effect on the diameter; it rises with time, under the influence of heat transmission in the material nearby the hole.

Fig. 5: The effect of time on Entrance diameter at power (24) W.
IV. Statistical Result

In this section the result of the design of expert using Box Bhenken design, in addition to the ANOVA and final equation.

Crack Length

Figure 8 show 3D graph showed the crack length at powers (24, 25 and 26) and figure 9 Showed the normal plot of residual stress of the crack length at powers (24, 25 and 26). Extra to the final equation of this process used.

Final equation in terms of actual factor:

\[
\text{Crack length} = 0.16752 + 0.011400 \times \text{Power} + 5.11500E-003 \times \text{Exp. Time} - 4.61250E-003 \times \text{NO. of Pulses}
\]  

(1)

Where A= Power, B= Exp. Time, C= No. of Pulses.

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor.
Fig. 8: 3D graph showed the crack length at powers (24, 25 and 26).

Fig. 9: Showed the normal plot of residual stress of the crack length at powers (24, 25 and 26).

Entrance Diameter

Figure 10 show 3D graph showed the entrance diameter at powers (24, 25 and 26) and figure 11 showed the normal plot of residual stress of the entrance diameter at powers (24, 25 and 26). Extra to the final equation of this process used.

Final equation of actual factor for Entrance diameter:

Entrance diameter = 0.092985 +9.87500E-003 * Power +3.65000E-003 * Exp. Time +0.17400 * No. of Pulses

(2)
Where A = Power, B = Exp. Time, C = No. of Pulses.

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor.

**Fig. 10:** 3D graph showed the entrance diameter at powers (24, 25 and 26)

**Fig. 11:** Showed the normal plot of entrance diameter of the Entrance Diameter at powers (24, 25 and 26)

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V. Conclusions

I. Drilling of soda lime glass of 1.15 (mm) in thicknesses has been utilize using CW, CO\textsubscript{2} laser beam to study the influence of the laser power and exposure time on the dimensions and characteristic of the holes, finally the following comments can be concluded.

II. The multi pulse is very important role when increase the pulses the cracks are minimized.

III. The exposure time plays an important role on the dimensions of the drilled holes.

IV. Increasing the exposure time leads to increase the hole diameter and the crake length.

V. Power of 24W, five seconds exposure time and three pulses give the minimum crack length.

VI. The best results of the hole diameter were achieved at 24W laser power, one pulse and exposure time of five seconds.

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