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# EFFECT OF POWER ON HOLE QUALITY OF UNDERWATER GLASS DRILLING USING $CO_2$ LASER

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**Abstract:** The aim of this paper to study the effect of power on the drilling of soda lima 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 $CO_2$ laser. The laser parameters used were (24, 25 and 26) W power, (5, 7.5 and 10) sec and exposure time and (1, 2and 3) pulses. Were determined using images for samples and study quality of holes using images. These ones of the dimensional of hole and crack length measured by image j program of the samples, it was watched that hole diameter and the length of cracks could be regulated by the power, time and no. of pulses. When power or pulses were increased, the hole diameter increased. The length of cracks decreased with increased no. of pulses and increased when the power increased. The small hole was 0.469mm found at working power (24) W, five sec and one pulse for hole diameter. While, the minimum crack length was 0.4mm found at three pulse, five sec. and 24 W power. In addition, the parameters were analyzed statistically using design of expert software, Box Behnken design from surface response methodology and the results were significant.

**Keywords:** *Laser Drilling, Soda Lima Glass, Brittle Materials Drilling, Under Water Laser Processing, $CO_2$ Laser, ANOVA, Box Bhenken Design.*

## 1. Introduction

Laser material processing is a non-contact, adaptable and delicate process usable to a wide-ranging range of materials [1]. This interaction of light and matter are some of the greatest basic and communal of the physical processes [2]. The applications contain laser cutting, engraving, drilling, welding, marking etc. [3]. Laser hole drilling in materials like as polymer, ceramic, copper, nickel, brass, aluminum, soda lime glass, rubber and composite materials suggestion great truth and repeatability for the medical device trade, semiconductor industrial and nanotechnology support systems [4,5]. In laser drilling, there are a lot of limits like exposure time , power, Laser ablation mentions to photon sputtering process, the explosive removal of material from a sample under the irradiation of an intense laser pulse or continuous wave [6,7]. In the laser removal of a solid material, a CW laser is used to warm a solid surface and a small amount of material is vaporized. Through further photon absorption, the ejected material is heated up until it ionizes and expands from the sample surface as a plasma cloud. There is a threshold in laser flounce or intensity under the sample surface without destruction occurs. Focal location and spot size, that should be measured to achieve the desired hole features [8]. **In 2005 Ran et al.** [1] Longitudinal and transverse micro holes where drilled in soda lime glass via water aided ablation along with pulses of femtosecond laser. At low incident pulse power, just 1 transverse

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micro hole is seen. While at high incident pulse power, many transverse micro-holes can be concurrently drilled. In 2009 Chung et al. [2] use liquid assisted laser processing (LALP) technique for linear through wafer deep engraving of Pyrex glass deprived of cover materials to get a smaller crack surface. The outcome of water depth and laser scanning rate on the engraving of 500.00 µm thick Pyrex glass covered in liquid water was examined. A mechanism of thermal stress decrease in water and shear force improved debris ejection is explained. Quality enhancement of glass engraving utilizing LALP is because of the cooling influence of water to decrease temperature slope for natural convection and crack less surface during engraving to take away the debris for reducing bulge creation. In the same year Tsai et al**.** [3] Investigated the date on underwater laser drilling methods for brittle substrates. A $CO_2$ laser utilized to drill holes in alumina substrates also LCD glass. Researchers discovered that the underwater laser drilling attribute for those materials is far greater compared to laser drilling in air. Also, the underwater laser drilling decreased the phenomena of micro cracking and reduced the area of the area influenced by heat from the laser. In 2013 Nagesh et al. [4] examined the influence of carbon black alongside with laser bounds like, scanning speed pulse frequency plus laser power on heat influenced area and taper angle of laser drilled holes according to L16 orthogonal array layout. Together with heat influenced area and taper angle considerably decreased with increment of carbon black. Outcomes revealed that heat influenced area is decreased by applying lower laser power and taper angle is decreased via utilizing greater laser energy. In 2014 Barada group [5] use multiple and single laser pulse hole drilling in mixed silica has been done utilizing a CO2 laser method working at 10.6 µm. Laser pulse span, pulse power and the number of pulses hitting on the silica plate have been measured in-situ for drilled holes. The outcomes are matched upon the foresight of a numerical model. This model studies surface evaporation as the key material extraction mechanism. For the case of single pulse drilling, volume and depth of the drilled holes are foretold exactly and the difference between experiments and the model are noted lower than 10%. In 2015 Nagesh and his colleagues [6] study the impact of Nano fillers on $CO_2$ laser drilling of vinyl ester/glass based on L9 Orthogonal Array Tests and Grey Relational Analysis. 3 Nano fillers like Closite 15-A, carbon black and nickel Nano powder were investigated. Various responses like Taper Angle, Surface Damage and Damage Widths were optimized employing Grey Taguchi system for laser power, Nano filler content, air pressure and cutting speed. Carbon black created more comprehensive surface damage at the entrance of the hole because of the burning of the fibers and very thin char blanketed the fibers through the hole length. Regression patterns were established to estimate the laser drilling reaction. In 2019 xin.w.et.al. [7] Used a new technique under water treating technology was introduced, named underwater wet laser cladding (UWLC). For illustration, the direct UWLC and protective material supported UWLC conducted under different water depths with uniform test parameters. The UWLC methods below water 15.00 mm depth were measured in particular. The blue purple plasma rises while the direct UWLC methods pointing to UWLC failure. The mental plume appears throughout the protective material supported UWLC methods. Furthermore, the protective material supported UWLC is more likely to work by improving the content of protective material. Furthermore, the 316L coating corrosion resistance by direct UWLC in 3.5 wt % NaCl liquids is enhanced evidently via using shielding material. The power loss in the method of underwater wet laser treating is pointedly decreased through the protective material supported system, that presents significant theoretic assistance for underwater laser fixing.

This made previous researcher did many attempts to using more techniques like under water drilling by using $CO_2$, Nd:YAG lasers, but did not cover the effect of underwater laser drilling with different inputs like multi pulse, exposure time and power to minimize the crack length and enhanced hole quality.

From the above concluded remarks this work aims to study the effect of using under water technique on $CO_2$ laser drilling of soda lime glass, and predict the laser parameters to obtain drilling with minimum cracks and smaller diameter.

## 2. 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)

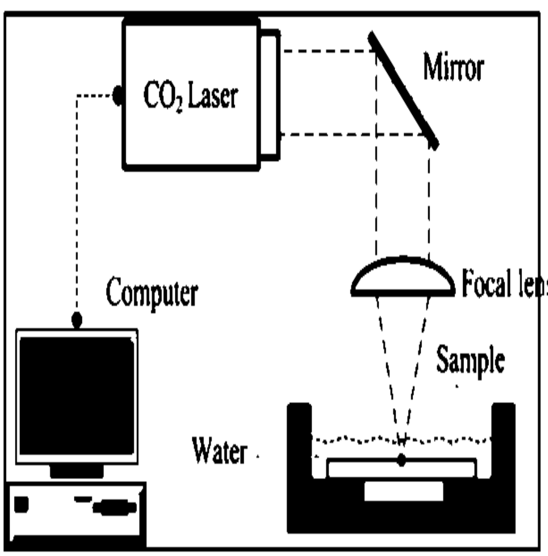


**Figure 1.** The schematic diagram of liquid assisted laser processing for drilling soda lima glass.

After many pilots 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 0.3 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 tapper angle. These measurements were conducted using ImageJ 1.52a free software from Wayne Rasband, National Institutes of Health, USA.

## 3. Results and Discussion

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

### 3.1 Effect of Power on Crack Length

Figures (2 to 4) show plot diagrams for the different resultant length of cracks versus the different working powers at each adjust time. It seems that the crack length was increased with increasing the power for all Exp. Time. This is expected due to the increasing in the amount of heat which increase the temperature of sample and that increase the heat affected zone which means increasing the crack lengths.

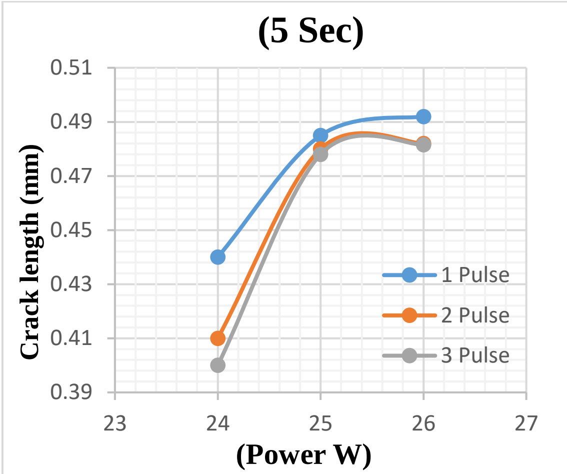


**Figure 2.** Show the effect of Powers on Crack length at exposure Time (5) Sec.

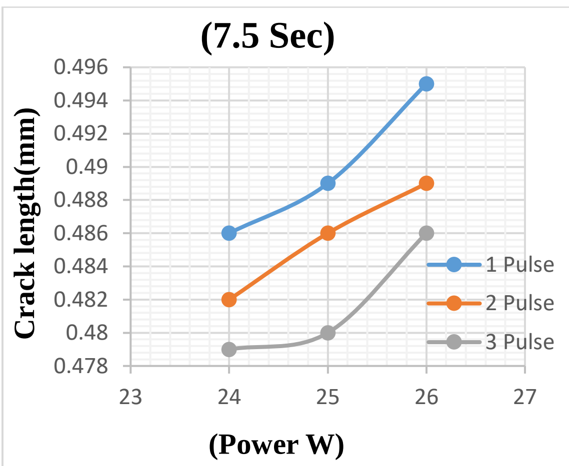


**Figure 3.** Show the effect of Powers on Crack length at exposure Time (7.5) Sec.

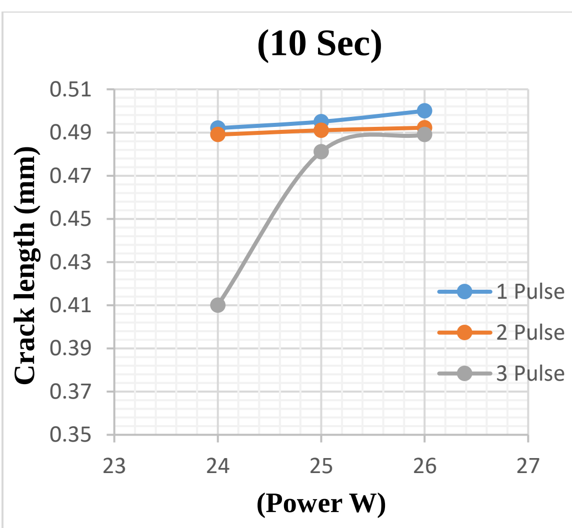


**Figure 4.** Show the effect of Powers on Crack length at exposure Time (10) Sec.

**3.2 Effect of Power on Entrance Diameter**

From figure (5 to 7) show plot diagrams for the entrance diameter versus the different working powers at each adjust time. we note that when the laser power increases the diameter increases progressively. This can be explained by the fact that when the laser beam attacks the surface to be drilled, the heat imported by the beam propagates in all directions, this spread will widen the hole and create plastic flows over the entire contour of the holes and contaminates the vicinity of the hole.

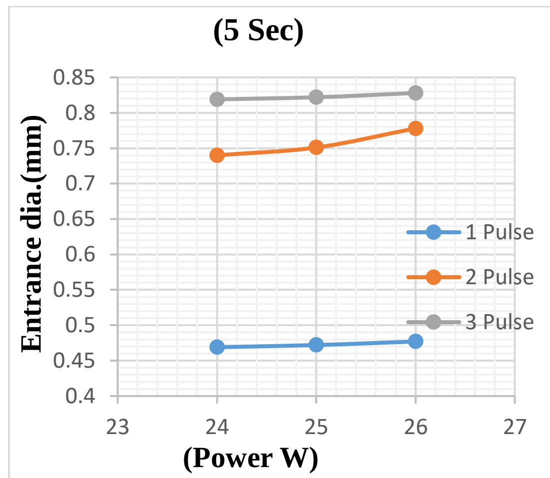


**Figure 5.** Show the effect of Powers on Entrance diameter at exposure Time (5) Sec.

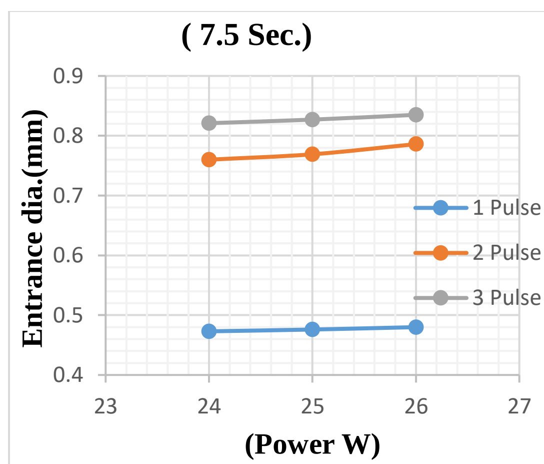


**Figure 6.** Show the effect of Powers on Entrance diameter at exposure Time (7.5) Sec.

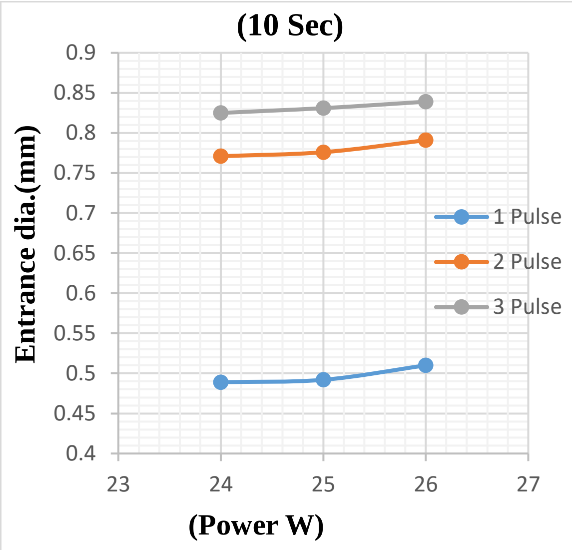


**Figure7.** Show the effect of Powers on Entrance diameter at exposure Time (10) Sec.

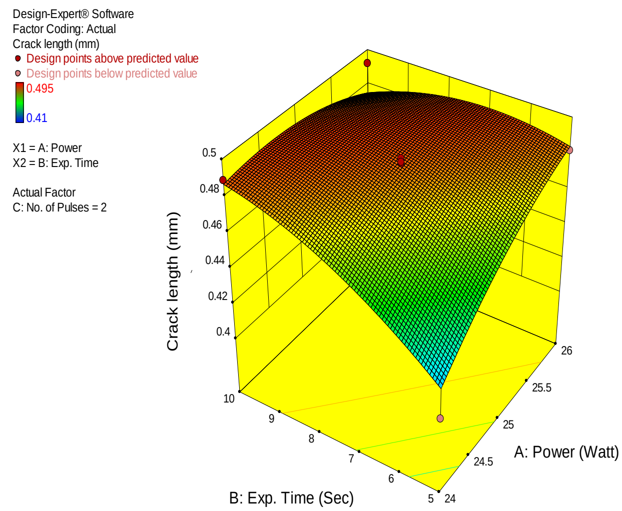


**Figure 8.** 3D graph showed the crack length at powers (24, 25 and 26).

## 4. Statistical result

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

### 4.1 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:

**Crack length** = 0.16752 + 0.011400 * Power + 5.11500E-003 * Exp. Time – 4.61250E-003 * 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.

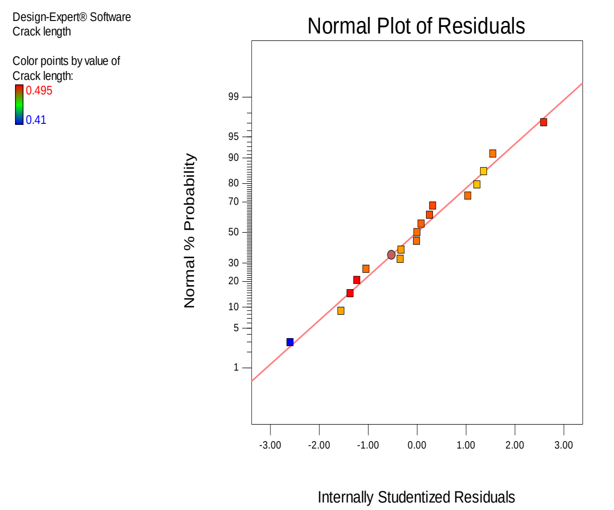


**Figure 9.** Showed the normal plot of residual stress of the crack length at powers (24, 25 and 26).

### 4.2 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.

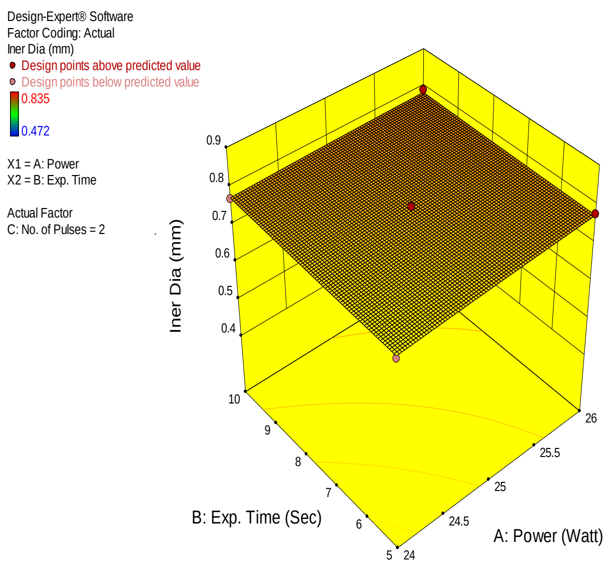


**Figure 10.** 3D graph showed the entrance diameter at powers (24, 25 and 26)

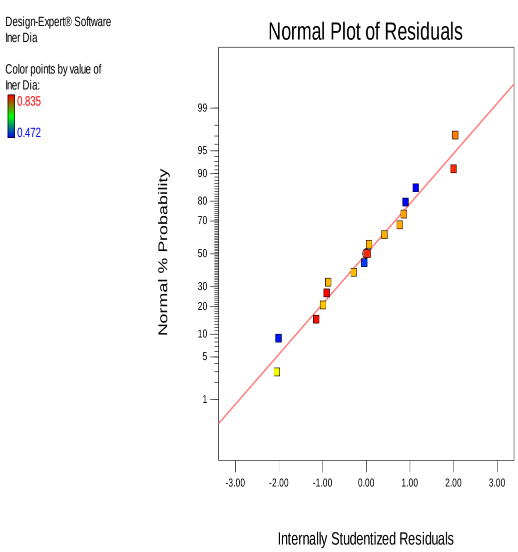


**Figure 11:** Showed the normal plot of entrance diameter of the Entrance Diameter at powers (24, 25 and 26)

## 5. Conclusion

Drilling of soda lime glass of 1.15 (mm) in thicknesses has been utilize using CW, $CO_2$ 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.

- The power is very important role when increase the power the cracks are maximum.
- The exposure time plays an important role on the dimensions of the drilled holes.
- Increasing the exposure time leads to increase the hole diameter and the crack length.
- Power of 24W, five seconds exposure time and three pulses give the minimum crack length with value (0.4mm).
- The best results of the hole diameter were achieved at 24W laser power, one pulse and exposure time of five seconds. With value of (d= 0.469mm)

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