EXPERIMENTAL INVESTIGATION OF DEFOCUSED FOCAL PLAN AND ITS EFFECT ON HOLE PROFILE IN MILLISECOND PERCUSSION LASER DRILLING

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ABSTRACT: *High aspect ratio, accuracy, elimination of conventional tool wear and drilling difficulties to cut material enables laser drilling for widely used in industries to meet modern technology requirements. This study was carried out to investigate longitudinal hole profile with respect to variable focal positions under different combinations of technical parameters. As focal position has significant influence on laser beam processing, which ultimately affect the beam energy exchange to the work piece. Laser percussion drilling was carried out on 1.0mm thick plates of 18CrNi8, to produce higher than 5:1 aspect ratio holes by millisecond laser system. These micro holes containing diameter range 100 to 600 µm were empirically investigated for the sway of displaced focal plan with respect to different parameters such as pulse width, no of pulses etc. This research is mainly focused on longitudinal profiles along with varied focal positions and their inter relations with other outcomes such as tapering, debris, hole diameter etc. Experimental results were analyzed comprehensively in order to discuss the focal effect on hole profile and proposed how to remove or reduce the unwanted outcomes of laser drilling.*

Keywords: *Laser percussion drilling, defocused beam, millisecond laser, longitudinal profile, tapper angle, debris.*

INTRODUCTION

Laser Drilling is the most important and efficient application of industrial lasers which emerges as a viable and successful substitute for holes less than 0.25mm in diameter that are almost impossible with mechanical drill. The application field of the laser drilling process has been extended due to the growth in the market of electronics, computers, communication products, and automotive parts [1-3]. The non-contact machining characteristics of the laser drilling process can reduce appreciably problems related to mechanical piercing and boring of thin sheets, such as serious deformation of the cut part, eccentricity of the hole and crumbling of the cut section, induced by direct contact of tools with the work piece [4-5]. Laser drilling is employed to metals to produce tiny orifices for nozzles of fuel injection, cooling channels in air turbine blades, etc. For direct hole drilling, the quality of the laser beam, wavelength, intensity, pulse duration, pulse repetition rate are all important parameters. Many issues include cracks, large taper size; unsatisfactory shapes still remain to be solved when high quality holes are required in various materials [6].

It was found by Qin Yuan [7] that in millisecond laser drilling by increasing its laser energy. It was suggested that the depth of the hole increases with the increase of laser energy which resulted in large difference between calculated and the experimental results. Drilling speed of millisecond pulsed laser for different materials like aluminum, copper, silver and titanium was investigated and it was evaluated that the drilling speed for titanium is the fastest because of more absorptivity for laser and poor conductivity. L wang developed Systematic method for comprehensive characterization of holes produced by millisecond pulsed laser was established, which illustrate how to enhance the quality of the holes by Parameter optimization [8]. In that method of laser drilling was employed to GH2302 alloy workpiece 4.0mm thickness. The results revealed that micro cracks induced in those areas where thermal stress is concentrated which leaded to non-uniform distribution of elements and local elevated temperature caused rise to the debris formation near the entrance of holes. Maclean employed millisecond Laser drilling to semiconductors revealing many material processes including laser energy absorption, heating, melting, vaporization and resolidification occurred [9]. They observed results on the characterization of materials with different basic material parameters via drilling holes using a 2000W max power 1070nm fiber laser with 1-20m/s pulses using single crystal silicon, gallium arsenide and sapphire. Experiments of micro-hole ablation were first time conducted on titanium alloy Ti-6Al-4V by Nd: YAG millisecond pulsed laser. Depth of recast material was suggested as a significant factor which influences the depth of the hole. WQ Mei investigated the regularity of recast depth with the change of different laser parameters [10]. He proposed that the ratio of recast depth as well as the entire hole depth decreases if pulse width decreases, and increases if there is a hike in peak power. And it was later verified by conducting laser drilling by millisecond laser on stainless steel 1Cr13. Melt emulsion and ablation was keenly observed during millisecond laser drilling to deeply investigate the laser beam and material interaction phenomena [11]. In these years, higher-performance devices have been widely used to investigate the dynamical process of melt ejection with higher spatial and time resolution Low et al. [12–14] observed the melt ejection in laser drilling on both dielectrics and metals. It was concluded that melt ejection is mostly dependent on the parameters of laser pulses.

Keeping in view the importance of the process, this focal position problem is chosen for this experimental research. Only a few researchers have carried out the studies on laser drilling with respect to defocused beam past few years. Chao-Ching Ho and Yuan-Jen Chang [15] discussed a method for controlling the laser-drilling process for a hole optical emission monitoring for

defocusing laser percussion drilling. Jackson and O'Neill [16] investigated the interaction phenomena of Nd:YAG laser pulses on M2 tool steel [17]. This study mainly focused on laser percussion drilling with different number of pulses at different focal positions in order to discuss the behavior, effect of defocused beam and its influence on the hole profile.

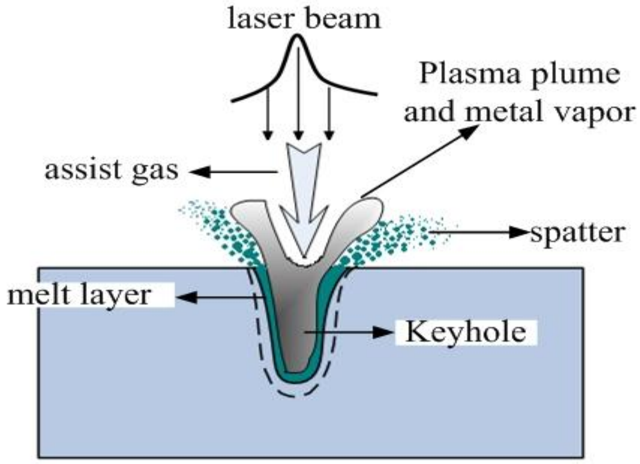

Fig. 1: Schematic laser drilling.

Further investigation indicates that the variation of beam radius affects the hole's depth greatly under other unaltered conditions. Thus, the defocusing effect was induced to modify the analytical solution and obtained results are in agreement well with those of the experiments. The fundamental idea behind conducting this experimental investigation was mainly to observe the effect of defocused focal distance on hole longitudinal and horizontal profile.

EXPERIMENTAL SETUP AND MATERIAL

Laser machining mainly consist of three main systems, including laser systems, beam transfer system, beam positioning system, beam delivery system and 3 axis work table. Millisecond Laser drilling system used in this experimental study is a CHUTIAN LASER EQUIPMENT GROUP possessing laser output power around 120W as shown in figure 2 and 3. Input power of 10kw to two lamps resulted in 380V from two lamps to produce a laser beam having wavelength of 1064nm. The different parameters setup ranges are current range 80-500a, Frequency 0-10Hz, pulse width 0.1-20 and power stability rate of laser system is variable by 5%. The laser beam from the cavity after injection, has passed beam expander and 45 ° turn mirror and finally after focusing lens by the focal length of 75mm acting on the upper surface of the target. Specific parameters of the laser as shown in table 1. Experiment bench for 3-DOF (XYZ-axis) CNC, precision 0.01mm, and repeat positioning accuracy is 0.002mm. Experimental procedures, with specific clamps on the Board level will be fixed to the bench plane, changed by adjusting the XY axis CNC hole spacing between holes, adjust the z axis to change the lens focus distance with the upper surface of the target. Jet nozzle for conical, diameter 1.2mm, distance 1.5mm from the material's surface.

Table 1: Compositions of the Work Piece Material

Material	Content (%)
C	0.13-0.21
Cr	1.80-2.20
Ni	1.80-2.21
Si	0.15-0.40
Mn	0.40-0.60
P	<0.035
S	<0.035

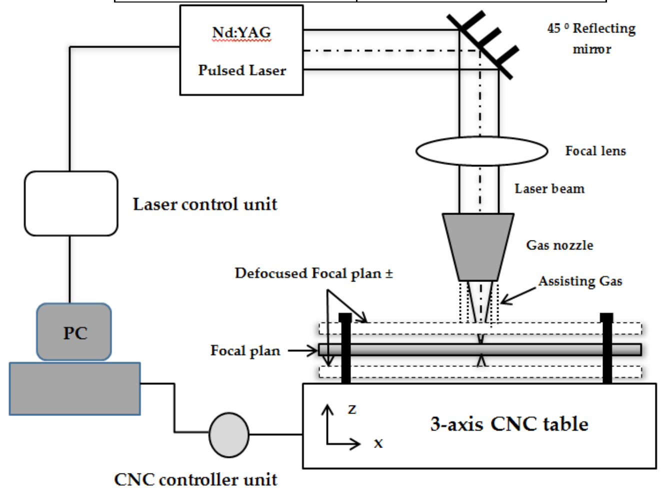

Fig. 2: Experimental setup.

Material used for this experimental study is high grade steel 18crNi8 made by company Bosch (BOSCH).Standard material hardness of HB180~240 enables this material application to wind turbine blades, fuel injection nozzles holes and other high temperature applications. This material possesses high tensile strength (231Mpa) and yielding strength (154Mpa). Work piece thickness was measured as 1mm and has length of 20mm. Process parameters used for experimentations are given in table 2.

RESULTS AND DISCUSSION

Laser percussion drilling was done by a millisecond laser system emitting Gaussian beam to drill holes in work piece of thickness 1mm for one, two and three no of pulses. Observation were recorded in hole entrance, exit and longitudinal profile in Fig 3. All the experimental results are illustrated in table 2, 3 and 4; containing hole entrance, hole exit and longitudinal hole profile. Results obtained are deeply analyzed in terms of hole entrance and exit diameters and their trends with respect to increasing or decreasing focal distance, tapper angle, material deposition and debris.

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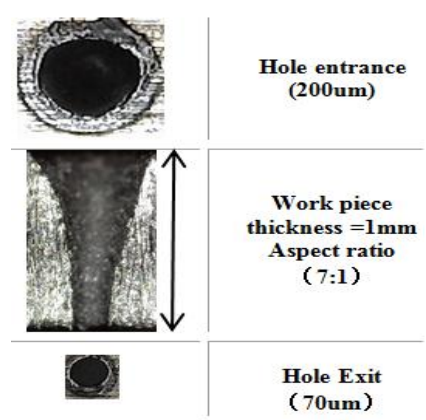


Fig. 3: Observational diagram

Table 2. Entrance holes of pulse 1, 2, 3; Focal Position (mm)

2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0

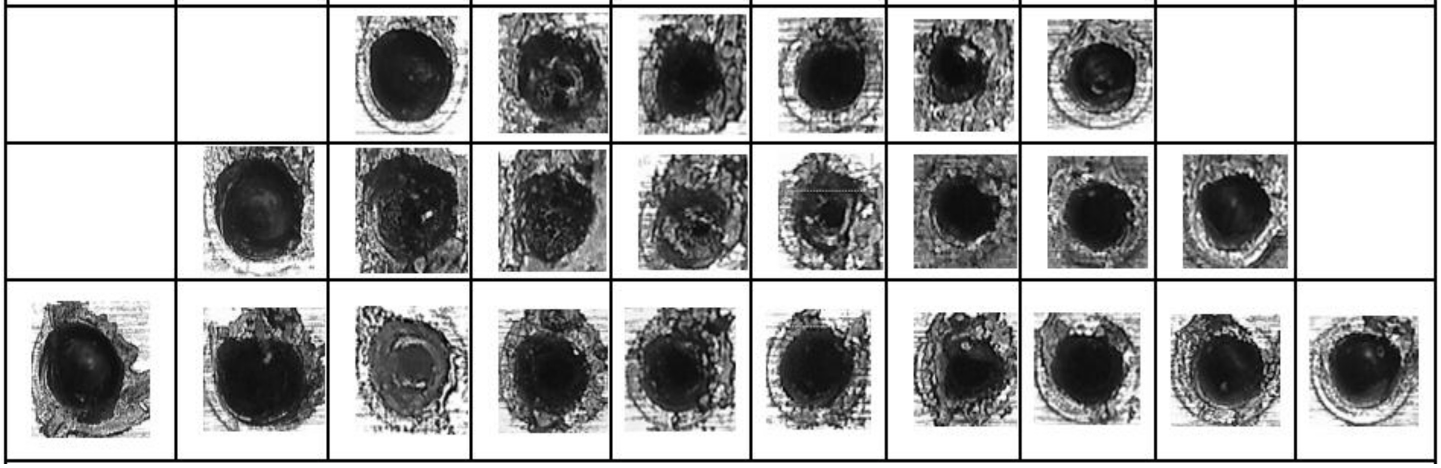


Table 3. Exit holes with pulse 1, 2, 3; Focal Position (mm) as per Table 2

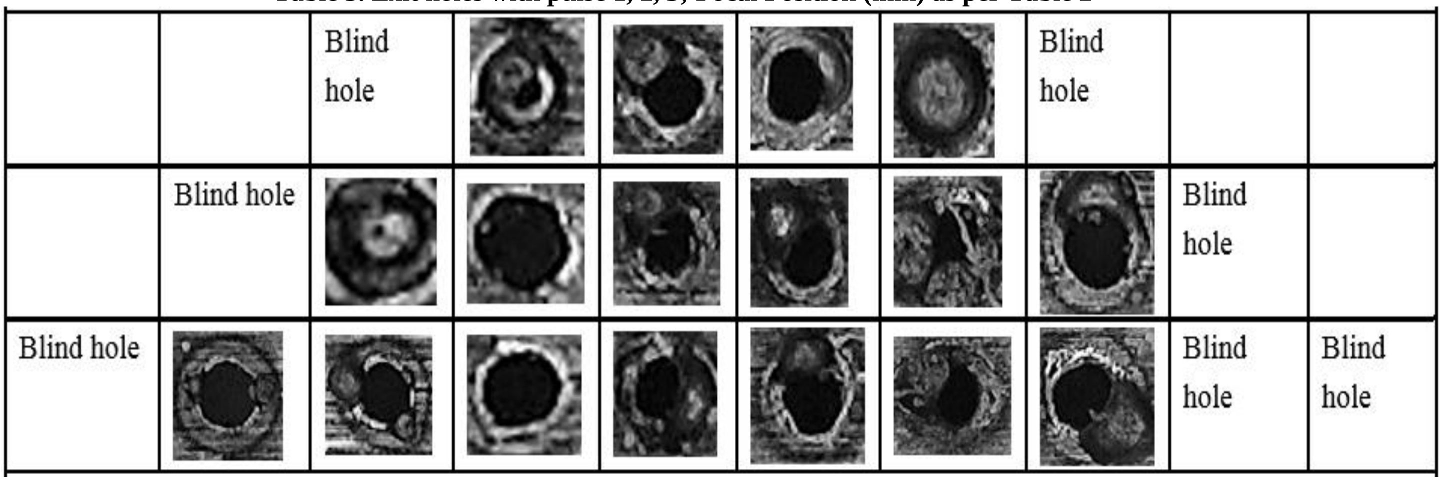
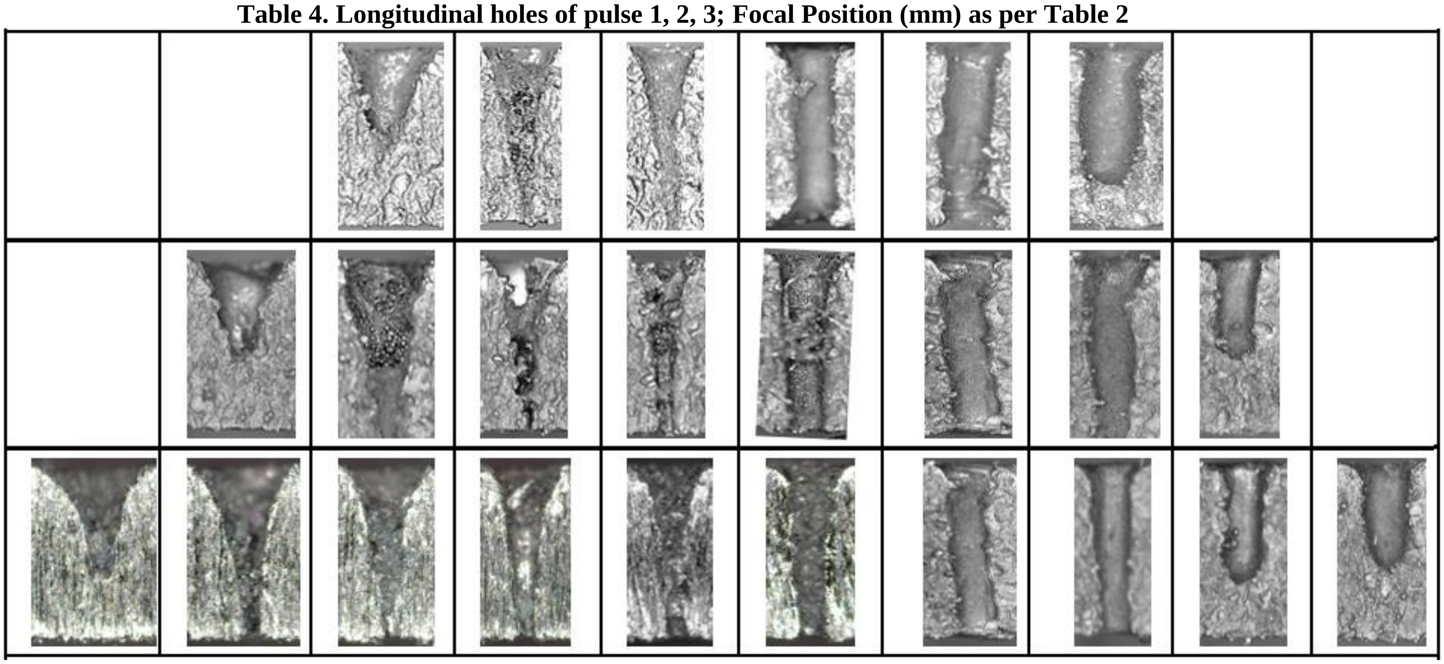


Table 4. Longitudinal holes of pulse 1, 2, 3; Focal Position (mm) as per Table 2



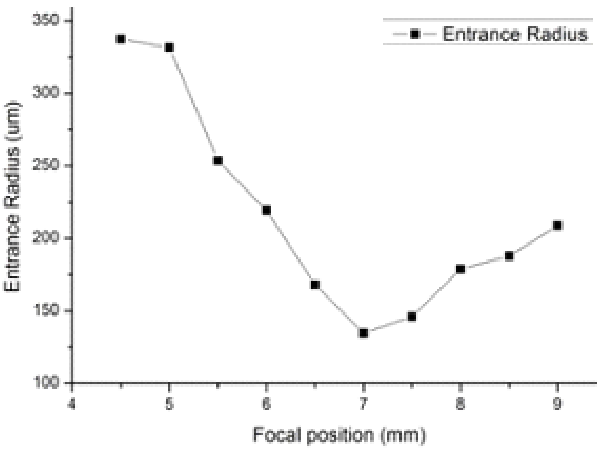


Fig. 4: Entrance hole radius.

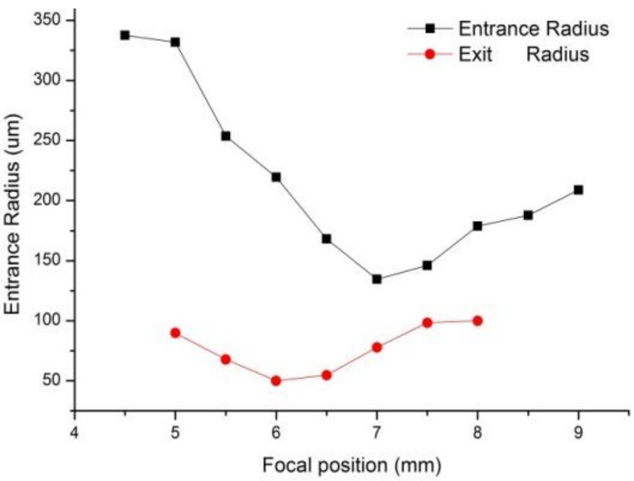


Fig. 5: Entrance and exit hole radius.

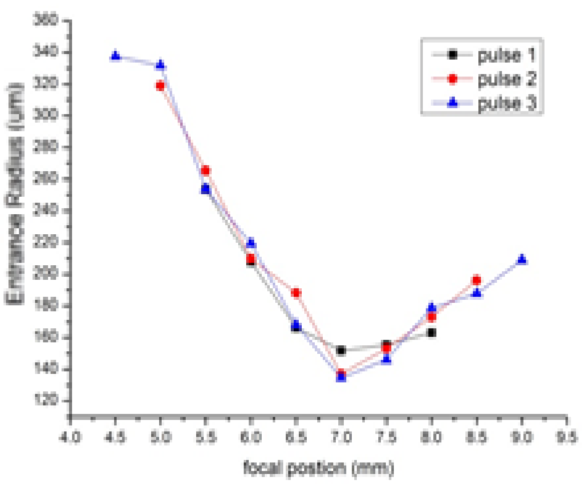


Fig. 6: Entrance radius for all pulses

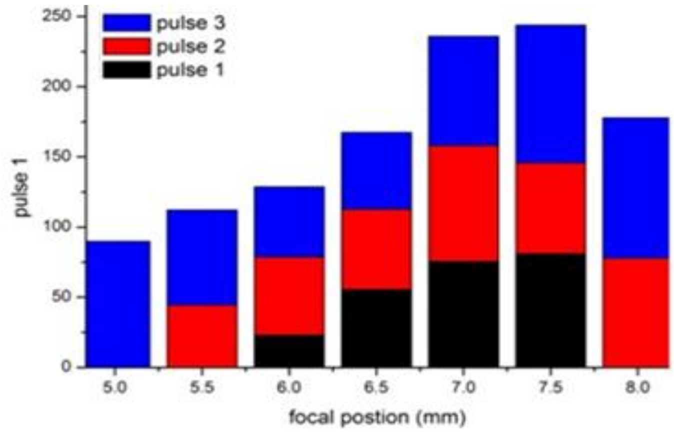


Fig. 7: Entrance and exit radius

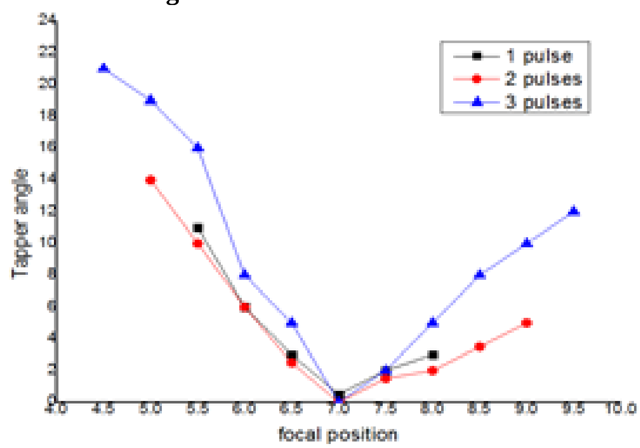
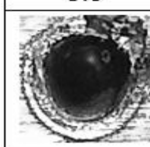
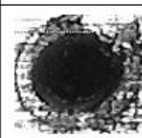
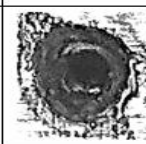
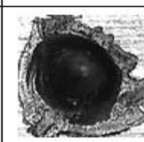
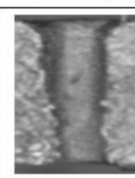


Fig. 8: Tapper angle for all pulses.

Table 5. Material deposition and debris 3 pulses

9.0	7.0	5.5	4.5
			
			
Blind hole			Blind hole

Hole's Horizontal Profile

All experimental results shown that there is an increase in entrance diameter while moving away from the focal point on both sides either increasing or decreasing. While the ratio of demons.

Focal distance in figure 4 is 7mm. From 7mm to 5mm (-2.0mm) there is noticeable increase is the diameter while after 5mm increase is quite lower as compared to earlier increase. While on the other side increase in entrance diameter is almost continuous and smaller. At the end of both ranges of focal positions have blind hole.

Similarly, on hole exit there is decrease in diameter in start but soon after there is a significant increase in diameter (table 3 and figure 4). It was noted that the ratio of increasing diameter is almost same as compared to the hole entrance diameter. With decreasing focal distance, there is decrease in hole entrance, after 1mm there is gradual increase in exit hole diameter (figure 5).

Up to 1mm the increase or decrease diameter's ratio is (1.5-1.8) while after moving away from 1mm the ration increased to (3.2-4.7). For example at 7.5mm hole entrance diameter is 145um and exit diameter is 98um at the ratio of 1.5. While on 5.0mm the hole entrance diameter is 331um and exit is 88µm at the ratio of 3.8.

Figure 6 illustrate that increasing and decreasing radius trend for 1pulse, two pulses and three pulses is same. But 3pulses have more through holes even 2mm away from the focal position because of increase in the total amount of power transferred to material. Similarly for single pulse holes drilled are less as compared to others 2 and 3 pulses. Same trend was observed in exit diameter case shown in figure 7.

Hole's Longitudinal Profile

Table 4 deeply shown the changes occurred in terms of longitudinal profile during focal position change. It has shown the evaluation of straight hole to blind hole on either side of focal position. Significant tapper is recorded while moving away from focus point on decreasing focal length. While on the other hand increase in tapper angle was measured less with respect to increase in focal length.

Figure 8 shown that the tapper angle in the start increased at low rate till 1mm but after that there is a gradual change in increase. The reason behind this is as much as laser beam will be defocused then there will be more increase in spot size and decrease in beam energy which results in blind hole in the end. For single pulse, double pulse and triple pulses the main trend remain same but changed with different ratio as the focal positions changed. Figure 8 demonstrate that tapering effect became dominant before approaching to blind hole on both sides of focal positions. While near focal point this trend seems quite low. For pulse 1 and pulse 2 the tapering effect seems similar while for pulse it seems considerably.

Material Deposition and Debris

Material deposition and debris formation is not constant in all cases of single, double and triple pulses. But at exact focal 7.0mm point in three cases the debris formation and molten material solidification is less, Material deposition, increase as we move away from a focal distance at hole entrance, but quantity or ratio is almost constant. While on exit of the hole trend was observed as dominant and unpredictable.

Table 5 demonstrates this phenomena quite clearly by showing relatively clean hole entrance at 7.0mm while more destructive on decreasing focal position because of high beam intensity and fairly large spot size. But on the other hand, while increasing focal distance material deposition at the entrance is still negligible, which also can be illustrated by longitudinal hole profile. For three pulses on exit of the hole, the dominance factor remained almost same on either sides. Some heat affected zones as also seen among vertical profile because of elevated temperature during the process which also influence the uniformity of the hole.

CONCLUSION

It is concluded that the drilling process seems much dependent on the beam propagation property of laser system. Focal position have considerable influence in terms of change in the thermal properties of the material (thermal conductivity, density, specific heat capacity) and the degree of melting material which has an important role in the drilling process. It is mainly concluded that:

- Entrance and exit diameter increases considerably while moving above from focal plan. While increases slowly if beam is defocused below focal plan.
- Tapper angle also increases as defocusing of beam occurred by the ratio of 5:1 with respect to defocusing distance.
- Melt deposition and debris trends were evaluated and proposed that destructive melt emulsion found on exit and entrance as beam was defocused. Most of the cleaned holes were found on focus positions.

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