Hole Geometry Features Analysis in Fiber Laser Percussion Drilling Process

Alireza Mohazab Pak[1], and Mahmoud Moradi[2]

***Abstract*—**Creating Micro holes on the sheets is challenging in industries that could be achieved by using a laser. Laser drilling is performed by single pulse drilling, percussion drilling, helical drilling and trepanning drilling methods. A common method of drilling is Percussion Drilling. This study is focused on investigating the parameters of laser percussion drilling process of nickel-base superalloy Inconel **718** with thickness of **1** mm. Fiber laser with the wave length of **1070** nm was used as laser source. Laser power, laser pulse frequency and assist gas pressure were assumed as the laser drilling process variable parameters. Oxygen was used as assist gas. Optical microscope was used to investigate the geometrical features of the holes on the samples. The hole geometry features (hole entrance and exit diameters, circularity of hole entrance and hole exit circularity, and hole taper) were measured using imagej software. The results indicated that laser pulse frequency has a direct influence on the diameter of the entrance hole. Increasing the pulse duration leads to increases in hole taper. By increasing the laser power, entrance and exit hole diameter increased and hole taper increases. Holes with a diameter of about **300** to **700** micrometers created on the sheet.

***Keywords*—** laser percussion drilling, hole geometry features, fiber laser.

I. Introduction

SINCE the invention of the laser in 1960, lasers have been used by the engineering and industry including welding, drilling, cutting, heat treatment and medical surgeries. Machining is one of the important areas in the engineering discipline. To meet today's challenges, it is necessary to incorporate advanced machine tools in manufacturing processes. Laser drilling is considered to be one of the advanced machining processes filling the gap in the advanced manufacturing systems because of their precision, low cost, localized processing, and high speed of operation. In laser drilling applications, a laser beam is used as a heat source increasing temperature rapidly to the melting and evaporation temperature of the substrate material. Since the arrangements of the optical setting for the laser beam are very precise, the localized heating can be controlled easily[1]. Laser percussion drilling is extensively used in the industry for small hole fabrication, such as effusion cooling holes in aerospace components. It is a drilling process whereby the workpiece is subjected to a series of laser pulses at the same spot at a specified laser parameter setting, which results in melt ejection and consequently forming a hole. It is often difficult to produce repeatable holes with laser percussion drilling[2]. It is desirable to make the drilled holes circular and without any taper. Taper and circularity are the most important characteristics of any drilled holes in laser percussion drilling process[3]. Hanon et al. [4] investigated the effects of laser parameters such as peak power, pulse duration, focal position and repetition rate on the alumina ceramic plaques of 5 mm and 10.5 mm thickness using 600 w Nd:YAG laser. The authors identified three different layers namely a thin layer, a resolidified material inside the hole and a recast layer at the entrance region of the hole. The crater depth increased with the number of pulses due to insufficient recoil pressure inside the cavity. Mutlu et al. [5] investigated the influence of laser wavelength and operation pressure on the crater depth and diameter in drilling 0.8 mm alumina ceramic plates using Nd:YAG pulsed laser. The crater depth and diameter increased non-linearly with laser power because of the plasma shielding effect. Both wavelength and ambient pressures showed the same characteristics. yilbas [6] examined four materials nickel, tantalum, en 58 b and titanium to obtain laser drilling speed using a statistical analysis. Khan et al [7] investigated different sizes of supersonic micro gas jets percussion drilling of 200μm thick 316l stainless steel plates using 355nm wavelength nanosecond laser. Other relevant approaches, carried out by mishra and yadava [8], include the estimation of the drill profile considering temperature-dependent thermal properties, optical properties and phase change phenomena of the sheet materials. Recently laser is widely used for materials processing. In the previous researches of the aouther, the effects of diferent process parameters on the weld- bead profiles in the laser welding process were investigated and analysed [9], [10], [11]. RSM and taguchi method were applied to analyze and optimize the laser welding mechanical properties[12],[13]. Since laser drilling is associated with several parameters development of a physical model becomes complicated and hence researchers have developed statistical models for taper [3],[7],[14],[15],[16],[17],[18] HAZ [14],[18] and circularity [3],[19],[20]to analyze parameters such as laser peak power, laser power, pulse width, pulse frequency, focus plane position, number of pulses and assist gas pressure.

In the present study the effects of fiber laser percoausion drilling process parameters, laser pulse frequency, laser power, and assist gas pressure on the hole geometrical features of ni-

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base super alloy inocnel 718 with thickness of 1mm is investigated. The hole entrance diameters (di), the hole exit diameters (dout), circularity of hole entrance (cirin) and circularity of hole exit (cirout) were considered as geometrical features. the hole exit circularity is important hole geometry features that Already not been investigated . Performing a fiber laser as laser machine on the nickel-base super alloy inconel 718 with thickness of 1 mm and circularity at the hole exit are innovation of the present study over the previous research studies. Figure 1 shows the geometrical features of laser drilled holes.

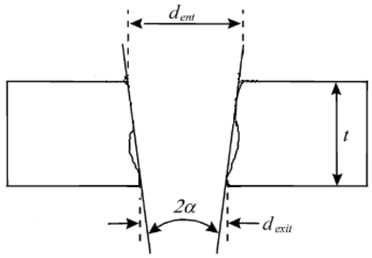

Fig1.Geometrical features of cross-section of the hole

II. EXPERIMENTWORK

Nickel-base super alloy Inconel 718 with 1 mm thickness was used as workpiece material with the chemical composition presented in Table 1, which is the average of three X-ray fluorescence measurements.

TABLE I
CHEMICAL COMPOSITION OF NICKEL-BASE SUPER ALLOY INCONEL 718(WT.%)

Ni	Fe	Cr	Nb	Mo	Ti	Al	Ta	Zr
Base	18.1	17.2	4.75	3.0	1.0	0.55	Trace	Trace

The sheets were drilled by fiber laser (Fig. 1) delivered 500 W emitting at 1070µm wavelength. Table 2 shows the specification details of fiber laser machine used in research. the Oxygen was used as assist gas in the experiments.

Fig 2. The laser used for experiments

TABLE II
SPECIFICATION DETAILS OF FIBER LASER MACHINE USED IN THE RESEARCH

SPECIFICATION	DESCRIPTION
Laser type	Fiber laser
Wave length	1070 ± 10nm
Laser beam spot diameter	10µm
Average power	200-500 w
Mode of operation	Cw and modulated
Maximum modulation rate	10 khz
Minimum pulse width	<10 µs

Laser drilling of 13 tests were performed on sheets. Experimental tests were carried out in accordance with table 3. As it is observed in table 3, laser power, laser pulse frequency and assist gas pressure were considered as the laser drilling process variable parameters. The focal plane position was 1mm above the sheet surface and the duty cucle of the drilling was 40%. these parameters were fixed in all the tests. The geometry features of the hole entrance and exit were measured using Axioskop 40 optical microscope at a magnification of 940× and by Imajej software the images were exactly measured. The hole geometry features such as hole entrance and exit diameters, circularity of hole entrance and hole exit circularity, and hole taper as a function of entrance and exit holes were measured by Imajej software and considered as responses. Effect of the input parameters variations on hole profile geometry is shown in Figure 3. The top row of Figure 3 shows the entrance hole diameter while the bottom row shows the exite diameter.

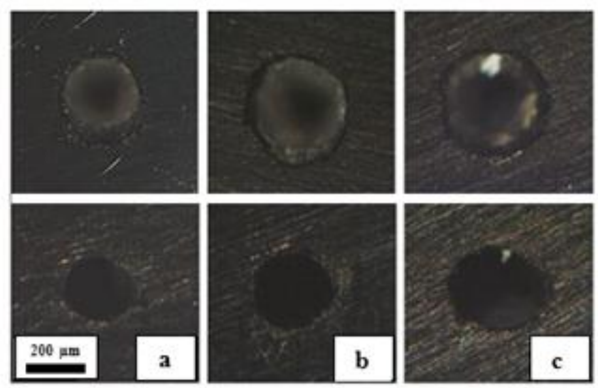

Fig 3. Effect of the input parameters variations on profile geometry.a) F_1, b) P_5, c) G_2

After measuring the hole entrance diameter and hole exit diameter, hole entrance and exit diameters equivalent by the area of the hole entrance and exit can be achieved by"Eq. (1)".

$$A = \pi \frac{d_{eq}^2}{4} \rightarrow d_{eq} = 2\sqrt{\frac{A}{\pi}} \quad (1)$$

The taper was defined by "Eq. (2)" [3].

$$Taper(^\circ) = \frac{d_{entrance} - d_{exit}}{2t} \times \frac{180}{\pi} \quad (2)$$

where dentrance is the hole entrance diameter, dexit is the hole exit diameter and t is the material thickness. Results of the mesurment of the values of the diameters, circularity of hole entrance and hole exit, and hole taper are shown in Table 3.

TABLE III
LASER PARAMETERS AND THE RESULTS OF GEOMETRICAL FEATURES

PARAMETERS				RESPONSES				
SAMPLES	FREQUENCY (HZ)	POWER (W)	GAS PRESSURE (BAR)	D_{IN} (μM)	CIRCULARITY$_{IN}$	D_{OUT} (μM)	CIRCULARITY$_{OUT}$	TAPER (°)
F_1	600	500	4	642	0.777	356	0.784	13.3
F_2	500	500	4	410	0.826	186	0.869	6.42
F_3	400	500	4	410	0.827	172	0.854	6.82
F_4	300	500	4	422	0.835	182	0.861	6.88
P_1	600	475	4	662	0.84	292	0.872	13.87
P_2	600	450	4	670	0.745	182	0.841	13.75
P_3	600	425	4	418	0.824	186	0.863	6.65
P_4	600	400	4	394	0.852	174	0.824	6.3
P_5	600	375	4	398	0.86	168	0.883	6.59
G_1	600	500	6	420	0.829	192	0801.	5.9
G_2	600	500	5	400	0.865	168	0.791	7.22
G_3	600	500	3	440	0.764	164	0.841	8.14
G_4	600	500	2	680	0.876	356	0.787	14.44

III. DISCUSSION

The hole entrance diameters (d_i), The hole exit diameters(d_{out}), circularity of hole entrance (cir_{in}) and circularity of hole exit (cir_{out}) were considered as geometrical features. The effects of laser process parameters, on geometrical features were investigated. The results show that the relationship between the geometrical features and laser process parameters.

IV. EFFECTS OF LASER PULSE FREQUENCY

The Pulse Frequency versus geometry features plots are shown in Figs.4. The higher pulse frequency generates larger hole entrance diameter, as shown in Fig. 4 (a) because the increase of the pulse frequency accumulated the heat input applied to the workpiece[21]. pulse frequency as shown in Fig. 4 (b) has no clear trend on the hole exit diameter and highest value of exit hole occurs at 500 Hz. Fig. 4 (c) illustrates that at lower pulse frequency the more entrance circularity could be achived. At lower pulse frequency the pulse off-time becomes longer and the material has more time to be chilled and becomes closer to solidness.

This can prevent ferment and any disorderliness during the material removal process and result in greater circularity excessive pulses after the laser beam breaks through conducts to molten material exiting from the hole exit [3]. when pulse frequency increases pulse off time (time between two sequential incidents of laser beam) becomes shorter also the beam energy generated becomes lower. As a result, material is melted and solidified with less disorderliness and higher circularity of exit hole is generated[19].

Fig. 4 (e) illustrates that the hole taper decreases with increasing pulse frequency. because heat generation is high, and as a result the top surface of workpiece where laser beam is focused is melted and vaporized instantly and a large amount of material is removed from the top surface during hole formation[19]

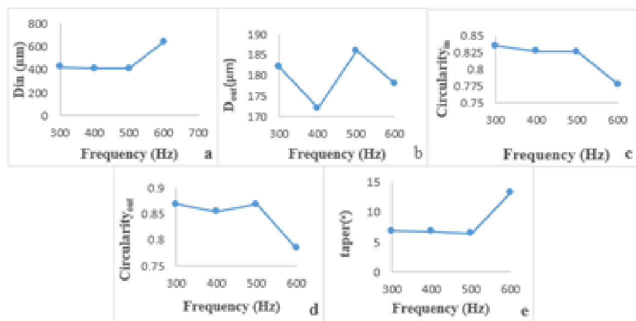

Fig. 4 influnces of laser frequency on hole geometry features

V. EFFECTS OF LASER POWER

Fig.5 shows the effects of the laser power on the geometrical process of the drilled holes. According to the Fig. 5(a) and Fig. 5(b) increasing the laser power result in greater hole entrance and exit diameter. As the laser power increases,the Energy per pulse is higher[3]. Fig. 5(c) and Fig. 5(d) illustrate that the laser power variations had no clear trend on the circularity of hole entrance and hole exit circularity. Fig. 5(e) shows that The low power of laser beam generates less hole taper.

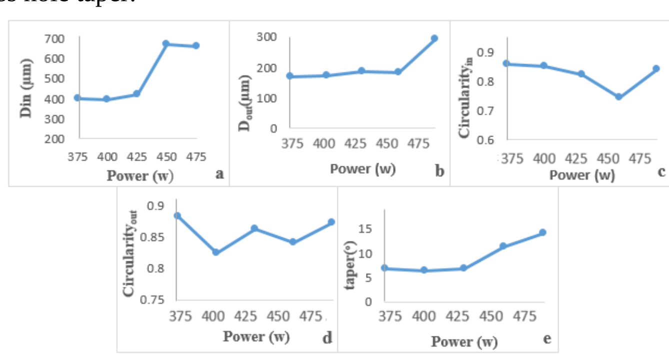

Fig 5. Influences of laser power on hole geometry features

VI. EFFECTS OF ASSIST GAS PRESSURE

Fig. 6 shows the assist gas pressure variation for geometry features. According to the Fig. 6 (a) and (e) by increasing the assist gas pressure, entrance hole diameter and hole taper decreases. Also Fig. 6 (b), (c) and (d) indicated that the assist gas pressure variations had no clear trend on the hole exit diameter, circularity of hole entrance and hole exit circularity. Highest values of exit hole diameter, circularity of hole entrance and hole exit circularity occurs at 6, 2 and 3 bar Respectively.

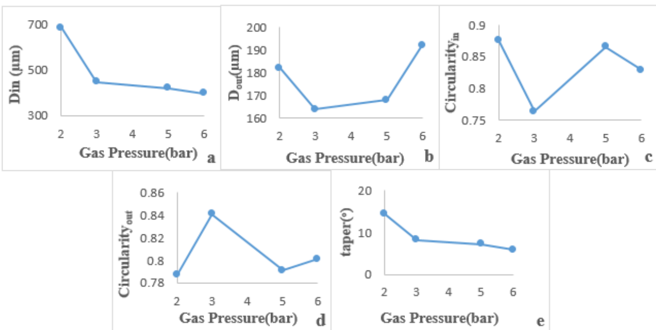

Fig 6. Influences of assist gas pressure on hole geometry features

VII. CONCLUSIONS

The present work analyses the geometry features of fiber laser percussion drilling process on Inconel 718 with thickness of 1 mm. The following conclusions can be drawn:

1- At higher laser power,pulse frequency and lower assist gas pressure produce greater hole entrance diameter and by increasing laser power exit hole diameter increased.

2- lower laser pulse frequency increases hole entrance circularity. Laser power and assist gas pressure variations had no clear trend on the hole entrance circularity.

3- By increseasing pulse frequency the hole exit circularity decreased. Laser power and assist gas pressure variations had no clear trend on the hole exit circularity.

4- By increasing the pulse frequency, laser power, and lower assist gas pressure, be obtained in order to achieve higher hole taper.

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