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Drilling on Fibre-Glass Composite using CO_2 Laser

M.M.Noor, T.T.Mon, K.Kadirgama, M.R.M.Rejab, M.S.M.Sani, R.Rafizuan, W.A.W.Yusof

Faculty of Mechanical Engineering Universiti Malaysia Pahang, 26300 UMP, Kuantan, Pahang, Malaysia
Phone: +609-5492223 Fax: +609-5492244 E-mail: muhamad@ump.edu.my / montt@ump.edu.my

Abstract

Fibre-glass composite has been increasingly used in automotive, aerospace and electronics industries, where hole making on this material is a major process. In this paper, non-traditional machining method was employed to drill the fibre-glass composite sheet of 2 mm in thickness having four layers of glass-fibre with orientation <0, 90, 0, 90>. The machining setup consists of computer-controlled laser source and air supply by a compressor that acts as assist gas for cooling. The type of laser source was CO_2 with a maximum power of 30W. The machining parameters under consideration were laser power and pulse duration. A total of 12 holes were drilled varying laser power and pulse duration. Laser power was varied from 15 to 25W while pulse duration from 2 to 5 minute. Laser-drilled holes were investigated under optical microscope. The hole quality was evaluated with the hole size, hole geometry, burn mark and heat-affected zone. Hole quality were then compared for each parameter combination. It was found that the laser power had predominantly affected the quality of the hole in fibre-glass composite material during laser-drilling.

Keywords: laser-drilling, CO_2 laser, fibre-glass composite, heat-affected zone

Introduction

Manufacturing process nowadays demands advanced machining techniques to fulfil the stricter design requirements and to machine difficult-to-machine materials such as tough super alloys, ceramics, and composites. Traditional machining processes also tend to be obsolete when dealing with advanced design and materials. As a result, manufacturers and machine design engineers are turning to advance machining processes. One of the most-useful advanced processes is laser machining where modified light energy is used to fabricate any geometry on difficult-to-machined materials. Particularly, hole making by laser or laser drilling of composites is one major process that may be found in automotive, aerospace and electronic industries [1]-[9].

Basically, there are two common techniques used in laser drilling: percussion and trepanning. Percussion drilling is a process where multiple pulses are applied per hole to achieve the desired results. Trepanning is a process by cutting large holes or contouring shaped holes. The one that interests the authors in this research is the percussion hole drilling on glass-fibre composite as this material has been increasingly used in above-mentioned industries [2], [4], [8], [10], [11]. Looking back at the past study, unfortunately only limited work on laser drilling have been reported. Their research were mainly focus on indentifying possible parametric optimization in laser drilling, modelling the laser drilling mechanism and studying the effect of laser drilling on different types of materials. The materials tested are mostly metals. The process parameters considered were laser pulse width, pulse energy, beam intensity, and material thickness. Based on quantitative and qualitative analysis method, the hole quality was identified in term of barrelling size, re-solidified material, surface debris, inlet cone, exit cone, and mean hole diameter. From the parametric study in laser drilling of stainless steel, nickel and titanium, it was stated that the material thickness were the most significant parameter that affect the quality of hole [12]-[17].

One remarkable research on laser drilling of composite was conducted by [6] whose focus was laser drilling of carbon-fibre composite. It was reported that common defects occurred in laser drilling of such composite were overheating, fibre swelling and large affected zone. The substantial fibre swelling observed around laser-drilled holes was associated with rapid volatilization of impurities within the fibre occurring simultaneously with the structural reordering expected when high temperatures (1300–2000°C) were attained. The objectives of this research are to experimentally analyze the effect of laser parameters on drilling of fibre-glass composite and to investigate the quality of hole associated with the laser parameters under consideration.

Experimental Setup

The type of laser source used was carbon dioxide laser. It has pulse duration of 300µs with 100Hz frequency. Maximum power that the laser could generate is about 30W. However, due to a safety reason the maximum power usage was limited to 25W. The working distance i.e. the distance between the workpiece surface and laser tip was 27mm. This distance was considered as the optimum distance with built-in lens system according to the supplier and with this setting the spot size of the laser beam was about 0.3mm. Figure 1 illustrates the laser machine setup used in this research. The laser source was controlled by computer and integrated software. Figure 2 the glass-fibre composite specimen tested for laser drilling. The specimen was 3 mm thick and has four layers of fibre stacked in exposy with orientation of <0, 90, 0, 90>.

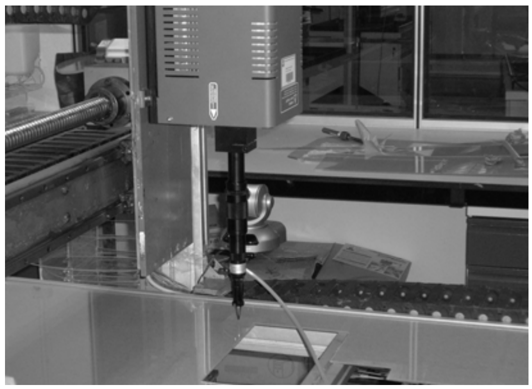


Figure 1: The laser machine setup.

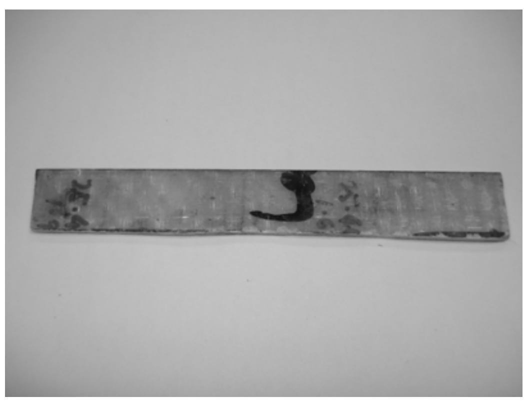


Figure 2: Glass-fibre composite specimen

Table 1 shows the process parameters varied in the experiment. Parameters considered were total pulse duration and laser power. From the preliminary experiments, laser power lower than 15W was found not effective to generate hole. Therefore, minimum power was set to be 15W and increased three levels with increment of three. Minimum total pulse duration needed to shoot at the same spot with this power was 2 minute. Hence, pulse duration was varied from 2 minute in increasing order. During laser drilling, the compressed air was used as an assist gas for cooling.

Table 1: Process parameters varied in the experiment

Hole no.	Laser power (W)	Pulse duration (min)
1	15	2
2		3
3		4
4		5
5	18	2
6		3
7		4
8		5
9	21	2
10		3
11		4
12		5

Hole quality was justified based upon the inherent characteristics of laser-drilled hole as defined in Figure 3 [13-17]. These characteristics were used as criteria to evaluate the hole quality.

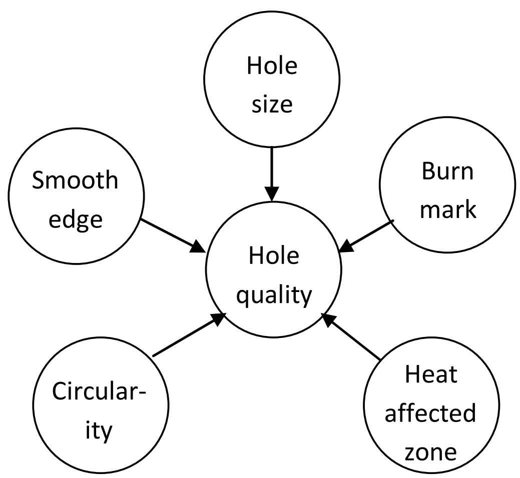


Figure 3: Characteristics of laser-drilled hole

Results and Discussions

Laser drilling process has been performed on glass-fiber composite. There are total of 12 holes in actual experiment based on the parameter range under consideration. Prior to this, trial holes were drilled in order to acquire minimum amount of laser power and pulse duration that can penetrate the composite specimen of 3mm thickness. Initially, the specimen was shot with the laser beam without the assist gas. It was found that the region under direct exposure of the beam was burnt. Then using the assist gas, the specimen was shot with the initial laser beam of 25% and pulse duration of 30 s. The specimen was checked every 30 s if the hole was made. The power and pulse duration were alternately increased until a hole was seen on the specimen. Finally, the hole was successfully made with 50% of laser power and 2 min pulse duration without major defects. Therefore, these values were used as a basic to vary laser power and pulse duration in the actual experiment.

Trial experiments indicated that the mechanism involved in laser-drilling was melt-driven mechanism in which the ejection of the melt occurred by pressure from the assist gas. Consequently, the assist gas plays an important role in laser drilling in order to make a debris-free hole successfully. According to [12, 17], the gas helps much to eject the melt from the drilling zone and thus leaves a clean cut. In addition, it cools the penetration zone significantly during drilling.

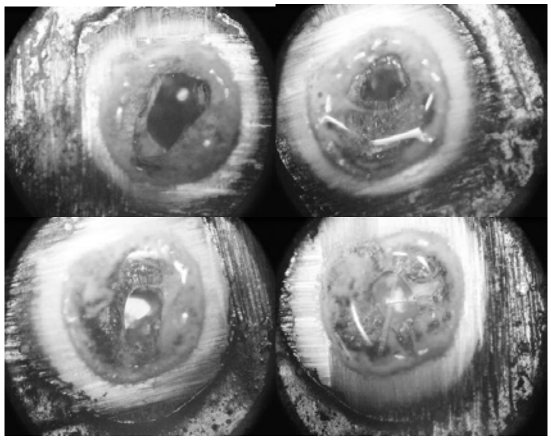


Figure 4. Holes features at 50% (15W) power and with different pulse duration
a) 2 minutes, b) 3 minutes, c) 4 minutes, d) 5 minutes

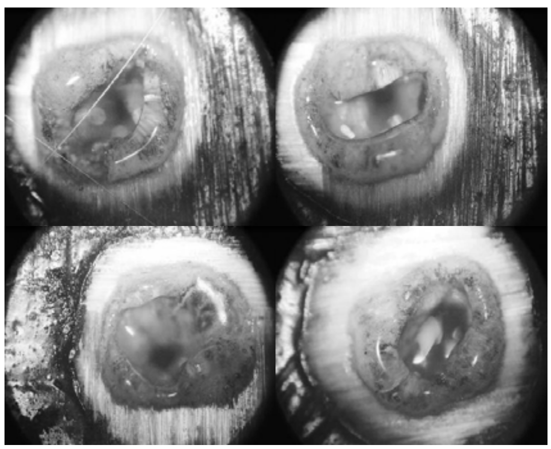


Figure 5. Holes features at 60% (18W) power and with different pulse duration
a) 2 minutes, b) 3 minutes, c) 4 minutes, d) 5 minutes

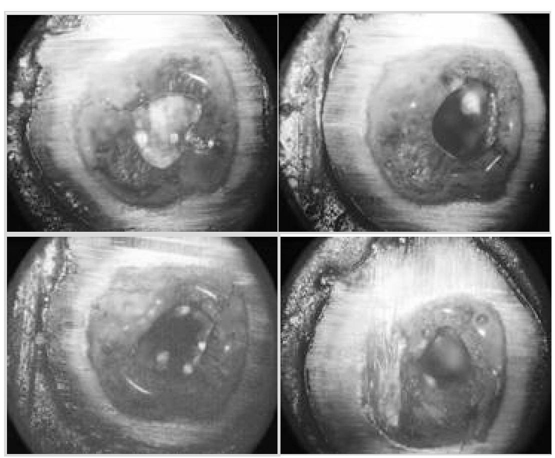


Figure 6. Holes features at 70% (21W) power and different pulse duration a) 2 minutes, b) 3 minutes, c) 4 minutes, d) 5 minutes

Figure 4 to 6 shows holes with inherent characteristics generated at various laser power and pulse duration. In general for the same laser source, hole size does not vary considerably with pulse duration. However, increase in laser power does affect the hole size. With 50% power, the hole size are about 0.8mm and 0.9mm and then increase to 1.1mm and 1.2mm at 60% laser power. When the laser power was increased further to 70% there was no more radical increase in hole size. This implies that hole size reached saturation with laser power and increasing laser power would not generate any larger hole for the same pulse duration. The main reason for saturation was that the laser beam could be completely through the specimen thickness at 60% power and there was no more material to interact with the beam since the laser source and the specimen were stationary.

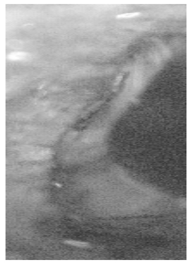
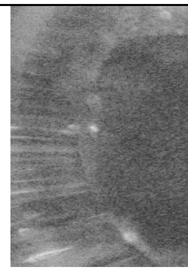
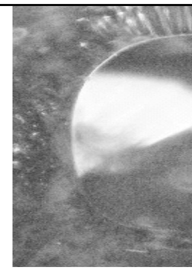
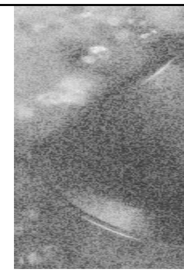
Also increase in pulse duration with 1 minute incremental doesn't seem to affect the hole size. As can be seen in Figure 4 to 6, at the increased pulse duration with the same power, hole size were almost the same. In this case, lower laser power and pulse duration are desirable for safety. In this experiment it was assumed that the laser beam was circular. The size of the laser-drilled hole was based on the uniform distance measured on the edge of the hole. In fact, for macro level it is fair to say that hole sizes were not much different from each other at varying power and pulse duration. For micro level only, the difference would be considered more pronounced. Furthermore, all hole geometries appeared as irregular shapes it is difficult to identify the exact hole size.

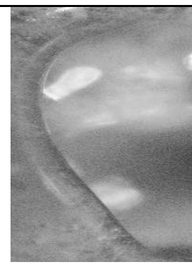
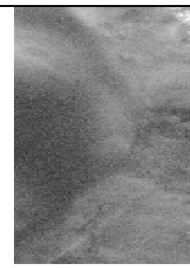
Again in the case of the burn marks, laser power was still found to be predominant parameter that had affected the burn mark. Although increasing laser power from 50 to 60% did not show considerable change in burn mark, further increase in laser power cause abruptly-large burn mark. It implies that the laser power play a major role in affecting the burn mark area and the amount of heat are more proactive than the heating time during laser drilling. The size of the burn mark was slightly reduced at 60% power compared to 50% power. This phenomenon occur due to the increase in hole size at 60% laser power. When the hole become larger, burn mark will decrease due to a farther position from the heat source, resulting less heat absorbed into the workpiece. In addition, for the same laser power no significant change in burn mark was found. It seems that the laser beam size and intensity tends to be stable once the laser beam penetrates through the thickness and subsequent increase in pulse duration does not affect the laser beam-material interaction.

In terms of heat-affected zone, the affected area was almost the same for the pulse duration up to 3 minutes for all laser powers. Then it gradually widened as the power and duration were increased. The greatest effect was observed with highest power and longest duration. Hence, it is fair to say that both parameters have a great effect on the affected area. Relative circularity shows inconsistencies from hole to hole in addition to poor circularity. Hole geometry does not follow a trend as the power or pulse duration. For the parameters range under consideration, hole geometry was closer to circular at 50% and 70% laser power whereas at 60% power, laser beam was less likely to generate circular geometry. The possible reason to this occurrence is due to different melting rate and material-beam interaction of the constituents of the composite material and during laser drilling. Generally circularity was better with the use of higher laser power.

Figure 7 compares the edge smoothness of holes generated at different laser powers and pulse duration. It shows an increasing trend for edge quality rating at 50% laser power and increasing pulse duration. However, at 60% laser power any changes in pulse duration did not tend to be dominant in affecting the edge quality. However simultaneous increase in both parameters is believed to have remarkable effect on edge quality.

Overall, laser power plays a major role and acts as a dominant parameter in affecting hole's characteristics such as hole size, burn mark and heat-affected zone. It indicates that the amount of heat generated through the laser beam-material interaction is crucial for hole size, burn mark and edge quality than the duration of the beam hitting the fibre-glass surface. On the other hand, edge quality is controlled by both laser power and pulse duration. Unlike other hole characteristics, increasing both parameters generally improve the quality of the edge.

HOLE NO.	1	2	3	4
EDGE QUALITY (View)				
LASER POWER (%)	50	50	50	50
PULSE DURATION (Minute)	2	3	4	5

HOLE NO.	5	6	7	8
EDGE QUALITY (View)				
LASER POWER (%)	60	60	60	60
PULSE DURATION (Minute)	2	3	4	5

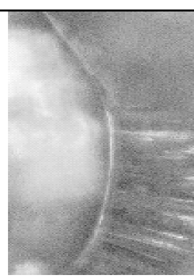
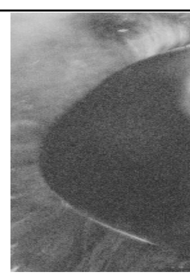
HOLE NO.	9	10	11	12
EDGE QUALITY (View)				
LASER POWER (%)	70	70	70	70
PULSE DURATION (Minute)	2	3	4	5

Figure 7. Comparison of edge smoothness at various powers and pulse duration.

Conclusion

The following conclusions can be drawn based upon the experimental laser drilling of composite:

- The degree of influence of process parameters on the hole quality in laser drilling of composite is the laser power followed by the pulse duration.
- Laser power is found to be predominant affecting the hole size, burn mark and edge quality. Subsequently, pulse duration made a major influence on affected area and edge quality.
- The best quality of hole that can be drilled with current laser source is the hole drilled by 50% laser power (15 W) with 3 minutes pulse duration.
- The lowest quality of hole occurred with 60% laser power (18 W) and longer pulse duration.
- In order to generate good quality hole, laser power and pulse duration needs to be properly compromised. In future, more process parameters should be taken into account and varied in wider range. Experiments should be carried out using systematic experimental design for analysis.

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References

[1] El-Hofy, Hassan, Advanced Machining Processes, (McGraw-Hill Professional Publishing 2005)
[2] Silent, dust-free drilling: ENGINEERING, Materials Today, 5(12), , Page 6 (2002)
[3] Miroslav, R., Laser cutting machines for 3-D thin sheet parts, UNIVERSITY'S DAY, 8th International Conference, Romania, May 24-26. (2002)
[4] Corcoran. A, Sexton L,. Seaman. B,. Ryan. P, The Laser Drilling of Multilayer Aerospace Material System. Journal of Materials Processing Technology, 123(1), 100-106, (2002)
[5] J. Gurauskis, D. Sola, J.I. Peña, V.M. Orera, Laser drilling of Ni–YSZ cermets, Journal of the European Ceramic Society, 28(14), 2673-2680, (2008)
[6] Voisey. K.T., Fouquet, Roy. D, Clyne. T. W, Fiber Swelling During Laser Drilling Of Carbon Fibre Composites. Optics and Lasers in Engineering, 44(11), 1185-1197 (2006)
[7] Naoki Wakabayashi, Takahiro Ide, Yasushi Aoki, New drilling technique for multilayered materials by single shot laser irradiation Applied Surface Science, 197-198, 873-876, (2002)
[8] W. S. O. Rodden, S. S. Kudesia, D. P. Hand, J. D. C. Jones, A comprehensive study of the long pulse Nd:YAG laser drilling of multi-layer carbon fibre composites, Optics Communications, Volume 210(3-6), 319-328, (2002)
[9] Renneboog. M. J., Advanced Composite Materials: An Overview, http://www.sciencemaster.com/columns/renneboog/renneboog_composite.php. (January 2009)
[10] M. Ghoreishi, D. K. Y. Low, L. Li, Comparative statistical analysis of hole taper and circularity in laser percussion drilling, International Journal of Machine Tools and Manufacture, 42(9), 985-995, (2002)
[11] N. Masmiati, P.K. Philip, Investigations on laser percussion drilling of some thermoplastic polymers, Journal of Materials Processing Technology, Volume 185, Issues 1-3, 30 April 2007, Pages 198-203
[12] K. C. Yung, S. M. Mei, T. M. Yue, A study of the heat-affected zone in the UV YAG laser drilling of GFRP materials, Journal of Materials Processing Technology, 122(2-3), 278-285 (2002)
[13] T. Young, D. O'Driscoll, Impact of Nd-YAG laser drilled holes on the strength and stiffness of laminar flow carbon fibre reinforced composite panels, Composites Part A: Applied Science and Manufacturing, 33(1), 1-9, (2002)
[14] D. K. Y. Low, L. Li, A. G. Corfe, Characteristics of spatter formation under the effects of different laser parameters during laser drilling, Journal of Materials Processing Technology, 118(3), 179-186 (2001)
[15] G. K. L. Ng, L. Li, The effect of laser peak power and pulse width on the hole geometry repeatability in laser percussion drilling, Optics & Laser Technology, 33(6), 393-402 (2001)
[16] Barsh. N, Korber. K, A. Ostendorf, K.H. Tonshoff, Ablating and Cutting of Planar silicon devices using femtosecond laser pulses, Applied Physics A 77, Material Science and Processing, 237-242. (2003)
[17] Chen, K., Yao, Y.L., Modi, V. Gas jet-workpiece interactions in laser machining, Journal of Manufacturing Science and Engineering, Transaction of ASME 122: 429-437, (2000)