MACHINING OF ADVANCED COMPOSITE

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ABSTRACT

In the laser drilling process, the quality of the drilled hole is the main task. A method of recognizing the effect on the quality of the laser drilled hole, by a few main process parameters needs to be developed, which seeks to improve the quality and explain the influence of each parameter. Twelve different holes have been drilled on two similar glass fiber composites with different laser power and pulse duration. Every hole then analyzed under optical microscope to inspect any comparable properties that can represent the quality of drilled holes itself. Preliminary result shown a significant different between comparable properties such as edge profile, burn mark diameter, heat affected zone and hole size prior to the increasing degree of parameters studied. The properties then evaluated by assigning a rating number from 1 to 10 to every comparable properties featured. Rating scheme conducted was highly based on comparative method between all holes. Laser power was then recognized as a most significant parameter in the laser drilling process.

ABSTRAK

Dalam proses penggerudian secara laser, kualiti lubang yang digerudi adalah paling utama. Satu kaedah mengenalpasti kesan terhadap kualiti lubang yang digerudi menggunakan laser oleh beberapa pembolehubah utama perlu diwujudkan, sambil meningkatkan kualiti dan menerangkan pengaruh setiap pembolehubah. Dua belas lubang telah digerudi keatas dua kaca gentian komposit yang sama dengan menggunakan kuasa laser dan masa pancaran yang berbeza. Setiap lubang kemudiannya di lihat menggunakan mikroskop optik untuk mengamati apa-apa ciri yang boleh membezakan lubang-lubang ini, yang seterusnya memperlihatkan kualiti pada lubang itu. Keputusan awal menunjukkan terdapat perbezaan yang ketara pada ciri-ciri pembeza iaitu profil pinggir lubang, tanda terbakar, zon terpengaruh haba dan saiz lubang akibat peningkatan tingkat pembolehubah yang dikaji. Ciri-ciri pembolehubah ini kemudiannya dinilai secara memberi markah dari nombor 1 hingga 10 kepada kepada setiap lubang yang dianalisa. Kaedah pemarkahan ini semata-mata berdasarkan kaedah perbandingan antara semua lubang. Kuasa laser kemudiannya dikenalpasti sebagai pembolehubah yang paling menonjol dalam penggerudian secara laser.

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LIST OF ABBREVIATIONS

ACM	Advance Composite Material
SEM	Scanning Electron Micrograph
CNC	Computer Numerated Control
TBC	Thermal Barrier Coating
PSM	Projek Sarjana Muda

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Manufacturing process nowadays require a more advanced machining technique that are mostly caused by the design requirements and difficult-to-machine materials such as tough super alloys, ceramics, and composites. The current traditional machining processes also tend to obsolete when it deals with complicated design shape and processing time requirement. As a result, manufacturers and machine design engineers turning to more advance machining processes. These machining processes utilizes electrical, chemical, and optimal sources of energy to bind, form and cut materials [5].

One of the mostly used advanced processes is a laser machining that use electrical energy to melt and vaporize the material substances. Since their invention in 1960, lasers have found diverse applications in engineering and industry because of their ability to produce high power beams. Laser applications include welding, drilling, cutting, scribing, machining, heat treatment, medical surgery and others. One of the principal advantages of laser cutting is its ability to cut very hard materials easily [10].

Basically, there are two common techniques used in drilling that were percussion hole drilling and trepanning. Percussion drilling is a process where multiple pulses are applied per hole to achieve the desired results. High speed on-the-fly drilling is a percussion type drilling process often used in drilling filter and guide vanes. Trepanning is a process by cutting large holes or contouring shaped holes. The one that are interested in this research are the percussion hole drilling [7].

A composite material is any material in which two or more separate materials have been combined to make a single construct having more desirable properties. For the purposes of this study, composite materials are those in which fibers or some type of linear structures, are bound tightly in a solid matrix, such as plastic or concrete. It been increasingly used in a variety of industries such as aerospace, automotive and electronic industries. This is due to their high strength-to-weight, stiffness-to-density and strength-to-density ratio [8].

Recently, a new term that define composite material as a more superior material in a lot of their mechanical and chemical characteristic has arise, it was Advanced Composite Material or ACM. ACMs are a much more recent and an entirely man-made 'take' on Nature's style. They consist exclusively of man-made specialty fibers bound in a matrix of specialty plastics. The variety of such materials is nothing short of spectacular, and the development and application of new ACMs are among the fastest-growing sectors of modern technology [8].

In the beginning of ACMs era, it was believed that, glass fibers composite are the first introductory product. Glass Fibers Composite or commonly known as Fiberglass is a composite materials in which extremely fine glass fibers are bound into a thick sheet of polyester resin. Relatively light and strong, fiberglass is one of the most generally useful and therefore most common of ACMs. There are several types of glass fiber and a variety of glass and other fibers see application in ACMs. Glass fibers are useful because of their high ratio of surface area to weight [9].

1.2 PROBLEM STATEMENT

Since the composite material already well known with great mechanical properties, the only problem that might limits the use are their machinability properties. Any machining processes that use inappropriate tools such as a band saw could damage the alignment of the fiber and then reduce their special mechanical properties. However, for a machining process such as cutting may not be a major problem due to the presence of various cutting tools, but the one that might gave a problem is in drilling process [15].

Conventional drilling actually not quite appropriate to drill a composite, since it produce a bad quality of hole with limited size, hence the only option left are through laser machining. Laser machining could drill a hole in very small diameter size, but it will require well controlled laser parameters in order to produce a high quality of hole. Defects that could occur due to inappropriate parameters setting are like overheating, fiber swelling and large affected zone. Most of the defects are caused by the rapid heating of the laser beam [4].

1.3 OBJECTIVES

The objectives of this experiment are:

- To identify the laser parameters that has the most significant effect on composite during laser drilling.
- To find out the highest quality of hole that can be drilled by current available laser machine.

1.4 SCOPE OF THE PROJECT

This research will focus on laser drilling process and carbon fiber composite. Laser parameters considered are their laser power and pulse duration. Different hole sizes will be made by adjusting these parameters. The effect of each parameter on hole's quality will be investigated under optical Microscope. Finally, the most significant parameter and how they affect the hole's characteristic will be identified.

1.5 ORGANIZATION OF THESIS

This thesis consists of five chapter including Chapter 1. Chapter 1 introduces the project background, related problems, objectives of the project, and the scope of the project. Chapter 2 reviews some related literature, which is gathered from different sources. Chapter 3 describes detailed methodology of executing the project. Chapter 4 presents and discusses experimental results and data analysis. Finally in Chapter 5, conclusions are drawn and some recommendations are proposed for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 STUDY OF LASER DRILLING MECHANISM

Since the introduction of drilling technique using laser application, a lot of manufacturing processes become easier, faster and more flexible. However, in order to improve the laser drilling technique in term of their power usage and hole quality a lot of researchers have conducted a different kind of experiment regarding the laser drilling technique. Their research were mainly focus on indentifying possible parametric optimization in laser drilling, modeling the laser drilling mechanism and studying the effect of laser drilling on different types of material [1]. Each researcher also applied a different approach in analyzing their experimental data, mathematical formulation and qualitative analysis. Hence, their result was presented in different view but still in logical manner. [1-4]

2.1.1 Parametric Study to improve Laser Hole Drilling Process [1]

In 1996, B.S Yilbas have conducted parametric study in improving laser hole drilling process. In his thesis titled "*Parametric Study to improve Laser Hole Drilling Process*", he uses three different materials, stainless steel, nickel and titanium as a drilling subject. The experiment designed to give insight into how and why variation in laser parameters and materials affecting the resultant hole quality when drilling [1].

The hole quality also being viewed in term of few properties with different order, it was barreling size, quantity of resolidified material, surface debris, inlet cone, exit cone, taper and mean hole diameter (Figure 2.1). While, in term of parameters B.S Yilbas pays his attention on the laser pulse's length, focus setting, energy and material thickness. The experiment was done through comprehensive analyses that include both quantitative and qualitative analysis method [1].

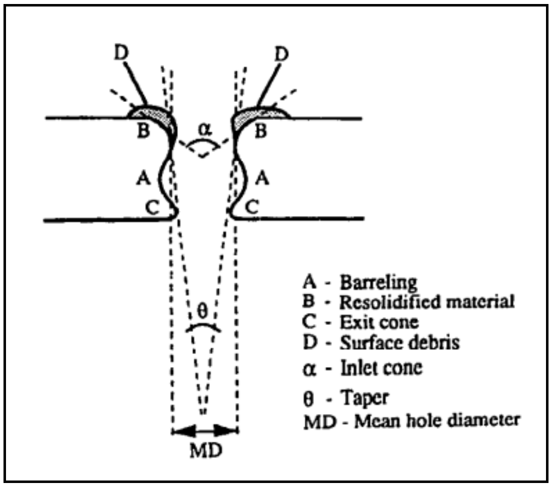

Figure 2.1: Features of laser drilled hole

Source: BS Yilbas (1996)

As a final conclusion, B.S Yilbas stated that the material thickness are the most significant parameter that affect the quality of hole itself, followed by a combinational parameters between pulse length-material thickness, then pulse length-focus setting-material thickness [1]. Furthermore, Yilbas also has made a different conclusion regarding each parameter varied as below:

- Pulse Length: The improvement of hole quality by varying the pulse length can only be found significant on mean hole diameter and inlet cone. In the case of nickel, pulse length reduce the amount of inlet cone, taper and mean hole diameter. Resolidified material reduces with a reduction in the pulse length for titanium [1].
- Focus Setting: The effect of focus setting is very significant and more critical than pulse length. Hole geometry can be improved by increasing the focus

setting above the workpiece surface with the local range employed in the present study. However, the optimum focus setting for each material varies, which may be due to the thermal properties and the coupling effect of the focus setting and power intensity distribution on the workpiece surface [1].

- Energy: An increase in pulse energy increases the mean hole diameter. Inlet cone, barreling and taper increase linearly with increasing energy for stainless steel. The effect of energy on the overall quality of the holes is significant for all of the materials examined [1].
- Thickness: The effect of thickness is found to be very significant in most cases. The common trend is that the amount of taper decreases as the thickness increases [1].

Therefore, from B.S Yilbas work, a lot of new information about laser drilling mechanism successfully discovered. Although this research was done with three different materials only, their explanation about a different geometry in different holes that are drilled through a different parameter setup, has improved the current knowledge about how the parameters will affect the hole's geometry. Hence, it will make ease for other researchers to set up their drilling parameters like in these work.

2.1.2 The Laser Drilling of Multilayer Aerospace Material System [2]

Another experiment that has been conducted regarding laser drilling mechanism is by A. Corcocran, L. Sexton, B. Seaman, P. Ryan and G. Byrne. Their journal that titled '*The Laser Drilling of Multilayer Aerospace Material System*' their experiment were largely focused on laser drilling in aerospace field. The objective of the experiment is to identify the parameters that have the most significant effect on the metallurgical quality of laser drilled-holes and thus optimize the process [2].

Material used was called Rene80 (Figure 2.2) that has been sprayed by Thermal Barrier Coating (TBC). Rene80 is superalloy materials that are being used for aircraft gas turbine blade. It commonly works in temperature range from 760 to 982 °C with high cyclic loading [11]. Due to the very high working temperature it require a series of cooling channel on the turbine blade that can increase heat dissipation and thus increase the blade's serving life. Hence, in order to produce a high quality cooling channels with accurate dimensions, laser drilling process applied.

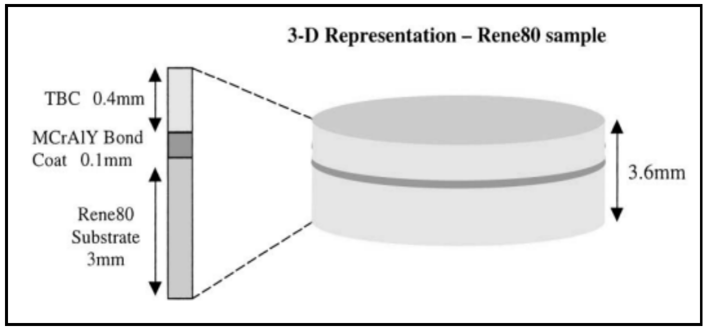

Figure 2.2: 3D representation of Rene80

Source: A. Corcocran (2001)

While, for the parameters studied, they investigate the laser's pulse energy, pulse length, pulse duration, TBC density and assist gas pressure. For easiness of the experiment also, they have outlined parameters involved in their experiment as depicted in Figure 2.3. There are four main parameters in laser drilling which is laser type, assist gas, laser pulse and optics.

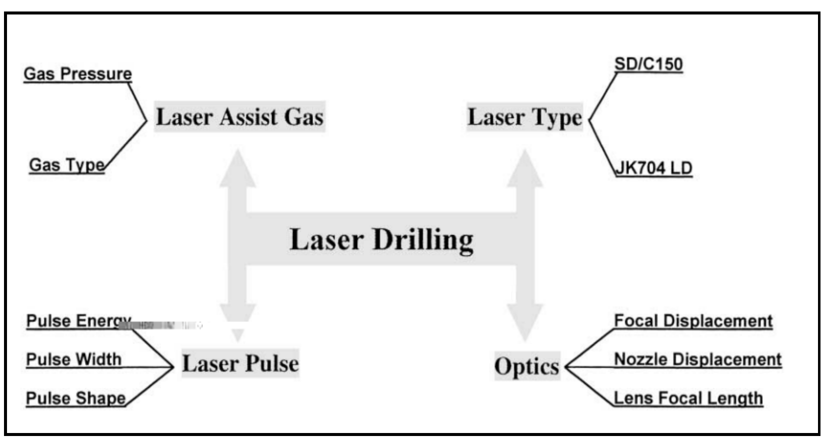

Figure 2.3: Laser process parameters

Since the experiment was focus on laser drilling parameter and the effect of parameters change, so the result mostly discussed in parameter effect. Their conclusions are outlined as below.

- Pulse energy. High pulse energy reduces the level of microcracking in the percussion laser drilled hole, however, reduces the level of adherent remelt material remaining on the side of the laser-drilled hole. Thus a conflict arises where one wants to minimize both these output responses. It has also been found that interaction occurs between pulse energy and pulse width [2].
- Pulse width. It has been demonstrated that a shorter pulse width reduces the severity of microcracking and delamination significantly [2].
- Pulse shape. Remelt layer thickness was generally unaffected by variation in the pulse shape in comparison with delamination and microcracking, a treble pulse shape proved superior [2].
- Gas Pressure. The higher gas pressure, 70 psi, was found to minimize all three output responses-delamination, remelt layer thickness and microcracking [2].

Obviously, the conclusions explain the effect of changing parameter only on three observed properties, which were remelt layer delamination, thickness and microcracking. From the conclusion they have made, it shows that some of the hole's defects are controllable and could be reduced. Through the results, it can improve product such like Rene80 with better design, less defects and higher machinability.

However, since this experiment only use a specially manufactured product for aerospace field as their test specimen; it has limited useful information for other field other than laser drilling mechanism with detailed drilling specifications.

2.1.3 Application of 3D Heat Flow Model to Treat Laser Drilling of Carbon Fiber Composites [3]

CF Cheng, YC Tsui and TW Clyne have conducted an experimental analysis of Laser Drilling mechanism on Carbon Fiber composite and metallic materials. A numerical finite difference heat flow model also developed and then compared with true experiment. They also studied the source of difference that arises between these two results and made their best assumption regarding that phenomenon. They used a same parameter for every hole been drilled with maximum average laser power [3].

Comparable properties of every hole that have been drilled (Figure 2.4) and modeled then inspected under Scanning Electron Micrograph (SEM) machine and through computerize data from the heat flow model. The properties that they inspect with both methods is the hole size, swelling condition, matrix melting and volatilization. Below is a picture from heat flow model with different materials (Figure 2.4) [3].

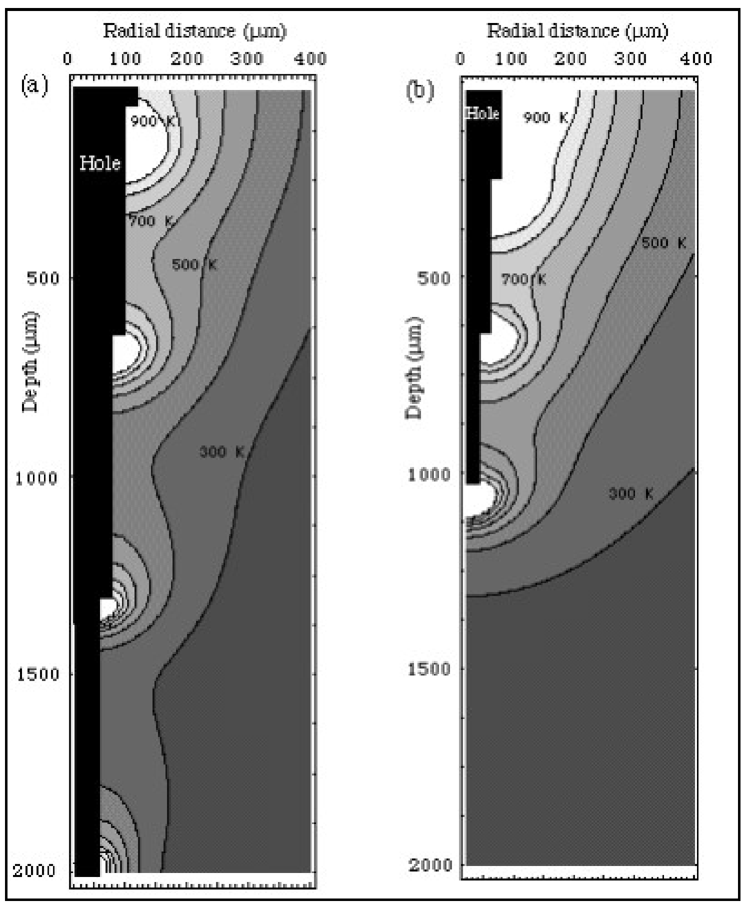

Figure 2.4: Predicted thermal field for a) aluminum and b) copper [3]

The conclusion that CF Cheng and other researchers draw out through this comparison and simulation process are like below:

- For composite specimens, very good agreement has been observed between measured and predicted hole shapes (Figure 2.4). It seems likely that melt ejection is much less pronounced for composites, in which the molten matrix is highly viscous and constrained by surrounding fibers [3].
- It is thought that the major source of error is melt ejection during drilling, which is not simulated in the current model. Experimental data suggest that such ejection is more significant with low density, low conductivity metals then with denser, more conductive ones. There is also some evidence that it is may be more pronounced when the hole penetrates completely through the specimen. These suggestions are consistent with the simple concept of melt ejection being controlled primarily by momentum transfer from the gas phase to the molten zone [3].

Following those result and conclusion that have been made, it show that, use of heat flow model could results in almost similar with real experiment but will need a great deal in modeling the drilling mechanism, a few assumption also should be precisely assigned. Through, the almost similar mechanism between real and simulated experiment it can help other researchers in understanding what was happening beneath the drilled area.

2.2 STUDY OF COMPOSITE MATERIALS

Since this work were about laser drilling of composite materials, so it also important to know a little much about composite behavior to a certain process. Hence, it will help the analysis process in classifying a certain occurrence on drilled composite. In order to stay in fact with trusted sources, information was only being taken from published journal or thesis.

2.2.1 Fiber Swelling During Laser Drilling Of Carbon Fibre Composites [4]

The research was conducted by K.T. Voisey, it mainly focused on swelling condition that often occurs on composites materials during certain machining process. So, in order to investigate about how swelling condition occur, Voisey conduct a laser drilling experiment on 3 different carbon fibers without changing any variable on laser parameters. Then, the laser was inspected under Scanning Electron Micrograph (SEM) for more clear view of the hole's geometry. Raman Spectroscopy analyses also applied in order to make the result are in quantitative values [4]. While, as an additional method a heat flow model also constructed as precise as it can be for comparison with real laser drilling mechanism. Below are properties of carbon fiber used (Table 2.1) and values for heat flow modeling (Table 2.2).

Table 2.1: Physical and mechanical properties of carbon fiber used

Fiber	Precursor	Density ($g\ cm^{-3}$)	Diameter (µm)	Axial Young's modulus (GPa)	T_{HT} (°C)	Carbon Content (%)
T300	PAN	1.76	7	230	1300	92-95
HM	PAN	1.86	8	360-400	1800	>99
P100	Pitch	2.15	10	690-720	2500	>99

Table 2.2 : Thermophysical properties used in model

	T300	HM	P100
Sublimation Temperature (K)	3650	3650	3650
Density ($g\ cm^{-3}$)	1.76	1.86	2.15
Thermal Conductivity ($W\ m^{-1}\ K^{-1}$)	24	105	520
Specific Heat ($J\ kg^{-1}K^{-1}$)	750	710	614
Latent Heat of Sublimation ($MJ\ Kg^{-1}$)	45	43	37

Results that are come out from SEM machine are quite expected since it was a different type of carbon fibers (T300) as depicted in figure 2.5. Swelling condition could found most on figure 2.5a, it caused by the type of fiber that have higher thermal conductivity and thus elongated to the fiber direction. While for other two types fiber (HM & T1000) (Figure 2.5b and 2.5c), it show less effect of swelling occurrence and their hole shape also less defined.

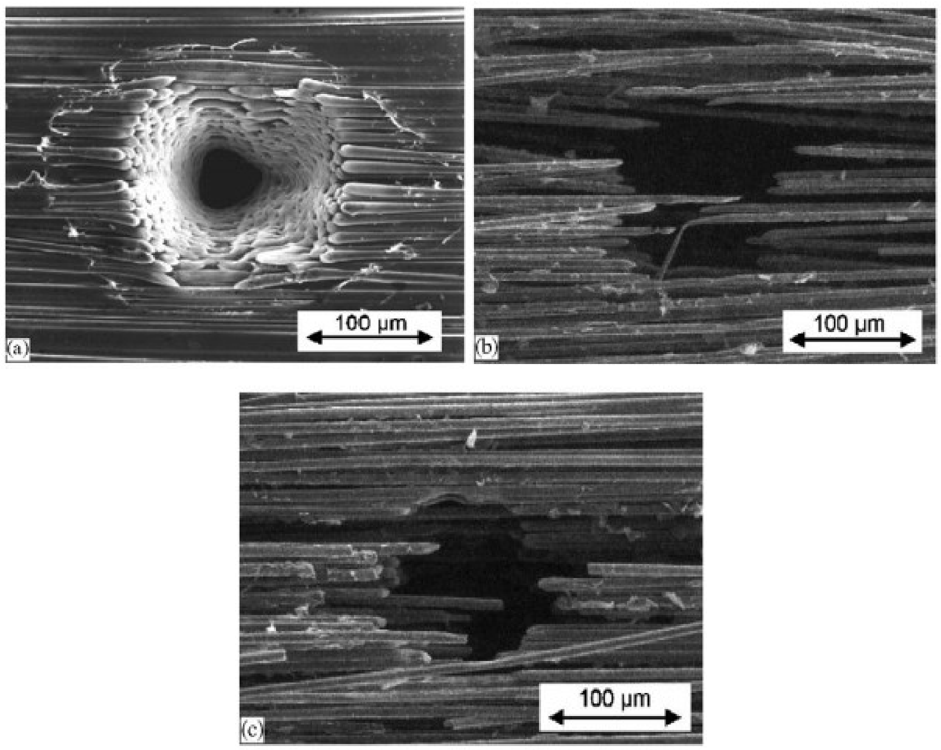

Figure 2.5: SEM micrographs of laser-drilled holes in a bundle of (a) T300 fibres, (b) HM fibres, and (c) P100 fibres.

Source: K.T. Voisey (2005)

In conclusion, Voisey stated a few main points regarding swelling phenomenon and their connection with the laser drilling mechanism. He concluded that,

- It is proposed that the substantial fibre swelling observed around laser-drilled holes in T300 fibres is associated with rapid volatilization of impurities within the fibre, occurring simultaneously with the structural ordering