THE STUDY OF LASER DRILLING OF POLYMERIC MATERIAL

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ABSTRACT

Polymeric materials is widely used in many applications due to its advantages character but unfortunately, this polymeric material are fragile and not rigid for their manufacturing process. In order to overcome this problem, the non-contact laser drilling process is the best solution. However, poor quality of drill has been rise as critical issues in industry due to the improper setting of drilling parameters. The purpose of this study are to study the possibilities of low power laser on drilling polymeric materials and to identify the optimum parameters in order to obtain a good geometry of drill hole. There were three different test to be analysed in this analysis that are depth, kerf width and angle for the laser drilling process. A polymeric specimen with the thickness of 3 mm were used in this analysis. The Taguchi method has been applied in this analysis. The results show that the optimum parameter for the standoff distance is 34 mm while for the optimum drilling time is 10 s is needed for the depth, kerf width and angle analysis for obtain the best geometry of the hole. Confirmation test has been done to prove this findings. It is proved that a low power laser drill machine can be used to drill the polymeric materials and the parameters stated were the optimum parameters to be used in order to obtain a good geometry drill hole.

ABSTRAK

Bahan polimer digunakan secara meluas dalam banyak aplikasi disebabkan sifat-sifat kelebihan tetapi malangnya, bahan polimer ini rapuh dan tidak tegar untuk proses pembuatan. Dalam usaha untuk mengatasi masalah ini, proses penggerudian tanpa sentuh laser adalah penyelesaian yang terbaik. Walau bagaimanapun, kualiti penggerudian laser telah menimbulkan isu-isu kritikal dalam industri kerana penggunaan parameter penggerudian yang tidak wajar. Tujuan kajian ini adalah untuk mengkaji kemungkinan laser kuasa rendah untuk menggerudi bahan polimer dan untuk mengenal pasti parameter yang optimum untuk mendapatkan geometri yang terbaik bagi lubang gerudi. Terdapat tiga ujian yang berbeza untuk dianalisis dalam analisis ini iaitu kedalaman, lebar garitan dan sudut untuk proses penggerudian laser. Satu sampel polimer dengan ketebalan 3 mm telah digunakan dalam analisis ini. Kaedah Taguchi telah digunakan dalam kajian ini. Keputusan menunjukkan bahawa parameter optimum untuk jarak ketinggian adalah 34 mm manakala bagi masa penggerudian optimum adalah 10 s diperlukan untuk analisis kedalaman, lebar garitan dan sudut untuk mendapatkan geometri yang terbaik lubang. Ujian pengesahan telah dilakukan untuk membuktikan penemuan ini. Ia membuktikan bahawa kuasa laser mesin gerudi yang rendah boleh digunakan untuk menggerudi bahan polimer dan parameter yang dinyatakan adalah parameter optimum untuk digunakan dalam usaha untuk mendapatkan geometri yang terbaik bagi lubang gerudi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

dB	Decibel
mm	Millimetre
Mpa	Megapascal
μm	Micrometre
η	Signal to noise ratio
$\sum$	Sum
s	Second
v	Volt
W	Watt

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASTM	American Standard for Testing and Material
CO_2	Carbon Dioxide
DOE	Design of Experiment
EM	Electromagnetic
F	F-value
MS	Mean of Square
MEDM	Micro-electro discharge Machining
Nd	Neodymium
OA	Orthogonal Array
P	P-value
S/N	Signal to Noise
S.O.D	Standoff distance
SS	Sum of Square

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Laser machine has been used in industry for many applications such as laser cutting, laser drilling and laser marking. Nowadays, laser is one of the important method used for drilling material and laser drilling process is one of the versatile applications of laser machine in industry. Laser beam usually used to drill small and precise specimen for assembly parts. However, poor quality of drill has been rise as critical issues in industry due to the improper setting of drilling parameters. In order to solve this problem, a research study on the impact of drilling parameters on quality of drill was carried out. In this research, the main objective will focus on the impact of the drilling parameters of a specify machine on the quality of drill on polymeric material (pure polymer).

1.2 RESEARCH BACKGROUND

The term of laser is an acronym for light amplification by stimulated emission of radiation. Laser radiation, in simple terms, is light and more specifically, it is an electromagnetic wave generated by a laser-active medium. In industrial laser technology, CO_2 gas and the element neodymium (Nd), in particular, are of primary importance as laser-active materials (Wirth, 2004).

The CO_2 laser have found many applications in manufacturing due to their capacity for high material removal rates in processing many classes of engineering materials and geometric flexibility. However, laser machining still relies largely on trial and error calibrations to determine appropriate operational parameters such as laser power, standoff distance of the workpiece and the assisting gas types.

Percussion drilling is accomplished by focusing the laser beam to a spot equal in diameter to the hole to be drilled. Both the laser beam and the workpiece are fixed in position while the hole is being drilled. The laser is operated in a pulsed mode, each pulse removing a certain volume of material (Masmiati et al., 2007).

The carbon dioxide (CO_2) gas laser is one of the most versatile for materials processing applications .Whether laser drilling with CO_2 or other assist gas, the principles employed are basically the same. The beam from the laser is focused on to the surface of the material being cut by means of a lens. The focused laser beam heats the material surface and a very local melt capillary is quickly established throughout the depth of the material. The carbon dioxide (CO_2) laser are frequently used in industrial applications for drilling metal, cutting metal and welding such as used in aircraft and automotive industries to trim, drill holes and weld sheet metal parts.

In laser drilling, drill quality mainly depends on many kind of parameters. The basic parameters in laser drilling the laser pulse length, the pulse energy, the focus settings of the focusing lens and the workpiece thickness and thermal properties. All parameters should be considered in order to get the maximum optimization quality of drill desired.

Carbon dioxide (CO_2) laser drilling on polymeric material is one of evolving industrial application. Laser applications in polyethylene drilling have grown considerably in many industries since it is now possible to achieve a superior quality finished product along with greater process reliability. The aim of this study is to investigate the drilling quality on polymeric material when different pulse energy and laser pulse length are used on the CO_2 laser.

1.3 RESEARCH OBJECTIVES

The objectives of this thesis are:

i. To study the possibilities of low power CO_2 laser on drilling polymeric material with the influence of the processing parameters in order to obtain a good geometry and desire hole dimensions.

ii. To identify optimum parameters for laser drilling on polymeric material.

1.4 RESEARCH SCOPE

The research scopes for this thesis are:

i. Conduct the analysis with different parameters which standoff distance and drill time.

ii. Use sample of polymeric material to be drill on CO_2 laser drilling system.

iii. Analyze effect of parameters of drilling process by identify the depth, kerf width and angle.

1.5 PROBLEM STATEMENT

Acrylic, polyamide, PVC etc are some of the polymeric materials widely used in many applications such as pharmaceutical. Among the advantages of polymeric materials are, they are chemical resistance, easy to workout, can be cheaply mass produced and some of them are non-toxic which is safe to be used on clinical materials. However, these polymeric materials are very fragile and not rigid which restricted their manufacturing processes. For example, conventional drilling may not be suitable to drill a hole on a soft non-rigid polyamide.

Therefore, a non-conventional process which is non-contact approach is the only solution to work out these materials. One of the example of non-contact process is by laser machining. Laser machining can be of drilling and cutting which is seen suitable to be used on soft materials. On top of that the process itself superseded conventional drilling in terms of mass production capability. CO_2 laser drilling may be used to drill a hole on the polymeric materials. This is because CO_2 laser system is cheap to run while producing of equal machining quality with the rest YAG and fiber laser system.

However, there is still lack of know-how knowledge to get the best parameters to drill certain polymeric materials. A lot of researches needed to be done in order to get an optimum machining characteristics on each polymeric materials. Therefore, this research is intended to focus on polymeric material drilling studies. The studies include drilling polymeric materials and observation of the drilling quality.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There are some previous studies on laser drilling for polymeric material based on the CO_2 laser drilling is being reviewed in this chapter. Through this paper, the description of the CO_2 laser drilling and the parameter of drilling process has being discussed in this chapter.

2.2 MANUFACTURING PROCESS

The general definition of manufacturing process is a process which are applied in the industrial environment with the aim to transform materials or objects to satisfy predetermined standards of form and function. The manufacturing process treated here are process aimed at making geometrically defined objects. More specifically this means that these process aimed at either creating form out of formless material, changing the shape of objects, connecting objects, fixing layers on objects and changing the material characteristics of objects (Florusse, 1992).

Manufacturing processes are usually carried out with a machine. A machine is defined here as an installation aimed at providing the energy and the capability of moving and positioning the tools which transform the material by some physical process. Tools are the material objects or the physical phenomena which enable a machine to carry out the material transformation (Skinner, 1969).

2.3 DRILLING PROCESS

Drilling is a major and indispensable machining operation widely used in manufacturing industry. According to a recent ClRP survey, drilling accounts for about 22% of all the processing time spent in material removal by the many different machining operations. It is therefore not surprising to note that this operation has been the subject of continual research and development (Armarego et al., 1998).

The drilling operation is also frequently a preliminary step for many machining processes like boring, tapping and reaming. It is estimated that approximately 250 million twist drills are used annually by US industry alone. Hence, a considerable amount of money is spent on drilling tools each year. For instance, according to the US Department of Commerce, approximately $1.62 billion was spent in the production of drill bits in the US in 1991. It was also estimated that drilling accounts for nearly 40% of all metal removal operations in the aerospace industry. Even for a small jet fighter, more than 245,000 holes need to be drilled (Ertunc et al., 2001).

2.3.1 Machine Tools of Drilling Process

In manufacturing process, drilling has many types of machine tools which are press drill, milling, laser drilling and super drill electro-discharge drilling.

2.3.1.1 Hand Drill

Hand drill or press drill is commonly used in our daily life. But it has many unreasonable factors especially in security aspects. Unreasonable designed hand drill will do harm to users. Hand drill is the best seller in the electric tool industry which is widely used in architecture, decoration, furniture etc to punch or make a hole in an object. Hand drill can be classified as household type and professional type. Household hand drills call for a lower demand in service life, work efficiency, work accuracy. It is under mass production, accounts for about (70~80) percent of electric products. The other (20-30) percent are professional type, this type has a higher demand over household ones in work accuracy, work reliability, service life and performance.

2.3.1.2 Laser Drilling

Laser drilling has been applied widely in industry due to the high processing speeds, exact tolerances, small dimensions and material flexibility that are achievable. Laser drilling involves a stationary laser beam which uses high power density to melt or vaporize material from the workpiece. Due to the thermal nature of laser drilling, holes can be made in materials, including ceramics, hardened metals and composites that are difficult to machine conventionally (Sheng et al., 1994).

2.3.1.3 Micro-electro discharge

Micro-electro discharge machining (MEDM) using water as a working fluid is systematically studied to find its characteristics. As a result, the unique advantages of high removal rate, low electrode wear and consequently higher working efficiency, without formation of carbonaceous materials are found under optimum experimental conditions, as compared with the case when kerosene is used. This was achieved by the choice of suitable combinations of electrode and workpiece materials and electrode polarity. Use of a tungsten electrode with straight polarity is exceedingly good with respect to high removal rate (Kagaya, 1986).

2.3.1.4 Milling

Peripheral milling is a widely used material removal process in automobile, aerospace and die or mold manufacturing industries for roughing and finishing profiled components. In peripheral milling, many undesired issues such as cutter breakage, cutter wear, chatter and surface error are greatly dependent on cutting forces, whose prediction is thus an essential subject of milling simulation (Yang et al., 2011).

2.4 LASER DRILLING

Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser is light of special properties, light is electromagnetic (EM) wave in visible range. Lasers, broadly speaking, are devices that generate or amplify light, just as transistors generate and amplify electronic signals at audio, radio or microwave frequencies. The light must be understand broadly, since lasers have covered radiation at wavelengths ranging from infrared range to ultraviolet and even soft x-ray range (Chen et al., 2011).

In principle, laser drilling is governed by an energy balance between the irradiating energy from the laser beam and the conduction heat into the workpiece, the energy losses to the environment, and the energy required for phase change in the workpiece (Mello, 1986).

Material removal occurs through either melting or vaporization of the workpiece material to form a hole. Additional energy losses can occur due to a number of phenomena, including superheating of the molten layer above the melting point, partial absorption of laser energy due to plasma formation above the erosion front, and reflection of beam energy from the workpiece surface (Yilbas et al., 1990).

There are various benefits to be gained from using lasers as cutting tools, these including no tool wear, ease of automation, small heat-affected zones, narrow kerf (cut) width and virtually no restrictions on the geometries that can be cut. Unfortunately, there is a high initial outlay on the laser, which can minimize their appeal (Sahin et al., 1994).

Laser drilling is a common commercially-developed process for metal working. There have been several research investigations conducted in the past on reducing the drilling time, the input energy, and the intensity of the laser irradiation. Laser drilling into electronic components was studied by Taneko et al. who showed that the use of a high peak pulsed CO_2, laser improved the drilling quality (Yilbas et al., 1995).

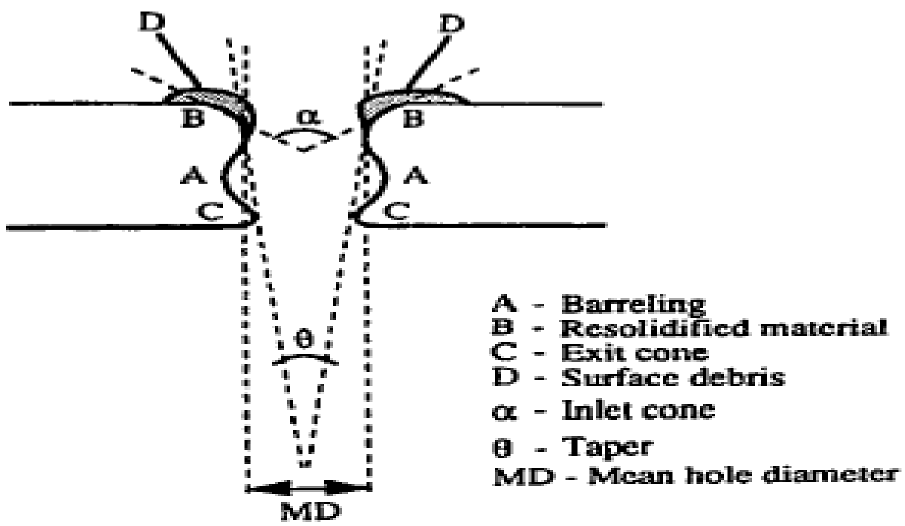

Figure. 2.1: Features of laser-drilled holes

Source: Yilbas (1997)

The increasing demand of laser in material processing can be attributed to several unique advantages of laser namely, high productivity, automation worthiness, non-contact processing, elimination of finishing operation, reduced processing cost, improved product quality, greater material utilization and minimum heat affected zone (Mordike, 1993).

High power CO_2 lasers or Nd: YAG lasers may also be used to drill holes. Figure 2.2 shows the basic set used in laser drilling, which is not very different from that used for other laser machining processes. Laser drilling can be done in both pulse and continuous wave modes with suitable laser parameters. The advantage of the laser is that it can drill holes at an angle to the surface – fine lock pin holes in Monel metal bolts is an example. Mechanical drilling is slow and causes extrusions at both ends of the hole that have to be cleaned. Mechanical punching is fast but is limited to holes further than 3 mm diameter. Electro chemical machining is too slow at 180 sec per hole but does give a neat hole. Electro discharge machining is expensive and slow at 58 sec per hole. Electron beam drilling is fast at 0.125 sec per hole but needs a vacuum chamber and is more expensive than a YAG laser processing. In comparison, a YAG laser takes 4 sec per hole to outsmart all other methods (TanPko et al., 1990).

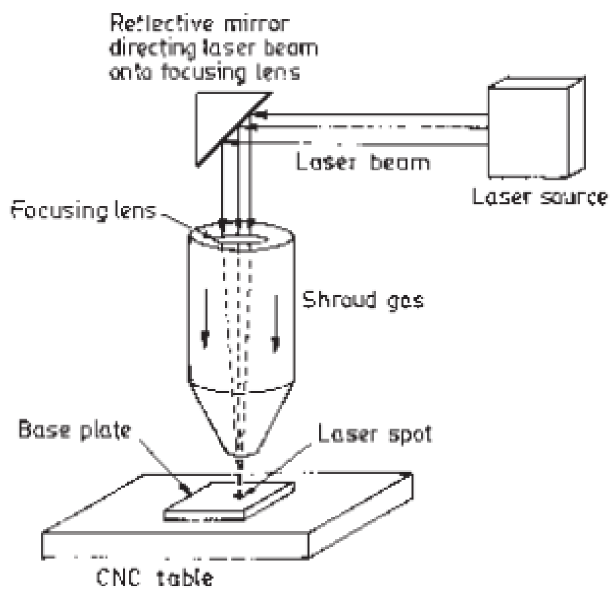

Figure 2.2: Basic system hardware for pulse laser drilling of thin sheets of metal, semiconductor or polymers

Source: Mordike et al. (1993)

2.4.1 Anatomy of Laser Drilling Machine

The laser drilling system used in the experiment is a 100 W pulsed CO_2 laser with a wavelength of 10.6 mm. Figure 2.3 shows the structure of a CO_2 laser drilling system, including a CO_2 laser, the optical system (delivery), the feeding system, the observer system, the base and the control system. The optical system delivers the laser beam (Fenoughty et al., 1994).

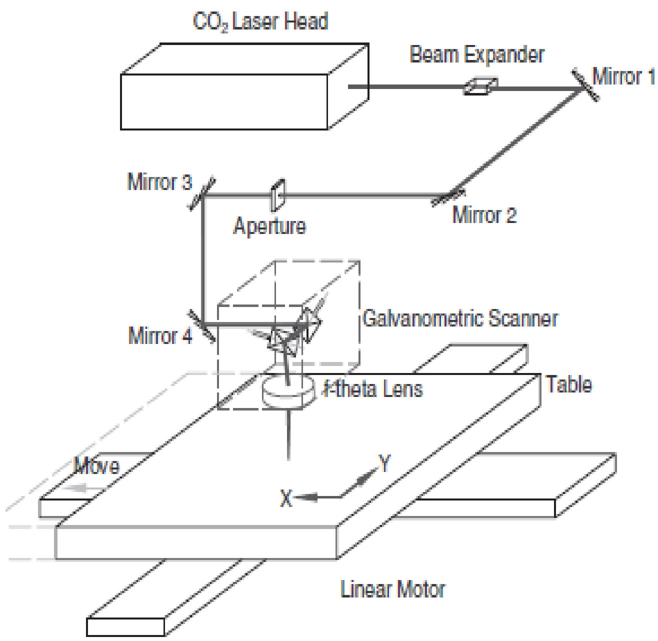

Figure 2.3: Schematic representation of the CO_2 laser drilling system used in experiment

Source: Chen et al. (2007)

The optical system includes a beam shaper (aperture and beam expender) system, which can improve the quality of the drilling and change the diameter of the holes. Additionally, the scanning technology can increase the speed of drilling in this optical system. The laser beam is focused using a lens with a focal length of 80 mm. The focal plane is positioned on a material surface that is fixed on a vacuum chuck, and the workpieces are placed on an XY movable table. The table is driven using a linear servo motor, which has a high positioning accuracy of ±5 μm. In this system, the scanning area of the scanner is 50 x 50 mm. The focal length of the F-θ lens and the scanning angle of the scanning mirror lens can be adjusted (Di Ilio et al., 1989).

2.4.2 Laser Types

There are two commonly used laser types in industry today. These are the carbon dioxide (CO_2) laser and the neodymium yttria-alumina garnet (Nd-YAG) laser, the former being a gas laser and the latter a solid state laser. CO_2 lasers tend to be high powered (up to 3 kW) and are used in the continuous-wave mode. The YAG lasers are used in the pulsed mode and can achieve peak powers of 7-10 kW, although their average power is of the order of 400 W. The use of these lasers in the pulsed mode actually enables some cooling of the material being processed during the time interval between the pulses. The wavelengths of the light sources are different also, CO_2 lasers having a wavelength of 10.6 μm and YAG a wavelength of 1.06 μm. The wavelength of the YAG laser is transparent to glass so that it is not an ideal candidate for the cutting of glass-fibre-reinforced materials (Muller et al., 1989).

There are various factors that have to be taken into account when using lasers as cutting tools, the main considerations including the absorption of the energy and how this varies with the temperature of the material, the thermal diffusivity of the material (as this controls how rapidly the heat is conducted away from the cutting zone) and thirdly the reaction temperature (of melting / vaporization / decomposition). There are other considerations such as the dimensions of the heat-affected zone, which is the zone where the capability of stress transfer from the matrix to the fibres is reduced or absent (Dell'Erba et al., 1992).

A preferred method of cutting carbon composites is with the pulsed YAG laser. Work done by Lawson (Laser Machining Inc.) on the cutting of graphite, glass and aramid (Kevlar) composites has shown that 3 mm thick graphite/epoxy can be cut faster and more cleanly when using a pulsed YAG laser (4 J, 30 pps, 2.5 mm/s speed) than when using a 5 kW CO_2 laser. A pulsed mode 500 W CO_2 laser has also been tried by Tagliaferri et al. (Naples/Milan Univ.), who found that a lower specific energies (power/spot diameter x velocity) a cavity is created due to the rapid vaporization of the (polyester) resin, which in turn interacts with the fibres, fracturing them into minute fragments: thus 'cutting' is achieved. At higher energies a keyhole situation occurs due to the vaporization of the fibres. The conclusion of this work was that a YAG laser should be used to lower the interaction time whilst maintaining the other parameters, to optimize the process. The carbon fibres absorb the YAG laser irradiation well and the high peak powers/short pulses minimize the damage to the matrix. Flaum and Karlsson (NDRI Sweden) agree with this approach, unless the laminate is thin (less than 2 mm) or the power is high (greater than 1 kW) (Lawson, 1986).

2.5 CO_2 LASER

Carbon dioxide lasers are being increasingly used in the aircraft and automotive industries to cut, trim, drill hole and weld sheet metal parts. Compared with other conventional mechanical processes, laser cutting removes little material, involves highly localized heat input to the workpiece, minimizes distortion, and offers no tool wear (De Iorio et al., 1987).