THE EFFECT OF ASSIST GAS ON THE SURFACE ROUGHNESS FOR CARBON DIOXIDE LASER CUTTING PROCESS

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ABSTRACT

This study focuses on the effect of assist gases on the surface roughness for Carbon Dioxide (CO_2) laser cutting process. The analysis of the surface roughness has been determined by Surfcom 130A surface roughness tester which it place in laboratory. The material used for this experiment is acrylic sheet with 2.5 mm thickness. In this process the cut quality is very important. The parameters in laser cutting are cutting speed, keft width, laser power, chemistry of gas, nozzle exit parameter, nozzle design, thickness of the specimen and surface quality. In oxygen assist laser cutting, the gas plays two roles, one is to generated additional thermal energy during penetration and second role is to supply the shear force to the gas boundary to eject the molten metal formed during the cutting process. However, for this study, two parameters are selected. There are type of assist gas and gas pressure. Finally, the result show that the no assist gas with the lower pressure bars at certain speed is better quality on surface roughness cutting.

ABSTRAK

Kajian ini memfokuskan kepada kesan gas bantuan pada mesin laser konvensional pancaran karbon dioxida. Untuk menganalisis kekasaran permukaan bahan telah ditentukan oleh alat penguji kekasaran Surfcom 130A yang terdapat di dalam makmal. Antara bahan yang digunakan untuk melaksanakan eksperimen ini adalah lembaran plastik jenis akrilik yang bertebalan 2.5 mm. dalam proses ini kualiti pemotongan laser adalah sangat penting. Pemilihan aspek parameter dalam permotongan laser adalah seperti menentukan kelajuan memotong, lebar kesan bahan yang dipotong, kuasa laser, bahan gas laser yang digunakan, ketinggian muncung pemancar dengan bahan, bentuk pemancar, ketebalan bahan dan kualiti bahan. Penggunaan gas oksigen membantu dalam pemotongan laser, gas bantuan memainkan dua peranan dalam eksperimen ini, pertama sebagai tenaga tambahan haba semasa proses penembusan dan kedua sebagai pembekal daya potongan semasa mengeluarkan plastik lebur yang terbentuk diantara celahan potongan. Walaubagaimanapun, di dalam experimen ini, dua parameter yang dipilih iaitu jenis gas bantuan dan tekanan gas yang digunakan. Akhir sekali, keputusan menunjukkan tanpa gas bantuan berserta tekanan gas rendah pada kelajuan tertentu adalah lebih baik kualiti permukaan pemotongannya.

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LIST OF SYMBOLS

CO_2	: Carbon Dioxide
Ra	: Average surface roughness
Rz	: Average maximum height
Rmax	: Maximum roughness depth
µm	: Micrometer
ns	: Nano per second
K	: Kelvin
C	: Celsius
L	: Length
kPa	: KiloPascal
kW	: KiloWatt
MPa	: Mega Pascal
LCD	: Liquid crystal display
%	: Percent

LIST OF ABBREVIATIONS

ANOVA	: Analysis of variance
DOE	: Design of experiment
CNC	: Computer numerical control
FYP	: Final Year Project
HAZ	: Heat-affected zone
PCNC	: Personal computer numerical control
Std. Err.	: Standard error
UMP	: University Malaysia Pahang
RSM	: Response surface methodology
PVC	: Polyvinyl chloride
CW	: Continuous wave
NG	: Non-gas
AD	: Anderson-Darling
Vs	: Versus
ASTM	: American Society for Testing and Materials
Std.	: Standard

CHAPTER 1

INTRODUCTION

1.1 ADVANTAGE OF LASER MACHINING

Laser cutting is an advanced machining process. It is material removal obtained by focusing a highly intense laser beam on the workpiece (T. Thöniß, 2003). The laser beam heat subsequently melts or vaporizes the workpiece throughout the thickness or depth of the material thus creating the cutting front. A pressure assist gas jet used to expel the molten material from the cutting front (Narendra B. Dahotre and Sandip P. Harimkar, 2008). The assist gas also help in enhanced material removal through chemical reactions such as oxidation of the material.

The specialties by using laser in mostly application nowadays are this process technique more cheaper than other technique such as conversional process. By using laser, the cutting edge has never dull. Besides, the laser cutting has be controlled by computer programming so the accuracy of the cutting is more precise (Priyanka Kosta Sonkushre, 2012).

Meanwhile, the equipment that mostly used in laser cutting is expensive. The equipment of laser cutting are expensive but the product that has be produce by laser cutting is more quality and make the whole cost has be cheaper (J.Stephen Spence, 2006). For example, the aspect of time cycle and the product produce. If the man uses has be change to laser cutting method, we can save the cost for labor salary. Second, the time taken for cutting by the laser is faster than labor. So, the we can increase the production.

Third, by using laser cutting we can decreasing the mistake or waste raw material such as usually happen if we used human. When the high price that we expand for that can be balance by high income that we gain make the overall process cheaper (J.Stephen Spence, 2006).

On the other hand, laser machining is a noncontact process. Laser cutting process not need the workpiece to be clamp or centered on the precise fixture as in conventional machining (EDM, water jet, ECM). Mostly the laser cutting use CNC-controlled processes to giving accurate control over the dimensions of cut and faster cutting speeds. Beside, laser cutting have high cutting speeds and fine precise cut dimensions. Laser cutting have better quality of cut and its flexible process approaches (Narendra B. Dahotre and Sandip P. Harimkar, 2008).

1.2 PROBLEM STATEMENT

The effect of assist gas on the surface roughness for Carbon Dioxide laser cutting process.

1.3 PROJECT OBJECTIVE

There are two project objectives which are:

1. To study the effect of assist gas on the surface roughness on the finish product.
2. To run experiment, collect and verify the data specimen.

1.4 PROJECT SCOPE

This study is focuses on four project scope.

i. To study the effect of assist gas on the interaction between the laser and acrylic material.
ii. This study will uses CO_2 laser cutting machine located in Manufacturing Lab for gas assist which are Oxygen (O_2), and Non-gas as the controller parameter.
iii. The result will be analyzed by using Microsoft Excel and Minitab software from that we can see the quality of cutting.
iv. Material used for this experiment is Acrylic sheet with thickness 2.5 mm thickness.

1.5 ORGANIZATION OF THESIS

This thesis consists of five chapters. Chapter 1 presents introduction. While Chapter 2 highlights on the literature review on article, journal and etc. Chapter 3 explained the methodology for the project. Chapter 4 shows the result from the experiment and the discussion regarding to the results. Finally, Chapter 5 concluded the project and provide with recommendation for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the findings and previous studies regarding to this project title will be presented. Most of the finding materials are based on book and published journals. From the findings, the general informations about the project can be gathered more easily before the experiment began. In section 2.2, the study and the finding of the fundamental of laser cutting is explained. The types and parameters of the assist gas for laser cutting machining had been told in section 2.3. Next, in section 2.4, the machining process is discussed specifically. The laser cutting process then will be explaining in section 2.5.

2.2 FUNDAMENTAL OF LASER CUTTING

The basic system build in laser cutting are laser projector, mirror, convex lens, assist gas and tapering tip. For cutting steel material, assist gas or reactive gas such as Oxygen are used to increasing the rate of cutting because the addition of the laser energy be absorbed into the beam. Besides, assist gas flow also help to remove the cutting waste on cutting area. Besides, to cut non-steel material such as ceramic, plastic and wood we should used an inert gas flow to avoid any oxidation occur. For this case all energy has be transmit into laser for cutting process (Noriah Bidin, 2002). The advantage use laser for cutting steel is it can produce a narrow kerfs width than use plasma arc. Kerf width is a thickness cutting rate occurs on material during cutting process. Usually kerf width appear during cutting process on steel of sheet 9.5 *mm* is 1 *mm*.

Laser machine used the assistance of a computer to give the laser cutter instruction of direction. The computer control will make the cutting processing more accurate and consistent. The laser nears the material being cut from the side. The laser beam concentrated onto one point the material to be cut so that the hole is made and cutting can be continued (MaloyaLaser, March 1, 2010). The concentration of the laser beam is 0.004 inch and laser take a large amount of energy to function. Laser cutting can widely used to any material such as wood, steel, plastic, aluminum, foam, fabric, paper leather, vinyl, film, rubber, acrylic, glass and ceramic (Gaynor Borade, 2000).

2.3 LASER MACHINING PROCESS

There is several machining process in this section such as drilling process, marking process and cutting process. Each process show different method and parameter used.

2.3.1 LASER DRILLING PROCESS

The application of laser drilling used in the aerospace, aircraft and automotive industries. Laser drilling are non-contact process, precise, and effectively technique that can be used to form small diameter (~100μm). The advantage of the laser drilling are it can drill holes in difficult to machine material such as super alloys and ceramic (Voisey and Clyne, 2004). The conventional mechanical drilling is slow process which is drilling time (~60*s/hole*) compare to laser drilling process (100 *holes/s*). There are three types of laser drilling which is single pulse, trepanning and percussion drilling. Table 2.1 on the next page present the type of laser drilling use in different condition.

Table 2.1: Types of laser drilling

Spec.	Single pulse	Trepanning	Percussion drilling
Drilling narrow	Less than 1 mm	Less than 3 mm	Less than 1.3 mm
Operating	Single pulse	Continuous wave	Series of short pulse
Energy	High	High	High

As show on Figure 2.1 below show the basic principle of laser drilling process where the unfocused laser beam are projected to the focusing lens to increase laser tendency.

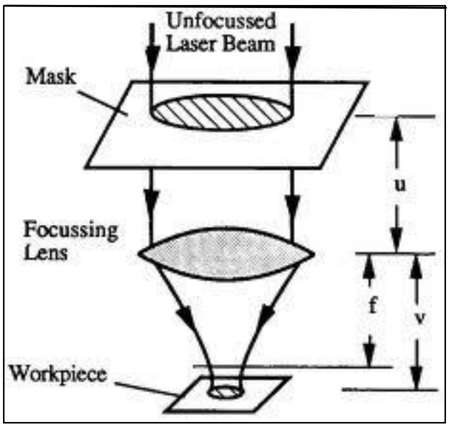

Figure 2.1: Laser drilling process (Dr-Ing J.Berkmanns, 2008)

2.3.2 LASER MARKING PROCESS

Another type of laser machining is laser marking. Laser marking use the pulse to cutting the material under 0.5 mm thickness (Jack Gabzdyl, 2007). It employ short pulse with 20 or more watts of average power and the necessary pulse flexibility and shaping option to optimize the cutting process. Laser marking also can used for drilling small diameter holes. The high peak power of laser marking helps the laser energy to quickly couple to the material while the long tail up to 200ns provides for deep penetration and high material removal rates (Miyachi Unitek, 2011). This process does not need assist-gas like other laser process, but a low pressure flow of gas may be useful in protecting the optics and to direct particulates away from the work piece.

Figure 2.2 below demonstrate the laser marking process. There are three pass level of laser marking on material surface show in figure below.

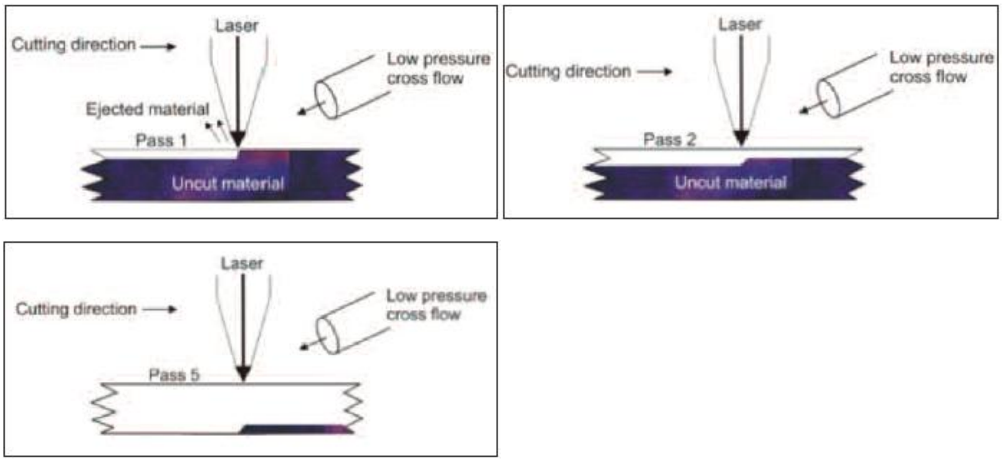

Figure 2.2: Show laser marking process (Miyachi Unitek, 2011)

2.3.3 LASER CUTTING PROCESS

The other laser machining process is laser cutting process as show in Figure 2.3 on the next page. The laser beam are projected by laser power to the mirror, then the mirror reflected the beam to the focusing lens. Cutting gas use to support the thermal of laser beam.

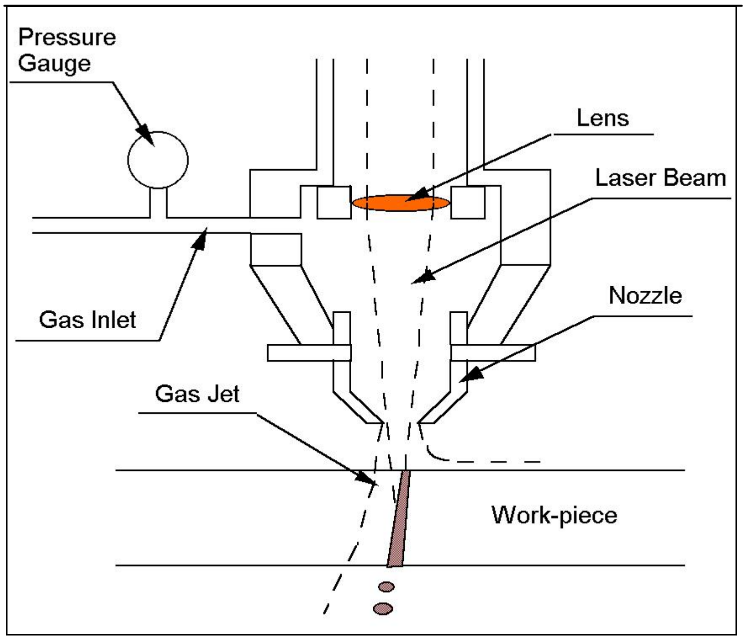

Figure 2.3: Principle of a laser cutting system (Dr.-Ing. M. Faerber, 2008)

The high intensity light beam quickly increasing the heat up the workpiece and melt the material (Dr.-Ing. J. Berkmanns, June 18, 2008). The assist gas or cutting gas is applied to remove the molten metal from the cut kerf and to cooling the focusing lens.

Two types of assist gas used be applied depending to the process. Cutting process by oxygen assist gas, the material is easily burn and vaporized because the reaction between the oxygen and the metal created additional energy which is supports the cutting process (Brian Welz, 2012). Meanwhile, cutting process by nitrogen gas (inert gas/non-reactive), the material is melt slowly. No additional heat generated but the laser power required by nitrogen assist gas is higher than by using oxygen cutting process. Besides, nitrogen gases can cut the material as clean cutting or high-pressure cutting.

2.4 LASER CUTTING

In this section, the type of the assist gas and advantage of laser cutting process has been discussed.

2.4.1 Type of the assist gas for laser cutting

There are four main approaches to cut the material using laser such as evaporative laser cutting, fusion cutting, and reactive fusion cutting and controlled technique. This technique depends on the condition of the material (Narendra B. Dahotre and Sandip P. Harimkar, 2008). The main aspects that are focus on the material condition are on the thermo-physical properties of the material, the thickness of the workpiece and the type of the laser employed.

In evaporative laser cutting, the laser has provided the latent heat until the material reaches the vaporization point and convert into vapor state. The quality of cut is highly with clean edges because the material removal is due to direct phase change to the vapor (Stephen Malkin and Changsheng Guo, 2008). This method is suitable for the materials with low thermal conductivity and low heat of vaporization (organic material, cloth, paper and polymers). Besides, in laser cutting they are moves relative to workpiece and follow a straight or curved path.

The variation of fusion cutting use oxygen assisted in which reactive gas instead of inert gas (Narendra B.Dahotre, 2008). In reactive fusion cutting, the heated is projected to material in on point where an exothermic reaction with an oxidizing coaxial gas jet is triggered another source of heat to the process. Due to combined effects of the absorbed laser radiation and exothermic reaction, the molten layer reaches the evaporation temperature thus facilitating the material removal by evaporation from the surface (Sandip P. Harimkar, 2007). The dominant mechanism of material removal is the oxidation of materials.

By the direct optical observations, the oxygen assist gas laser-cutting zone which showed the temperature in the pale yellow band (~2000 *K*) as against the blue-violet band (temperature higher than 2000 *K*) observed in evaporative laser cutting.

Higher cutting speeds are achieved in the oxygen-assisted cutting due to release of a large amount of exothermic heat. However, to sustain the exothermic reaction during laser cutting we must to deliver the sufficient amount of oxygen at high pressure (O'Neill and Gabzdyl, 2000). The heat balance at the molten layer is given by setting the heat gain by laser radiation and oxidation reaction equal to the heat losses by conduction, melting, vaporization and ejection of liquid material by from the bottom surface of the workpiece (Schuocker, 1986).

Besides assist gas laser cutting, there are several parameters we need to understand the effect of the parameter over surface roughness such as gas pressure, cutting speed and laser power (Mustafa Kurt, 2008). The method used to determine the quality of surface roughness are well know that surface roughness effect fatigue life, corrosion and friction and thermal conductivity of parts. The factors such as gas pressure, cutting speed and laser power can affect the surface roughness of the parts.

As show in the Table 2.2 below, the cutting condition of laser cutting by several number of test. There are three type of parameter used which are pressure gas, cutting speed and laser power.

Table 2.2: Cutting condition

Number of test	Pressure (bar)	Cutting speed (mm/min)	Power (Watt)
1	2.5	2	600
2	2.5	5	900
3	2.5	8	1200
4	4.5	2	900
5	4.5	5	1200
6	4.5	8	600

In table 2.2, there are several trials were performed in order to determined the effect of cutting parameter over surface roughness quality of parts. All the measurement was repeated three times in order to achieve more accuracy reading. R_a is define as the arithmetic value of the profile from the centerline along sampling length as shown in figure.

Figure 2.4 on the below show the result of surface roughness by using a contact-type stylus (Mahr Perthometer Concept). The maximum and minimum surface roughness value show that less than 5 µm.

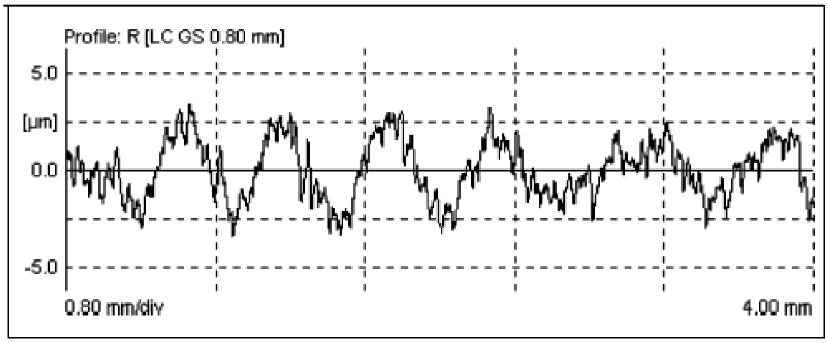

Figure 2.4: R_a graph (Mustafa Kurt and Yusuf Kaynak & Eyup Bagci, April 2008)

Besides, it can be expressed by the mathematical formula. Eq.(2.1) below show the formula of surface roughness.

$$R_a = \frac{1}{L}\int_0^L |Y(x)|dx \qquad \text{Eq.(2.1)}$$

Where R_a is the arithmetic average deviation and L is the sampling length.

2.4.2 Advantage of laser cutting

There are several advantages by using laser cutting over other methods of cutting such as CNC routing. Firstly, laser can cut the acrylic more accurately with a laser than a CNC cutter. Besides, conventional cutting leaves a rougher edge finish and need another process to clean in up. Contrary, laser cutting leaves a polished and no need further work. Laser cutting are easily and quick to set-up compare to the mechanical cutting that need the centre point before start the process (Kesheng Wang, 2006). Laser cutting also leave the width is much narrower than a typical CNC cutting tool, corners can be cut without a tool radius associated with mechanical cutting.

The use of laser cutting technique nowadays allows the machining process more faster and higher quality cuts than traditional torch cutting (John Green, 2010). Since the laser cutting is computer controlled, so the precise and faster cut can be easily made. An assist gas, usually used are nitrogen or oxygen, is blown along the material to remove any excess molten metal from the edge. Both of these gases have advantage and disadvantage. By using an oxygen as an assists gas allow us saving our time cutting. It also cost effective (Ed Craig, 2001**).** The oxygen gas assist role as the exothermic reaction that generates heat, as well as providing for better cut.

The oxygen cause oxidization and leaves an unattractive brown scale on the material. The major disadvantage by using oxygen assisted laser cutting is this extra step occur after machining (Billy Kite, 2008). On the other hand, by using nitrogen as an assist gas show the result in much clearer cut. As nitrogen is an inert gas, so there are no exothermic reaction between it and the material. Nitrogen assisted gas prevents the time consuming step by keeping the cut edge clean. But the nitrogen gas assisted cutting is slower than oxygen assisted cutting. Also, a nitrogen didn't have exothermic reaction, but the gas must be used at a high pressure. The cost of nitrogen is more expensive compare to oxygen (Devanney, M.T., 2007). Most of the laser cutting in industry today use nitrogen as the assist gas because to achieve the reliable result.

The laser is rated by their power output in terms of watts. Since the laser cutting is a thermal process, the amount of heat produced relates to its capabilities. So, the increase power allow for faster processing speed of cut of material (Richard Walker, 1998). To obtain the quality result of cutting, the stability of the laser's output is a key feature in cutting. This contain to maintaining unwavering output energy (power stability), consistent beam quality (mode stability), and fixed energy concentration (David Harvilla, 2002).

The effect such inconsistent edge quality, variations in kerf, edge smoothness and perpendicularly occurs due to the effect of polarization (David Bergström, 2008).

This is cause of uncontrolled or random polarization processing. To overcome this inconsistency, lasers must be same direction process. Laser cutting federates based on the available laser power density and the properties of material to be cut. Cutting rates are likewise inversely proportional to the materials density and thickness. Therefore, feedrates will increase with additional a laser power, smaller the focused spot size laser cutting, lower the required energy to initiate vaporization or material density (M.D. Perry, 1999). Lastly, decreased the material thickness to increase the quality result.

The choice of the focusing lens has a great impact on the resulting cut quality of the material. The focused spot size is proportional to the focal length, the power density that is produces is proportional to the square of the length (Hansma and Paul K, 1996). Short focal length lenses give very high energy densities, but are limited in their application due to a shallow working depth. Longer focal length lenses have lower power densities but are able to maintain those densities over a much broader range and therefore can be used for thicker cross sections of materials given that they have enough energy initially. The used of assist gas supplied to protect the lens and aid in the material removal process. For most metal cutting applications, a reactive gas such as oxygen can improve cutting speeds by 25% to 40% over the results obtained with use of air (Shang-Liang Chen, 1996).

2.5 LASER CUTTING PARAMETERS

The experiments had been conducted by researchers with the different factors or different variable. Some of them used the sheet metal as the material and few of them used plastic sheet as the material. The results obtained are used to investigate the quality of each factor as well the influencing on the observed quality characteristic.

The experiment on mild steel and stainless steel sheets (0.5 to 0.9 *mm* thick) in using oxygen assist gas at constant pressure of 700 *kPa*, cutting speed (600-800 m/min) and pulse width (0.2-0.9 *ms*) at constant values for each specimen (Kaebernick, 1999). The kerf width increase slightly with increase in cutting speed up to critical value then starts decreasing.