THE STUDY ON THE EFFECT OF LASER POWER ON KERF WIDTH FOR CARBON DIOXIDE LASER CUTTING PROCESS

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ABSTRACT

This study focuses on the effect of laser power on kerf width using CO_2 laser machine. The experiment was conducted by using laser cutting process on 2.5 mm thick of acrylic sheet. The laser cutting parameters considered include laser power and cutting speed. The good cut quality for laser cutting process has a uniform with smaller kerf width. The effect of the laser cutting parameter on the cut quality was further investigated by monitoring the kerf width using image analyzer. After performed the experiment and analysis it shows that the lower laser power and higher cutting speed produce narrower kerf width.

ABSTRAK

Kajian ini memfokuskan kesan kuasa laser terhadap *kerf width* dengan menggunakan mesin laser CO_2. Eksperimen ini telah dijalankan dengan menggunakan proses pemotongan laser terhadap kepingan *acrylic* dengan ketebalan 2.5 mm. Parameter bagi proses pemotongan laser yang diuji ialah kuasa laser dan kelajuan pemotongan. Kualiti yang baik bagi proses pemotongan laser mempunyai saiz *kerf width* yang lebih kecil dan seragam. Kesan parameter pemotongan laser terhadap kualiti pemotongan diuji dengan memberi permahatian terhadap *kerf width* menggunakan *image analyzer*. Setelah melakukan eksperimen dan analisis, keputusan menunjukkan lebih rendah kuasa laser dan lebih tinggi laju pemotongan menghasilkan *kerf width* yang lebih kecil.

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LIST OF SYMBOLS

mW	mili Watt
kW	kilo Watt
GPa	Giga pascal
µm	micro meter
mm	mili meter
s	second
min	minute

LIST OF ABREVIATIONS

LASER	Light amplification by stimulated emission of radiation
LBM	Laser beam machining
CO_2	Carbon dioxide
YAG	Yttrium aluminium garnet
KW	Kerf width
PMMA	Poly methyl methacrylate
DOE	Design of experiment
ANOVA	Analysis of variances
HAZ	Heat affected zone

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Laser, an acronym for light amplification by stimulated emission of radiation, is essentially a coherent, convergent and monochromatic beam of electromagnetic radiation with wavelength ranging from ultra-violet to infrared (J.D. Majumdar & I. Manna, August 2005). Laser can deliver very low mW to extremely high 1–100 kW focused power with a precise spot size or dimension and interaction/pulse time $10-3$ to $10-15$ s on to any kind of substrate through any medium. Laser is distinguished from other electromagnetic radiation mainly in terms of its coherence, spectral purity and ability to propagate in a straight line. As a result, laser has wide applications from very common bar code scanner to most sophisticated three dimensional holography.

These important properties that justify the use of laser in such a wide spectrum of applications are temporal coherence phase and amplitude is unique, low divergence parallel to the optical axis, high continuous or pulsed power density (William T. Silfvast, 1996)**.** Figure 1.1 on the next page show, presents a brief overview of the application of laser in different fields with various objectives. Though the list is not complete, it serves to show the variety of application of laser.

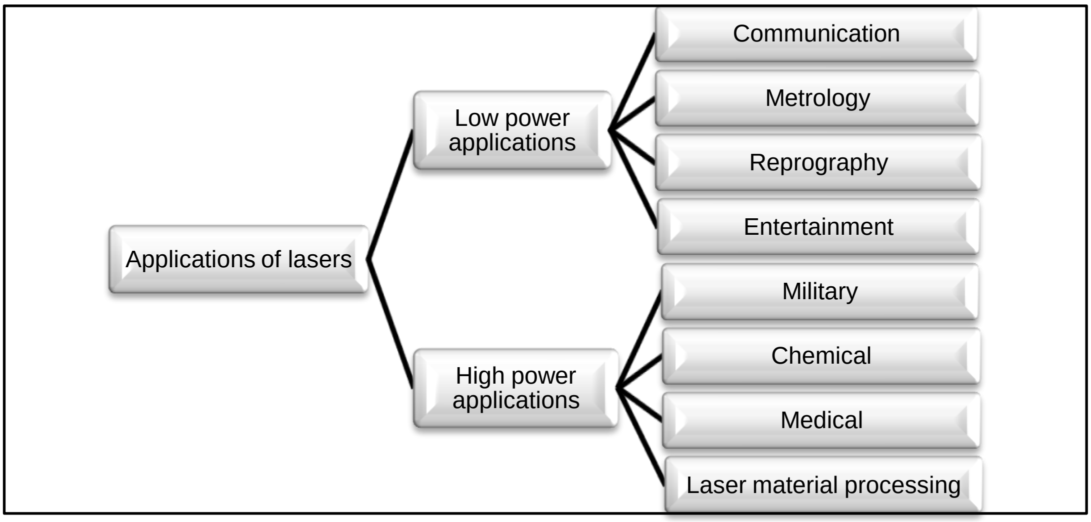

Figure 1.1: Application spectrum of lasers (J.D. Majumdar & I. Manna, 2005)

Lasers are commonly used to cut or machine different types of materials, especially difficult-to-cut materials, in many industrial applications, due to its advantages over the conventional cutting processes (F. Caiazzo et al., 2005). The main advantages of laser cutting are no tool wear or vibration as it's a non-contact process, low heat input which results in less distortion and its capability to be numerically controlled. In laser-beam machining (LBM), the source of energy is a laser which focuses optical energy on surface of the work piece. The highly focused, high density energy source metals and evaporates portions of the workpiece in a controlled manner.

Laser machining always be the first choice of machining since it is more flexible than other machining process. Laser machining in these days can be used to in many applications such as cutting, drilling, surface finish and even for milling operations. In addition, laser machining process is a process that very productive and it is very cost effective (P.S. Banks et al., 2002). Furthermore, laser machine had been used for many applications beside the machining process. As example, it had been used in medical application. In laser machining, there is lots of parameter that one need to pay attention to.

1.2 PROBLEM STATEMENT

Kerf width is one of important quality characteristic in laser cutting process. Smaller kerf width is a good quality for laser cutting process. This experiment will identify the effect of laser power on kerf width. So, the secondary process can be minimized. As a result, production time and cost will be reduced.

1.3 PROJECT OBJECTIVE

The aim of this project is generally to study the effect of laser power on kerf width, to collect the data and verify the relation between laser power and kerf width.

1.4 PROJECT SCOPE

This project will focus mainly on one of the laser beam machining function which is laser beam cutting. In order to achieve the objective notified earlier, the following scopes have been recognized:

- The machine that will use is CO_2 laser machine (30 Watt) at FKP lab.
- Laser power parameters will be determined before doing the experiment and the quality of cut determined by using image analyzer.

1.5 ORGANIZATION OF THESIS

This thesis consists of five chapters. Chapter 1 presents introduction. Chapter 2 highlights related literature regarding to the project title. Chapter 3 explained the methodology for the project. Chapter 4 shows the result from the experiment and the discussion regarding to the results. And Chapter 5 concluded the project and provide with recommendation for the project.

CHAPTER 2

LITERATURE REVIEW

2.1 LASER

Laser machining known as one of the advance machining process. The innovation of laser is very impressive on 20th century. The development of laser is very fast in science, engineering and technology history. The versatility of pure energy in a highly concentrated form make a laser emerged as an attractive tool and research instrument with potential for applications in an extraordinary variety of fields. The initial foundation of laser theory was laid by Einstein (John C. Ion, 2005).

In 1960, a ruby laser is developed for the first time. This was followed by much basic development of lasers from 1962 to 1968. Almost all important types of lasers including semiconductor lasers, Nd:YAG lasers, CO_2 gas lasers, dye lasers and other gas lasers were invented in this era. After 1968, the existing lasers were designed and fabricated with better reliability and durability. By mid 1970s more reliable lasers were made available for truly practical applications in the industrial applications such as cutting, welding, drilling and marking. During the 1980s and early 1990s the lasers were explored for surface related applications such as heat treatment, cladding, alloying, glazing and thin film deposition (Thomas R. Kugler, 2001).

Depending on the type of laser and wavelength desired, the laser medium is solid, liquid or gaseous. Different laser types are commonly named according to the state or the physical properties of the active medium. There are many types of laser such as crystal, glass or semiconductor, solid state lasers, liquid lasers, and gas lasers. The latter which is gas lasers can be further subdivided into neutral atom lasers, ion lasers, molecular lasers and exciter lasers (Atanasov and Baeva, 2001). The typical commercially available lasers for material processing are solid state crystal or glass laser, semiconductor laser, dye or liquid lasers solutions of dyes in water/alcohol and other solvents, neutral or atomic gas lasers, vapor laser, ionized gas lasers or ion lasers, molecular gas lasers, and exciter laser. Wavelengths of presently available lasers cover the entire spectral range from the far-infrared to the soft X-ray (Golnabi H. and Mahdien M. H., 2006). Table 2.1 below, summarizes commercially available lasers and their main areas of application.

Table 2.1: Commercially available lasers and their industrial applications.
(J.D. Majumdar & I. Manna, August 2003)

Laser	Year of discovery	Commercialized since	Application
Ruby	1960	1963	Metrology, medical applications, inorganic material processing
Nd-Glass	1961	1968	Length and velocity measurement
Diode	1962	1965	Semiconductor processing, biomedical applications, welding
He-Ne	1962		Light-pointers, length/velocity measurement, alignment devices
Carbon dioxide, CO_2	1964	1966	Material processing-cutting/joining, atomic fusion
Nd-YAG	1964	1966	Material processing, joining, analytical technique
Argon ion	1964	1966	Powerful light, medical applications
Dye	1966	1969	Pollution detection, isotope separation
Copper	1966	1989	Isotope separation
Excimer	1975	1976	Medical application, material processing, colouring

2.2 LASER MACHINING

Laser machining means material removal accomplished by laser material interaction, generally speaking, these processes include laser drilling, laser cutting and laser grooving, marking or scribing. Laser machining processes transport photon energy into target material in the form of thermal energy or photochemical energy, they remove material by melting and blow away, or by direct vaporization/ablation (Powell J., 1998). On the other hand, traditional machining processes rely on mechanical stresses induced by tools to break the bonds of materials (Anon, 2003). This basic difference in material removal mechanism decides the advantages and disadvantages of laser machining process compared with traditional machining processes.

Laser machining is localized, non-contact machining and is almost reacting-force free, while traditional machining usually has direct mechanical contact and need devices to balance the machining force, work piece needs clamping. The forces in laser machining are of micro scale (Choudhury I. A, 2010). The photon pressure on target material is negligible for bulk material. Laser beam size is usually very small, let's take the beam size to be radius 10 microns (which is the typical case to generate 10 *GPa* pressure in confined water regime), the force is 3.14 *N* (D. O'Sullivan and M. Cotterell 2002). Even for this extreme case the force is far less than traditional machining. This offers laser machining process flexibility in machining delicate parts where no large mechanical force can be acted on.

Laser machining process can remove material in very small amount, while traditional machining removes material in macro scale. Laser machining process are said to remove material "Atom by Atom". For this reason, the kerf in laser cutting is usually very narrow, the depth of laser drilling can be controlled to less than one micron per laser pulse and shallow permanent marks can be made with great flexibility (Caiazzao F, et al, 2005). In this way material can be saved, which may be important for precious materials or for delicate structures in micro-fabrications. This also means small removal rate in laser machining process compared with traditional machining. Laser cutting of sheet material with thickness less than 20 *mm* can be fast, flexible and of high quality (Anon, 2003).

Heat Affected Zone (HAZ) in laser machining is very narrow, usually there is a very thin re-solidified layer of micron dimensions, this promises negligible distortion in machining (Davim J. P. et al, 2008). And in ultra-short laser machining, HAZ is negligible. In traditional machining, a large area of work hardening is almost unavoidable. Laser machining process can be applied to any material that can properly absorb the laser irradiation, while traditional machining processes have to choose suitable tools for materials with different hardness or abrasiveness (R. Lambert, 2011). It is difficult to machine hard material or brittle material such as ceramics, laser is a good choice for solving such difficulties.

Laser machining process can achieve final quality level machining results in one process, while in traditional machining several processes are commonly used. Laser cutting edges can be made smooth and clean, no further treatment is required (J. D. Majumdar and I. Manna 2003). High aspect ratio holes can be drilled using lasers. Dross adhesion and edge burr can be avoided, geometry precision can be accurately controlled. The machining quality is in constant progress with the rapid progress in laser technology. Although some traditional machining can achieve higher surface qualities than common laser machining process, this technique has the potential of nm scale machining. It was reported that laser was used for interactive optics finishing.

Small blind holes, grooves, surface texturing and marking can be achieved with high quality using laser machining process. Traditional machining may be advantageous for macro scale applications, it is usually more economical and efficient to use laser machining process for micro scale applications (John F. Ready, 2001). Laser machining process has the potential for more flexibility. Precise 3D position control can be conveniently realized. The combination of transmitting laser energy through fiber and positioning the fiber using robots can provide a system with great dimensional freedom.

2.3 LASER BEAM CUTTING

Laser machining refers to controlled removal of material by laser induced heating from the surface of the work piece and includes laser assisted drilling, cutting, cleaning, marking and several other forms of material removal (Elsen F. O., 1980). Laser cutting is the most common industrial application of laser in material machining. Metals, ceramics, polymers and composite can be cut by laser beam. The laser beam cutting processing is easily automated for speed and accuracy giving clean edges with minimum heat affected zone. Laser cutting as shown in Figure 2.1 below, is the most widely technique used in industry.

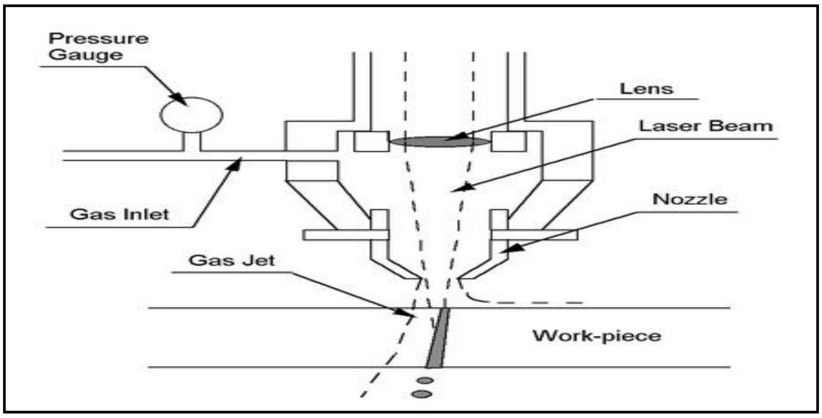

Figure 2.1: Basic laser cutting diagram (Thomas R. Kugler, 2001)

As an example, carbon dioxide lasers are being increasingly used in the aircraft and automotive industries to cut, trim, drill holes and weld sheet metal parts (Gabzdyl J. T. 1996). This is because the great advantage of this technique over traditional cutting methods and its ability since lasers can produce narrower kerfs and good cut quality compared to other cutting techniques. Laser cutting is one of other faster cutting process. It also can produce cuts in any direction with sharp corner.

The other important characteristic is the capability to cut almost any material which is (ductile/ brittle, conductor/non-conductor, hard/soft). All of these capabilities make the laser become the primary choice in industry (Dirk Petring, 2011). Some of these materials are different kinds of wood and wood composites which are cut with excellent results and productivity. In fact, CO_2 laser cutting of plywood die boards was one of the first commercial uses of these lasers in 1971. Lasers can separate workpieces along lines or curves, such processes are called laser cutting processes. Thin workpieces may be difficult to cut by other means, while laser cutting is suitable because of it noncontact feature. Lasers have been used to cut a wide range of materials. CO_2 laser and Nd:YAG laser are the most popular laser in cutting, they can provide high powers (above 1 KW) for high speed cutting. UV lasers are widely used for thin layer cuttings or organic material cutting. Gas jet is often used to improve the cutting efficiency.

Laser cutting can be basically divided into two types. First is the direct evaporative laser cutting, in which laser provides the latent heat until the material reaches vaporization point and ablate in vapor state, such as laser cutting of organic materials-paper, cloth or polymers. Such materials have poor thermal conductivity, a nonreactive gas jet maybe used to reduce charring (Elsen F. O., 1980). The second is laser cutting through melting, or fusion cutting. Laser energy melts the target material and the gas jet blows the molten material away. In this way the requirement on laser energy is lower compared with vaporization cutting.

One of the gas types is reactive gas jet. If the gas jet is reactive, the laser heat the material, laser heating combined with exothermic chemical reaction with the assisting gas provides the necessary melting of the target material, this is called Reactive Laser Cutting. This helps to further reduce the necessary laser energy. Conventional steels of up to 16 mm lend themselves reasonably well to oxygen assisted laser cutting by CO_2 lasers. The kerfs are narrow (as little as 0. 1 mm for thin material) and the resultant heat affected zones are negligible, particularly for mild and low carbon steel (John F. Ready, 2001). At the same time, the cut edges are smooth, clean, and square.

Stainless steel, alloy steel, tool steel etc. can be cut very well using CO_2 lasers. Due to their high reflectivity to 10.6 microns laser irradiation and high thermal conductivity, CO_2 laser is not suitable for cutting of Cu and Al material. However, Nd:YAG lasers (1.06 micron and their doubled and tripled wavelengths--532, 355 nm) which have shorter wavelengths can be used for Cu and Al materials (T. Akasawa, et al., 2003). Keep in mind that the absoptivity of materials is strongly dependent on laser wavelengths. In general, metal cutting requires higher average laser power than laser cutting of nonmetals due to their higher reflectivity and thermal conductivity, and oxygen assisted cutting is more commonly used. Table 2.2 below show the features of laser cutting for different materials.

Table 2.2: Features of laser cutting for different materials ((J. D. Majumdar and I. Manna 2003)

Material	Features
Metals	At room temperature, most metals are highly reflective of infrared energy, the initial absorptivity can be as low as 0.5% to 10%. But the focused laser beam quickly melts the metal surface and the molten metal can have an absorption of laser energy as high as 60~80%. Fusion cutting assisted with gas jet is used.
Non-Metals	Non-metallic materials are good absorbers of infrared energy. They also have lower thermal conductivity and relatively low boiling temperatures. Thus the laser energy can almost totally transmitted into the material at the spot and instantly vaporize the target material. Vaporization cutting is commonly used, nonreactive gas jet is used to prevent charring.

Table 2.2 above gives a brief view of laser cutting of different materials. Plastics, polymers, rubber, papers, wood, composites, stones and crystals have been successfully machined by lasers at infrared wavelengths. Some materials such as composites and gemstones can be readily cut with high quality using lasers, while they may be difficult to handle using other techniques (J. D. Majumdar and I. Manna 2003). UV lasers can even cut polymers with negligible heat affected zone, because the phone energy is comparable to the bonding energy of the material, photochemical instead of photo thermal ablation dominates. In general, non-metallic cutting requires less energy than metal cutting, direct vaporization cutting is used.

In laser cutting, cut edge is sufficiently clean and smooth, finish cut quality can be achieved in single process, the cutting kerf is very small. Sharp angles, small radius rounds and complex curves can be cut with high speed and flexibility. Edge burr and dross adhesion can be avoided. A small heat affected zone exists for laser cutting, but it is of micron scale, which means negligible thermal and mechanical distortions. For thin layers (<20mm) laser cutting of many materials is a faster and high quality process compared with other processes. Thick section cutting and high speed cutting need special consideration, we will talk about them in advanced levels.

Scanning speed of laser source, laser power, focal position, gas jet alignment and gas composition, as well as laser material interaction phenomena such as plasma and shock waves, all influence the cutting quality. In order, to precisely predict and control this process, modeling work is needed.

2.4 PARAMETER

The laser cutting parameters are dependent on the beam characteristics, the cutting rate required, the composition and thickness of the material to be cut, and the desired cut edge quality. The laser cutting process and cut quality depend upon the proper selection of laser and workpiece parameters (Yilbas B. S. and Yilbas Z., 1992). Deficiencies in cutting quality may be related to the slow process drifts and disturbances that are caused by velocity fluctuations, variation in power and spatial intensity distribution as well as optical integrity perturbations. The effects of the beam parameters, process parameters and material parameters are described in the following sections.

2.4.1 Laser Power

Laser power is one of the parameter that should be control in order to obtain high cutting quality narrower kerf width (Yilbas B. S., 1997). The parameters controlling the laser cutting operation are beam diameter, laser power, traverse speed, gas composition, material thickness, reflectivity and thermo-physical properties. In experiment (W.M. Steen, 1983) also suggested that there is an optimum range of cutting speeds for a given material, thickness and beam power.

Laser power determines the direct the energy input to the cutting process. Both cutting quality and the cutting performance depend on the laser power. (Shang Liang Chen, 1999) during the experiment prove that laser power is directly proportional to kerf width. Laser power also determines the maximum cutting speed which is defined as the minimum speed at which through cut is produced. There exist an optimum combination of cutting speed and the laser power which gives the maximum performance (Caherine wardera, 2006). Besides, laser power can be used to control the fracture technique. This case occurs in cutting ceramics, the ceramics is brittle so the optimum laser power must be obtain to avoid the fracture.

The power of a laser is the output optical power of the laser, normal working power and its maximum allowable power. Lasers operate in either continuous wave state or pulsed state. Both operation states have lots of applications (Kurt M., er al, 2009). For pulsed laser, an important parameter is the peak power. In general, CO_2 lasers have relatively high continuous wave power, while Nd:YAG lasers can provide relatively high peak power for pulsed operation (Modest Michael F., 2001). Output power is closely related with processing time and operation expense. If the selected laser power is lower, the processing time will be increased, if the selected laser has too high power than necessary, the operation expense will be higher than necessary. So the proper choosing of laser power is very important.

Basically, laser power depends on the type of laser. In this research, the laser will be used is continuous wave CO_2 which maximum power is 30 Watt. However, only 95% of maximum power can be reached. It means, the output power is ±28.5 Watt.

2.4.2 Cutting Speed

The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided into two parts namely, energy used in generating a cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken (Sharma A. and Yadava V., 2012). Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. A reduction in cutting speed when cutting thicker materials leads to an increase in the wasted energy and the process becomes less efficient. The levels of conductive loss, which is the most substantial thermal loss from the cut zone for most metals, rise rapidly with increasing material thickness coupled with the reduction in cutting speed (Eltawahni H. A., et al, 2010). The cutting speed must be balanced with the gas flow rate and the power.

As cutting speed increases, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When oxygen is applied in mild steel cutting, too low cutting speed results in excessive burning of the cut edge, which degrades the edge quality and increases the width of the heat affected zone (HAZ). In general, the cutting speed for a material is inversely proportional to its thickness. In (Kanaoka M. and Kitani M) study showed that speed must be reduced when cutting sharp corners with a corresponding reduction in beam power to avoid burning.

2.5 CUTTING QUALITY

The kerf width represents the amount of material melted during cutting and correlates to the focused spot size. A small kerf width can have advantages when small details are to be made such as when cutting sharp corners (Almeida I. A, et al, 2006). The kerf width mainly depends upon the focused spot size. The size of the focus spot is determined by the laser beam quality and focusing optics. Changing the beam waist position relative to the workpiece surface modifies the power intensity at the workpiece surface thus affecting the size of the kerf (Yilbas B. S., 2001). A shorter focal length also resulted in a smaller kerf width.

This is expected because the focal length is also directly related to the focus spot size with a shorter focal length giving a smaller focus spot size and hence a smaller kerf width. Kerf width is a width of the groove made by a laser cutter. The kerf is dependent upon the properties of the material being cut, the workpiece thickness, the lens, focal light and laser power. (Yilbas B. S., 2001) state that the main criteria of a laser cut workpiece are minimum kerf width. This statement also supported by (T. G. King, et al, 1985). Figure 2.2 below, show the kerf width portion at the workpiece.

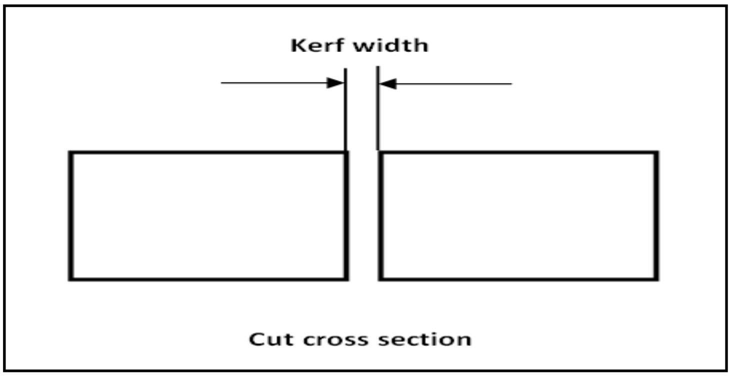

Figure 2.2: Schematic view of cut edges (B.S. Yilbas, 2001)

In (Guillas C., 1990) study showed that the properties of the motion system, laser beam power and frequency and the gas flow greatly influence the surface topography of the cut and have to be carefully controlled in order to acquire an optimal cut quality. The kerf width is increased when laser power is increased. This behavior is understandable because of the greater exposure of the top surface to the laser beam. If too high laser power exposed during cutting means that larger kerf width will be obtain and vice versa. In (Rajaram N. and Cheraghi S. H., 2003) experiment, laser cutting of phenolic resin boards also give the same result, when higher laser power is set, the higher curve width is obtain.