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Analysis Of Energy Consumption During Carbon Dioxide Laser Cutting

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Abstract

The objective of this paper is to analyze the influence of gas during carbon dioxide laser cutting process . A variety of cutting conditions like variation of pressure and velocities were applied to steel to analyze the effect of these mentioned parameters. It is observed through experiments that the most effective cut was at 1 bar pressure with 0.5m/min velocity by measuring the kerf width heat affected zone and power consumption..

KEY WORDS: Carbon dioxide laser cutting, HAZ, Kerf width, laser cutting, Steel, Energy balance equation, Power consumption

1.0 INTRODUCTION

Over the past decade, laser cutting has developed into state-of-the-art technology. It is estimated that more than 40,000 cutting systems are used for the high-power cutting of metals and non-metals worldwide. When including low-power applications, such as plastics cutting and paper cutting, the numbers are even higher. Laser technology of cutting is the method of thermal parting of material with no material removal due to the use of mechanical work; it uses physical and chemical processes or the combination of both. As a result, only minimal deformations arise both in the process of division and after it has finished. Laser is a beam with high brightness, high power and very good direction. Thus, laser cutting excels in applications requiring high productivity, high edge quality and minimum waste, due to the fast and precise cutting process [4,5].The cutting process is based on the interaction of laser beam, cutting gas and cut material. The gases used to generate the laser beam and expel the molten metal out of the cut kerf are important consumables during laser operations. They can prolong the lifetime of the optical component, increase the cutting speed and improve the cutting quality. All the above contribute to more profitable laser operation.[1,2. 3] Cutting with laser has a wide range of uses for production on a small scale as well as for large-scale production in batches. Laser cutting technology offers a major advantage in speed, quality and accuracy of burnouts; it achieves low manufacturing cost and minimizes the amount of waste, which is associated with the best possible use of the materials and energy. [1]
Considerable research studies have been carried out to examine the laser cutting process, with some of the findings summarized in recent comprehensive review papers [2-4]. Of particular interest to manufacturers using laser cutting technology are the maximization of productivity and quality and minimization of cost. Each of these goals often requires “optimal” selection of the laser cutting parameter settings.[5]. In theoretical modelling of gas laser cutting process, the dependence between the laser radiation power and cutting velocity is determined on the basis of energy balance equation. This approach allow us to find out the maximum velocity, which is not obligatory optimal from the viewpoint of cutting quality[6].

2.0 EXPERIMENTAL PROCEDURE

Care is taken to ensure that the gases helium, neon and carbon dioxide laser beam are aligned with color to identify the laser for safety purpose. It is also ensured that the focusing optical parts are cleaned and loaded into the holder. A stand off distance of 0.75 mm is fixed as the distance between the nozzle and the workpiece. In order to obtain omni- direction properties, it is essential that the beam is centered properly. Pressure of the gas is varied (0.5, 1, 2, 4 and 6 bar) and with a variation of velocity (0.5 and 1m/min), the cut is performed [3]. The power consumed for each cut has been calculated using the lumped heat capacity equation based on heat balance on the material.

2.0 ANALYSIS AND DISCUSSIONS

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The figure shows the various cut performed in the material with varied pressure and velocity as discussed in experimental details. Quality of the cut varies with the pressure and velocity of the gas used [3]. The following criteria were used in inspection for identification of good cut

1. Absence of dross or removable dross.
2. Through cut and low taper
3. Kerf width and Minimum heat affected zone
4. Smooth cut.

Figure 1 : cut for 0.5 bar pressure

Figure 2: cut for 1 bar pressure

The following table (table 1) gives the data pertaining to Kerf width and different heat affected zones [3].

Pressure (Bar)	Velocity (m/min)	Kerf Width (mm)			Heat affect zone (mm)		Cut condition
		top	bottom	average	top	bottom	
0.5	0.5	-	-	-	-	-	Material not removed.
1	0.5	0.634	0.321	0.477	0.33	0.549	Good cut(straight cut)
1	1	0.561	0.355	0.458	0.228	0.482	Good cut (zigzag effect)
1	1.5	-	-	-	-	-	Material melted, but no cut taken
1	2	-	-	-	-	-	Not even melted
2	0.5	0.645	0.397	0.521	0.293	0.547	Good cut
2	1	0.608	0.454	0.531	0.217	0.380	Good cut, No effect on increase in pressure
4	0.5	0.792	0.449	0.620	0.233	0.427	Good cut
4	1	-	-		-	-	Poor result
6	0.5	-	-		-	-	Too much material removed

Table 1: Quality of cut at different pressure and temperature [3]

From the above observations, a graph of speed against pressure (Figure no: 3) is plotted to show the permissible maximum & minimum speeds for good cutting at particular pressure. Here no cut was taken during 0.5 bar pressure, so the maximum and minimum speed is given as zero. The minimum and maximum velocity is zero for cut at pressure six, because the cut quality was very poor and it removed excess material. From the graph it's clear that, pressure ranges from 1 to 4 bar has more options to vary the speed in order to generate good cut. Area between those two lines in the graph generated good quality cut during the experiment.

Pressure (bar)	Min. speed (m/min)	Max. speed (m/min)
0.5	0	0
1	0.5	1
2	0.5	1
4	0.5	0.5
6	0	0

Table 2: Minimum and maximum speed at different pressures

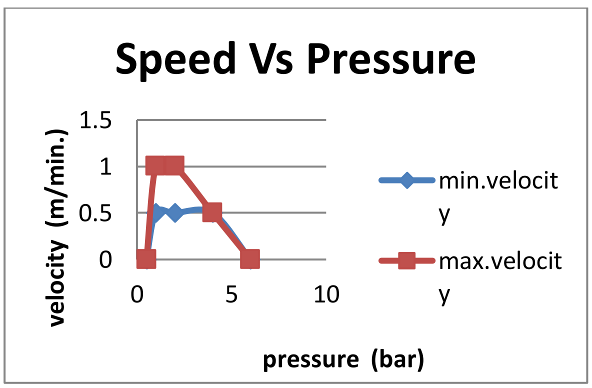

Figure 3 : Speed range Vs Pressure graph

3.1 :Energy balance equation:

Once a penetration hole is made or cut is started, it is possible with a sufficiently strong gas jet to blow the molten material out of the cut kerf and it avoids raising the temperature to boiling point or beyond that. Because of this, the cutting requires only 1/10th of the power for vaporization cutting. Here assuming that, all the energy enters the melt is removed before significant conduction occurs.

The lumped heat capacity equation based on heat balance on the material removed given as:

$\eta P = wtV\rho[C_p \Delta T + L_f + m' L_v]$ ………………………………. 1

Where,

P= incident power in W

W= Average kerf width in m

t= Thickness of work-piece in m

V= cutting speed in m/s

m'= Fraction of melt vapourised

Lf= Latent heat of fusion in J/Kg

Lv= Latent heat of vaporization in J/KgK

ΔT= Temperature rise to cause melting in K

η= Coupling coefficient

ρ= density in Kg/m3

Applying the equation 1 to the readings, values of ηP can be found out for all entries.

- In this case, conduction & latent heat effects are neglected.
- Density of mild steel is 7850 kg/m3
- Melting temperature mild steel is 1813 K.
- temperature difference to cause melting ΔT is 1813-293 = 1520K
- Specific heat capacity of steel, Cp is 620 J/kg
- Thickness of mild steel used is 0.003 m
- Let η is one

  Then the final equation is ηP = wVρCpΔTt ………………………………… 2

P =7850 x 1520 x 620 x 0.003 x w x V

= 22193520 x wV

For 1 bar & 0.5 m/min cut, power=22193520 x 0.5 x 0.477 / (60 x 1000) = 88.2 W

For different pressure and velocity cut, the power consumption is given below.

Pressure	Velocity (m/min)	Average Kerf width (mm)	Power (W)
1	0.5	0.477	88.2
1	1	0.458	169.4
2	0.5	0.521	96.3
2	1	0.531	196.4
4	0.5	0.620	114.66

Table 3: power calculated for different cuts.

According to the data the minimum energy consumed during the cut is at 1 bar and 0.5 m/min and the highest is at 1 bar and 1 m/min.

But the most efficient cut in the experiment is at 1bar gas pressure with 0.5 m/min velocity due to the straight cut with minimum heat affected zone generated.

4.0 CONCLUSION

Experimental result shows that the most effective cut was at 1 bar gas pressure with 0.5 m/min velocity. The cut at 1 bar and 1 m/min was also good but some zigzag effect was noticed in the microscopic analysis and even the power consumption is high there. While finding the optimum conditions for cutting, it is also important to consider the costs involved because the gas being used for this process is very expensive. According to the data the minimum energy consumed during the cut at 1 bar and 0.5 m/min and the highest is at 2 bar and 0.5 m/min. But the most efficient cut in the experiment is at 1bar gas pressure with 0.5 m/min velocity due to the straight cut with minimum heat affected zone generated and the energy consumed during the same is very less.

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