Effects of the Laser Process Parameters on Kerf Quality

Teeraphat Kongcharoen and Maturose Suchatawat
Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
Email: 58601121@kmitl.ac.th, maturose.su@kmitl.ac.th

Abstract—**This paper presents an experimental study on the effects of the process parameters on laser cutting of 3 mm thick mild steel plates. The parameters investigated includes laser power, gas pressure and cutting speed. The kerf width and the cut edge roughness are examined. The laser source used is a continuous wave CO_2 laser with maximum power of 4 kW. The obtained results show that as the laser power increases, the average kerf width increases. Oxygen gas pressure also has a remarkable effect on the cut edge roughness. It is found that as the gas pressure increases, the roughness is increased. Increasing of the cutting speed gives the narrower average kerf width and the smoother cut surface.**

Index Terms—**laser cutting, kerf width, cut edge roughness, striation formation**

I. Introduction

Laser cutting has been found its applications in many industries, e.g. aerospace, automotive and electronics etc. It is classified as a thermal process with outstanding advantages such as high precision, small metal deformation and small kerf. To produce the high quality end products, it is necessary to have a good cutting quality with minimum striation or roughness.

During the past years, many researchers have focused on developing the laser cutting process. Chen [1] investigated the effects of gas-composition variation and gas pressure on CO_2 laser cutting of 3 mm thick mild steel. It was found that pure oxygen gave the best cutting quality whereas using inert gas (nitrogen, argon and helium) with gas pressure lower than 6 bar were not able to produce the good cut quality.

Yilbas [2] investigated the effects of laser power, cutting speed and oxygen gas pressure on CO_2 laser cutting of 12 mm thick mild steel sheets. He reported that laser power and oxygen pressure had significant influence on the percentage of kerf width variations. Increasing of the laser power and the oxygen pressure provided high oxidation rate and hence deepened the melt zone. Consequently, the depth of stria increased drastically. Low cutting speed and low oxygen gas pressure lead to premature formation of the dross. Thomas [3] performed an experimental study on laser cutting of high stress steel. It was concluded that increasing of the laser power resulted in more distinctive of the striation as well as enlarging of the kerf width. Chen [4] found that the roughness increased with increasing oxygen and air pressure. Sharma and Yadava [5] modeled laser cutting of thin Al-alloy sheet for straight profile. They concluded that the surface roughness decreased smoothly with the increase of oxygen gas pressure regardless of the cutting speed. Cekic et al. [6] investigated the surface roughness and heat affected zone (HAZ) for the laser cutting of alloy steel using nitrogen assist gas. The reduction of roughness and HAZ width were observed at high cutting speed. Scintilla and Tricarico [7] investigated an inert gas fusion cutting. They reported that the dross height was decreased with increasing the cutting speed. In addition, the inclination of striation became higher as cutting speed and gas pressure increased. Wee and Li [8] found that the melt film thickness has influence on the formation of striation. It was also observed that melt film thickness decreased with increasing cutting speed. Salem et al. [9] investigated the dependence of oxide layers formation on oxygen gas pressure. It was shown that increasing of the oxygen gas pressure would increase the thickness of the oxide layers. Chen and Yao [10] investigated striation formation and melt removal in the laser cutting. They reported that increasing of the cutting speed or decreasing of the oxygen gas pressure resulted in decreasing of the striation depth.

Most laser cutting process aims to reach the high cutting quality with minimum processing time and cost. These can be achieved by adjustment of the laser cutting parameters which are laser power, gas pressure and cutting speed. The output parameters which indicate the cutting quality typically include the surface roughness, striation, dross, spatter and kerf width.

This paper presents an experimental investigation on the effects of process parameters on CO_2 laser cutting of 3 mm thick mild steel plates. The parameters considered are laser power, oxygen gas pressure and cutting speed. The upper and lower kerf widths and the roughness of the laser cut surfaces obtained from each operating condition are examined and measured.

II. Experimental Procedure

A. Experimental Setup

The workpieces used in the experiment were as received SS400 mild steel. The sheet dimensions were 100×100 mm^2 with thickness of 3 mm. FANUC C4000 was used to generate a CW laser beam with maximum

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power of 4000 W. The laser beam was moved by means of a CNC system (AMADA FO-3015NT). Oxygen assisting gas was supplied coaxially with the laser beam through a nozzle of 0.8 mm in diameter. Fig. 1 illustrates the schematic diagram of the experimental apparatus. Table I shows the cutting parameters used in the experiment.

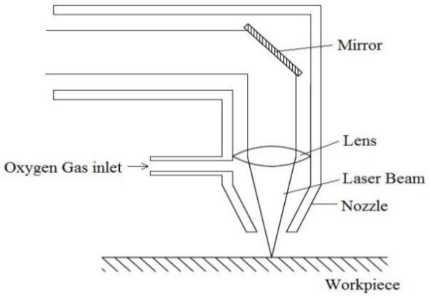


Figure 1. Schematic diagram of the experimental apparatus.

TABLE I. PROCESS PARAMETERS USED IN THE EXPERIMENT

Parameters	Values
Material	Mild steel
Thickness	3 mm
Laser power	2000, 2200, 2400 W
Gas type / pressure	O_2 / 0.07, 0.12, 0.17 MPa
Cutting speed	3100, 3400, 3700 mm/min
Nozzle diameter	0.8 mm
Nozzle standoff distance	0.7 mm

B. *Cutting Procedure*

On each mild steel plate, three straight cuts were produced using identical cutting conditions. To avoid piercing, the cut was started from the plate edge. The cut was 50 mm long with 25 mm space to the next cutting line. Note that the space between the successive cutting lines should be large enough to minimize the thermal effect from the previous cut. Fig. 2 illustrates the three cut kerf on a plate.

C. *Measurement of the Kerf Width*

The kerf width measurement was performed using the optical microscope (Olympus U-TV1X-2) with 50x magnification. Upper and lower kerf widths were measured at three locations along each cutting line and the images were captured as shown in Fig. 3. Therefore, for each operating condition, there were 9 measurements of the upper kerf widths and 9 measurements of the lower kerf widths. The average kerf width for each operating condition was then calculated by averaging the values from all 18 measurements.

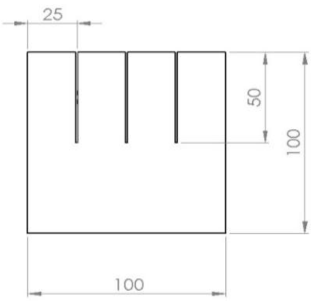
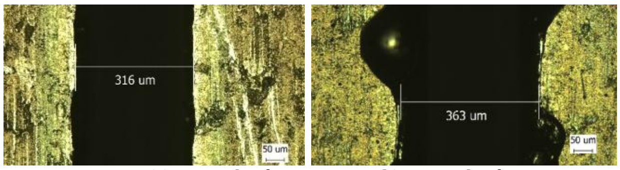


Figure 2. Laser cut kerf on the workpiece.



(a) Upper kerf (b) Lower kerf

Figure 3. Morphology of kerf.

D. *Measurement of the Roughness*

After measuring of the kerf width, the samples were cut apart to measure the roughness. A roughness tester Mitutoyo S-310 was used to measure the mean roughness, R_z, of the cut surfaces. Assessment length of the roughness tester machine was 4.8 mm with 0.8 mm cut off length.

III. RESULTS AND DISCUSSION

A. *Average Kerf Width*

Fig. 4 shows the effect of laser power on the average kerf width. Oxygen was used as an assisting gas at a constant pressure of 0.17 MPa. The laser power was varied from 2000 to 2200 and 2400 W, respectively. It can be seen that the kerf width increases as the laser power increases. This is due to the fact that higher laser power transfers more energy to the material, hence more material is melted and removed from the interaction zone. This eventually leads to the larger kerf width. Similar result was reported by other researchers [2-4]. It is also observed that the kerf width is smaller at high cutting speed. Nonetheless, effect of the cutting speed on the kerf with is less pronounced compared to the laser power.

Fig. 5 shows the plots of average kerf width versus cutting speed. Oxygen gas pressure was kept constant at 0.17 MPa. It can be seen that the kerf width generally decreases as the cutting speed is increased. This is because at low cutting speed, there is a long interaction time between the laser beam and material. Thus, more material is melted and the kerf width is larger.

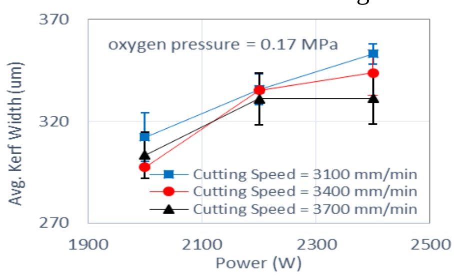


Figure 4. Effect of laser power on average kerf width.

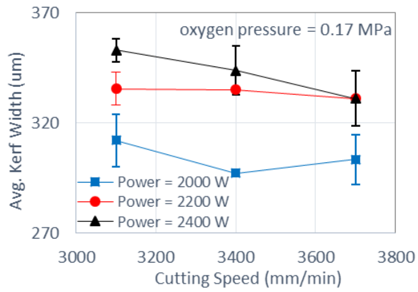
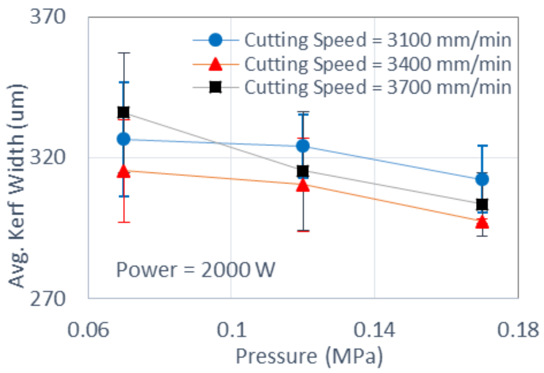
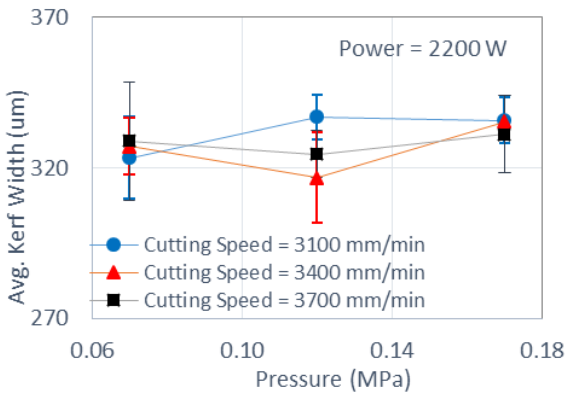


Figure 5. Effect of cutting speed on average kerf width

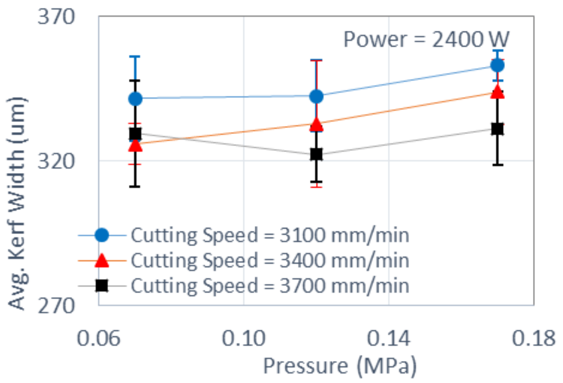
Figs. 6(a)-(c) show the average kerf width as a function of assisting gas pressure for the cases of 2000, 2200 and 2400 W laser power, respectively. It can be observed that for the cases of 2200 and 2400 W, the kerf width increases when assisting gas pressure is increased. This is because at high gas pressure, there is more oxygen to interact with the metal. This results in more exothermic energy generated. Consequently, more molten liquid is produced and blown away from the interaction area leading to the larger kerf width. Nevertheless, for low laser power (2000 W), the kerf width decreases with the increasing in gas pressure as shown in Fig. 6(a). This suggests us that there might be a threshold of the laser power in which the gas pressure causes a different affect to the kerf width.



(a) Laser power = 2000 W



(b) Laser power = 2200 W



(c) Laser power = 2400 W

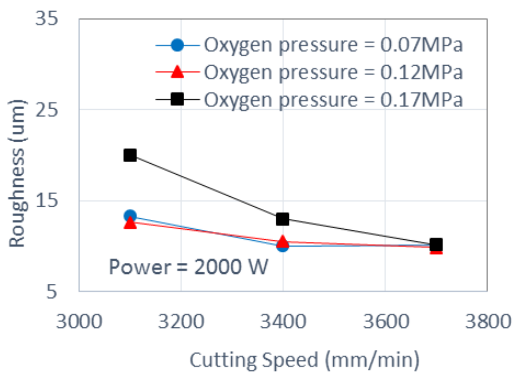
Figure 6. Effect of oxygen gas pressure on kerf width.

B. *Cut Edge Roughness*

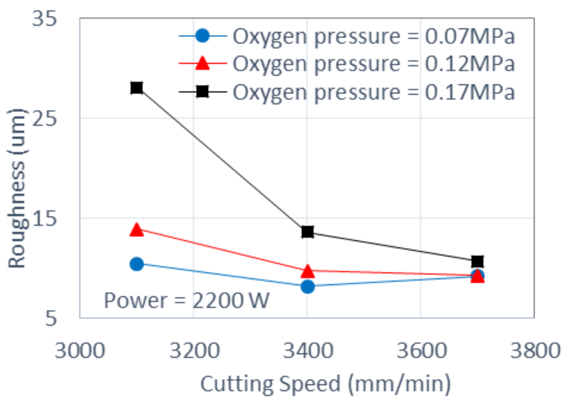
Figs. 7(a)-(c) show the cut edge roughness as a function of the cutting speed for constant laser power at (a) 2000 W, (b) 2200 W and (c) 2400 W. Obviously, the surface roughness decreases with increasing of the cutting speed for all values of the laser power. At high cutting speed, the roughness converges to a constant which is in the order of 10 µm. It is also observed that the surface is getting rougher as the gas pressure increases.

Figs. 8(a)-(c) show the effect of laser power on the cut edge roughness at three values of the cutting speed i.e. 3100, 3400 and 3700 mm/min, respectively. The results obtained exhibit distinct behavior at different cutting speed. At 3100 mm/min cutting speed, the roughness tends to increase as the laser power increases, whereas at higher cutting speed, the roughness tends to decrease. At the lowest cutting speed employed (3100 mm/min), the high gas pressure creates the largest magnitude of the cut edge roughness. This is possibly because under this operating condition, a large amount of metal melts and hence the thicker molten layer. This eventually leads to the formation of striation with high roughness. Therefore, in order to generate a smooth cut edge surface, low gas pressure should be employed.

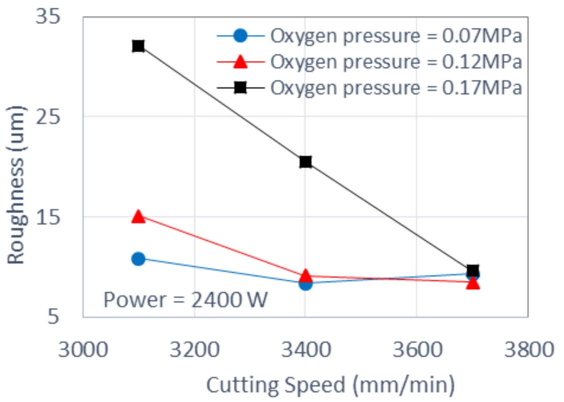
Figs. 9(a)-(c) show the effect of oxygen gas pressure on the cut edge roughness. It can be seen that the roughness increases as the gas pressure increases for all values of laser power. The amount of the oxygen supplied relates directly to the rate of exothermic reaction. Because the oxidation process is transient in nature, the amount of material thermally disturbed at the cut kerf varies. At low oxygen gas pressure, the rate of oxidation is low and hence the less thermal erosion from the cut edge. The depth of striation is therefore smaller resulting in the smoother surface. Salem et al. [9] and Chen and Yao [10] also found similar results from their studies. It is also noticed that in Fig. 9(a) which is the case of low cutting power, for cutting speed of 3100 mm/min, there is a slight decrease in the roughness as the gas pressure increases from 0.07 to 0.12 MPa. At low cutting speed, the interaction time between the laser beam and material is quite long. Which leads to the thick melt film. However, since the gas pressure is too low, a large amount of the molten liquid is not expelled from the kerf. Instead, it adheres to the wall and subsequently resolidifies. This results in the rough cut edge.



(a) Laser power = 2000 W

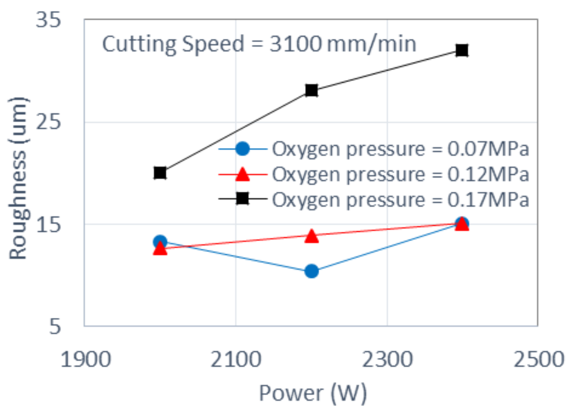


(b) Laser power = 2200 W

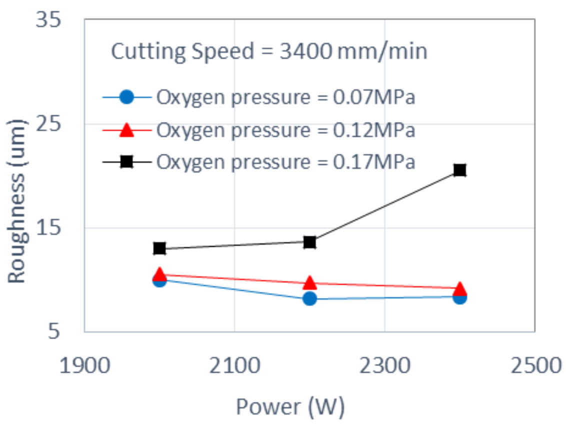


(c) Laser power = 2400 W

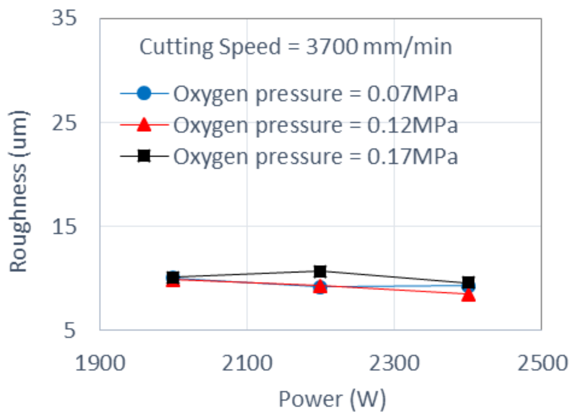
Figure 7. Effect of cutting speed on the cut edge roughness.



(a) Cutting speed = 3100 mm/min



(b) Cutting speed = 3400 mm/min

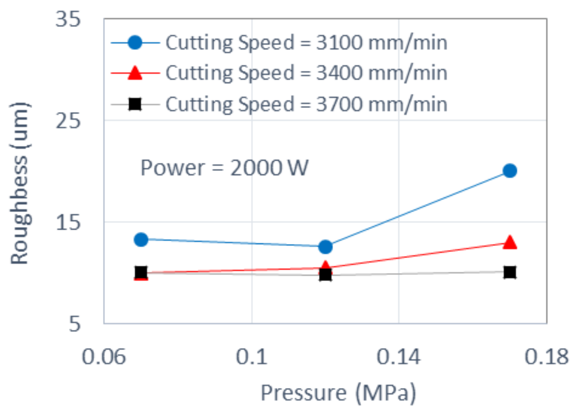


(c) Cutting speed = 3700 mm/min

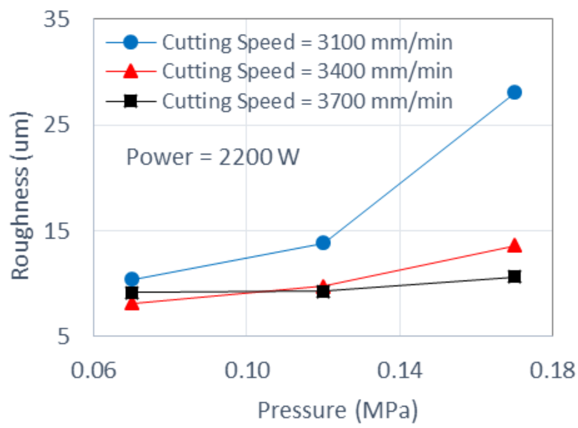
Figure 8. Effect of laser power on the cut edge roughness.

From the results presented above, the three successive values of the minimum average surface roughness (R_z) found from this experimental study are 8.174 µm, 8.371 µm and 8.517 µm, respectively. These are corresponding to the following conditions:

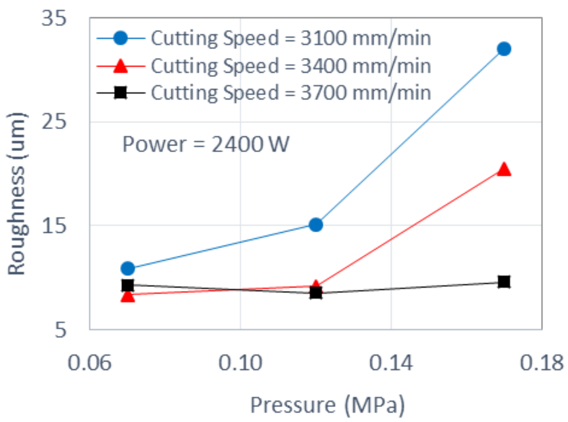
- 8.174 µm: laser power 2200 W, cutting speed 3400 mm/min, and gas pressure of 0.07 MPa.
- 8.371 µm: laser power 2400 W, cutting speed 3400 mm/min, and gas pressure of 0.07 MPa.
- 8.517 µm: laser power 2400 W, cutting speed 3700 mm/min, and gas pressure of 0.12 MPa.



(a) Laser power = 2000 W



(b) Laser power = 2200 W



(c) Laser power = 2400 W

Figure 9. Effect of oxygen gas pressure on the cut edge roughness.

IV. Conclusions

In this present study, CO_2 laser cutting of 3 mm thick mild steel plates was performed. Effects of the laser power, oxygen gas pressure and cutting speed on the kerf width and the cut edge roughness were investigated. From the obtained results, the following conclusions can be drawn:

1. The average kerf width decreases with decreasing of the laser power.
2. The average kerf width decreases with the increasing of the cutting speed.
3. Effect of the gas pressure on the average kerf width depends on the laser power applied. At low laser power, increasing of the gas pressure reduces the average kerf width. On the other hand, for moderate to high laser power, increasing of the gas pressure enlarges the kerf width.
4. The surface roughness of the cut edge decreases with increasing of the cutting speed.
5. The surface roughness of the cut edge decreases with decreasing of the oxygen gas pressure. However, at high cutting speed, impact of the oxygen gas pressure on the cut edge roughness becomes less prominent.
6. For laser power, depends on the cutting speed, increasing of the laser power can either increase or decrease the cut edge roughness.

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Maturose Suchatawat received a Ph.D. in Mechanical engineering from the University of Manchester, UK in 2012. She is currently a lecturer in the Department of Mechanical Engineering, King Mongkut’s Institute of Technology Ladkrabang, Thailand. She has taught a number of courses including Heat transfer and Fluid dynamics. Her current research focuses on the laser materials processing, of particular interest is laser drilling and cutting of metals, and two-phase gas-liquid flow in microchannels.

Teeraphat Kongcharoen obtained his bachelor’s degree in Mechanical Engineering from Burapha University, Thailand in 2013. He is currently a master student at King Mongkut’s Institute of Technology Ladkrabang. His research interest is development of the laser-metal cutting.