# Optimization of High Power $Co_2$ Laser Machining Centre's Machining Parameters by Experimental Analysis

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## ABSTRACT
**An experimental investigation is presented, which analyses the $Co_2$, laser cutting process for S.S and M.S sheet. It shows that by proper control of the cutting parameter, good quality cuts are possible at high cutting rates. Some kerf characteristics such as the width, heat affected zone (HAZ) and dross; in terms of the process parameters are also discussed.**

*Keywords* - **HAZ, Laser Cutting, Process parameter**

## I. INTRODUCTION

A statistical analysis has arrived at the relationships between the cutting speed, laser power and work piece thickness, from which a recommendation is made for the selection of optimum cutting parameters for processing S.S and M.S material. The analysis of kerf width for constant cutting speed by varying power and assist gas pressure and for constant assist gas pressure by varying power and cutting speed. The author has explained the variation in cutting speed by changing plate thickness at constant power for both the materials of S.S. and M.S., by using experimental data. Some experiments also carried out for power by changing the thickness of plate at constant cutting speed for same materials.

The author has also carried out the comparison between M.S and S.S for various process parameters and microscopic examination results. Finally, here some general conclusions are concluded from various experiments carried out for different process parameters.

## II. RELATION BETWEEN CUTTING SPEED AND LASER POWER

### 2.1. Experiement-1

| Material Thickness (mm) | 2 | 3 | 4 | 5 | 6 | 8 |
|---|---|---|---|---|---|---|
| Assist gas (Oxygen) pressure (KPa) | 10 | 10 | 10 | 8 | 7 | 7 |
| Laser Power (Watt) | 700 | 700 | 800 | 800 | 800 | 900 |
| Cutting Speed (mm/min) | 3000 | 2600 | 1800 | 1200 | 1000 | 800 |

Table 2.1 General data of process parameter

Standard sheet of M.S. has taken for an experiment. The variation of cutting speed by varying the laser power and material thickness is shown in Table 2.1

From above data it can be seen that

Material Thickness (↑) (mm) → Laser Power (↑) (watt) → (but) Cutting Speed (↓) (mm/min)

If we have increase material thickness of sheet metal then laser power increase but cutting speed decrease.

### 2.2. Experiement-2

At constant thickness, to check other process parameter such as Laser Power and Cutting Speed.

Material – Mild Steel
Assist gas pressure – 10 KPa
*2.2.1* At 2 mm thickness:

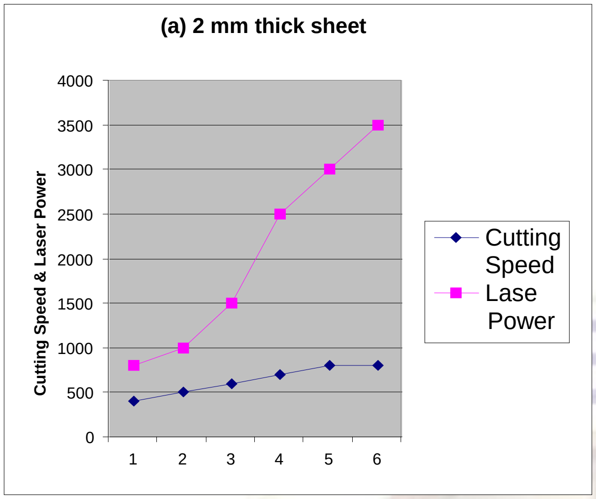


Figure 2.1 Cutting Speed Vs Laser Power

for 2mm M.S. Sheet

| Laser Power (watt) | Cutting Speed (mm/min) |
|---|---|
| 400 | 800 |
| 500 | 1000 |
| 600 | 1500 |
| 700 | 2500 |
| 800 | 3000 to 3500 |

2.2.2 At 3 mm thickness:

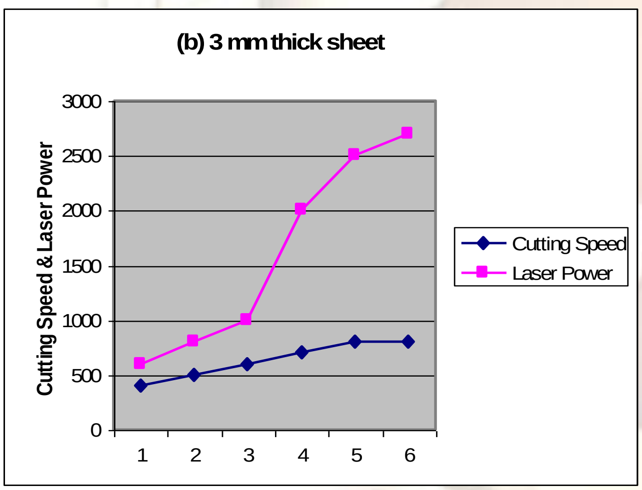


Figure 2.2 Cutting Speed Vs Laser Power

for 3mm M.S. Sheet

| Laser Power (watt) | Cutting Speed (mm/min) |
|---|---|
| 400 | 600 |
| 500 | 800 |
| 600 | 1000 |
| 700 | 2000 |
| 800 | 2500 to 2700 |

2.2.2 At 4 mm thickness:

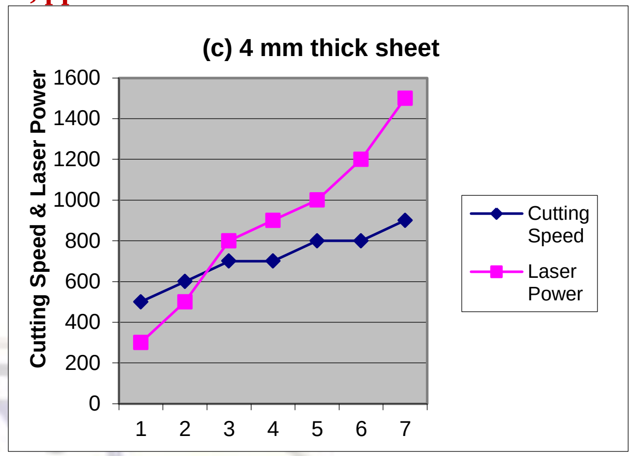


Figure 2.3 Cutting Speed Vs Laser Power

for 4mm M.S. Sheet

| Laser Power (watt) | Cutting Speed (mm/min) |
|---|---|
| 500 | 300 |
| 600 | 500 |
| 700 | 800 to 900 |
| 800 | 1000 to 1200 |
| 900 | 1500 (MAX.) |

## Conclusion:

If we have increased Laser Power then increase Cutting Speed at constant thickness.

### 2.3. Experiement-3

For stainless steel (S.S.) material:

(2.3.1) 400 Watt Power

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 1500 |
| 3 | 1200 |
| 4 | 800 to 850 |

(2.3.2) 500 Watt Power

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 2000 |
| 3 | 1500 |
| 4 | 1200 |

*(2.3.3) 700 Watt Power*

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 3000 |
| 3 | 1800 |
| 4 | 1400 |

For mild steel (M.S.) material:

(2.3.4) 400 Watt Power

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 800 |
| 3 | 600 |
| 4 | 300 |

(2.3.5) 500 Watt Power

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 1000 |
| 3 | 800 |
| 4 | 300 |

(2.3.6) 700 Watt Power

| Thickness (mm) | Cutting Speed (mm/min) |
|---|---|
| 2 | 2500 |
| 3 | 2000 |
| 4 | 800 to 900 |

From above experimental data, we can see that the cutting speed decreases with increase in material thickness at constant power supply.

## III. EXPERIEMENT FOR KERF CHARACTERISTIC

### 3.1. Experiment –1 (Kerf width in μm)

Material – Mild Steel; Thickness – 4 mm; Cutting Speed – 1350 mm/min

(3.1.1) Top surface of work-piece:

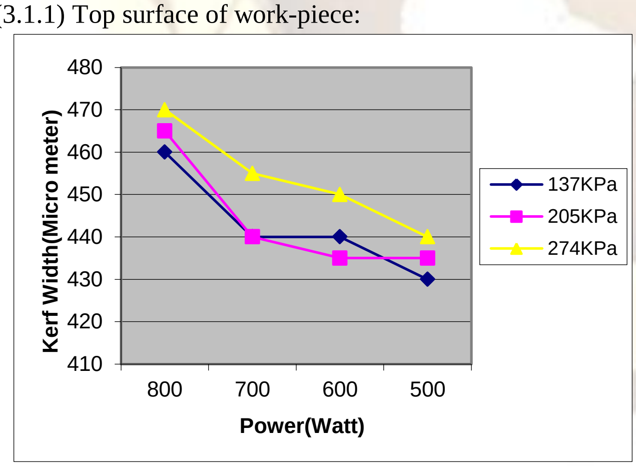


Figure 3.1 Kerf width Vs Laser Power for V=1350mm/min, e=4mm, M.S. (Top surface)

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 460 | 465 | 470 |
| 700 | 440 | 440 | 455 |
| 600 | 440 | 435 | 450 |
| 500 | 450 | 435 | 440 |

(3.1.2) Bottom surface of work-piece:

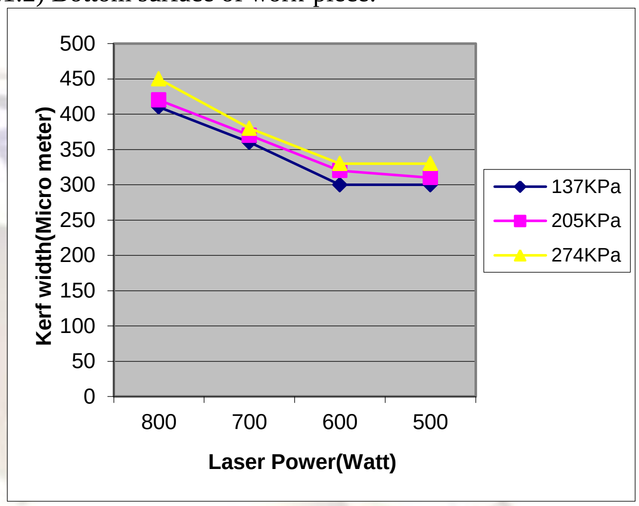


Figure 3.2 Kerf width Vs Laser Power for V=1350mm/min, e=4mm, M.S. (Bottom surface)

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 410 | 420 | 450 |
| 700 | 360 | 370 | 380 |
| 600 | 300 | 320 | 330 |
| 500 | 300 | 310 | 330 |

### 3. 2 Experiment – 2 (Kerf width in μm)

Material – Mild Steel; Thickness – 4 mm; Pressure – 102KPa

(3.2.1) Top surface of work-piece:

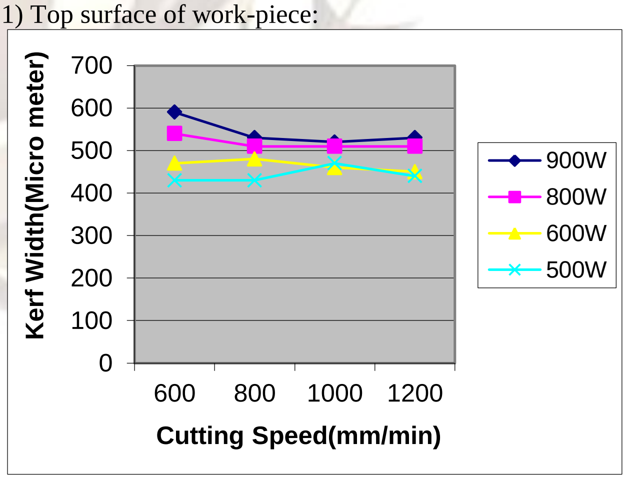


Figure 3.3 Kerf width Vs Laser Power for V=1350mm/min, e=4mm, M.S. (Top surface)

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 900 | 590 | 530 | 520 | 530 |
| 800 | 540 | 510 | 510 | 510 |
| 600 | 470 | 480 | 460 | 450 |
| 500 | 430 | 430 | 470 | 440 |

(3.2.2) Bottom surface of work-piece:

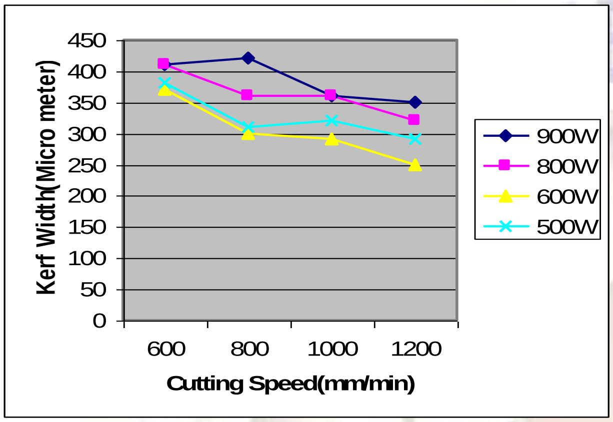


Figure 3.4 Kerf width Vs Laser Power for V=1350mm/min, e=4mm, M.S. (Bottom surface)

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 900 | 410 | 420 | 360 | 350 |
| 800 | 410 | 360 | 360 | 320 |
| 600 | 370 | 300 | 290 | 250 |
| 500 | 380 | 310 | 320 | 290 |

**3.3 Experiment –3 (HAZ -Heat Affected Zone in µm)**

Material – Mild Steel; Thickness – 4 mm; Cutting Speed – 1350 mm/min

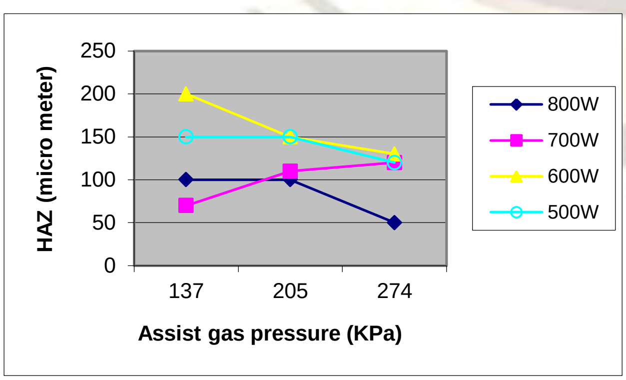


Figure 3.5 HAZ Vs Assist gas pressure for V=1350mm/min, e=4mm, M.S.

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 100 | 100 | 50 |
| 700 | 70 | 110 | 120 |
| 600 | 200 | 150 | 130 |
| 500 | 150 | 150 | 120 |

Material – Mild Steel; Thickness – 4 mm; Pressure – 102KPa

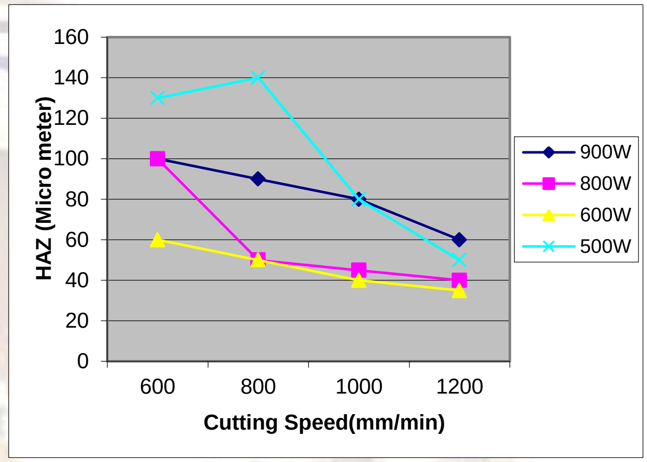


Figure 3.6 HAZ Vs Cutting speed for

P = 102KPa, e=4mm, M.S.

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 900 | 100 | 90 | 80 | 60 |
| 800 | 100 | 50 | 45 | 40 |
| 600 | 60 | 50 | 40 | 35 |
| 500 | 130 | 140 | 80 | 50 |

## Conclusion:

The kerf width generally increases with increase in assist gas pressure and laser power and decrease in cutting speed.

By actual ready of M.S. material of thickness 4mm in which kerf width increase with increase in assist gas pressure and laser power and decrease in cutting speed.

Size of HAZ increases with an increase in laser power, but reduces with an increase in cutting speed.

**3.4. Experiment – 1 (Kerf width in µm)**

Material – Stainless Steel; Thickness – 4 mm; Cutting Speed – 1350 mm/min

(3.4.1) Top surface of work-piece:

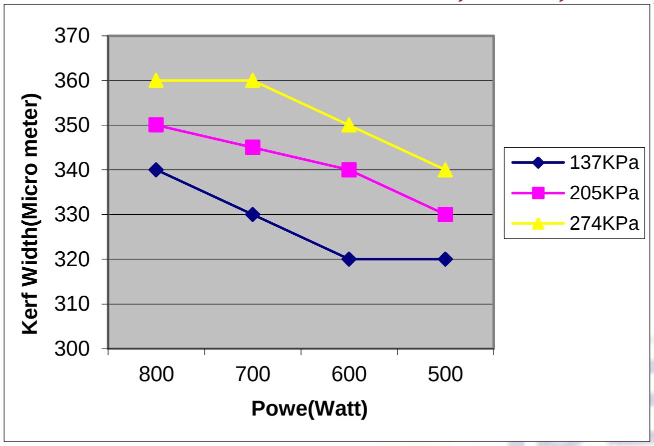


Figure 3.7 Kerf width Vs Laser Power for V=1350mm/min, e=4mm, S.S. (Top surface)

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 340 | 350 | 360 |
| 700 | 330 | 345 | 360 |
| 600 | 320 | 340 | 350 |
| 500 | 320 | 330 | 340 |

(3.4.2) Bottom surface of work-piece:

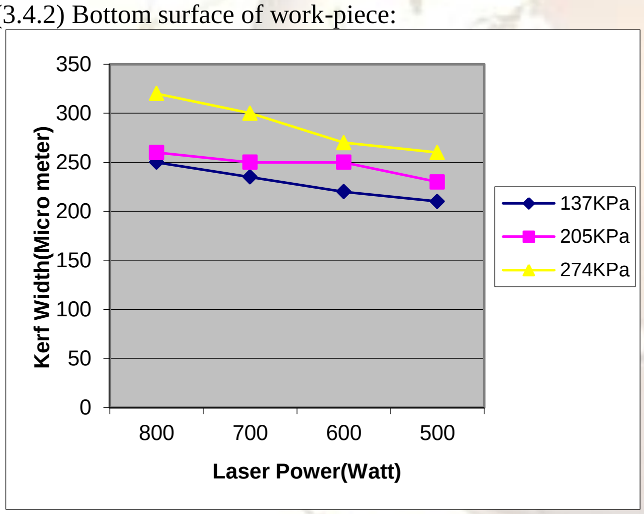


Figure 3.8 Kerf width Vs Laser Power for V=1350mm/min, e=4 mm, S.S. (Bottom surface)

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 250 | 260 | 320 |
| 700 | 235 | 250 | 300 |
| 600 | 220 | 250 | 270 |
| 500 | 210 | 230 | 260 |

**3.5. Experiment – 2 (kerf width in μm)**

Material – Stainless Steel; Thickness – 4 mm;
Pressure – 102 Kpa

(3.5.1.)Top surface of work-piece:

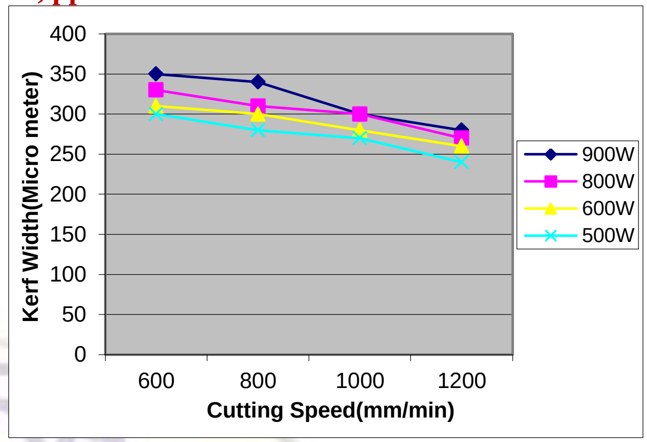


Figure 3.9 Kerf widh Vs Cutting speed for P = 102KPa, e=4mm, S.S. (Top Surface)

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 900 | 350 | 340 | 300 | 280 |
| 800 | 330 | 310 | 300 | 270 |
| 600 | 310 | 300 | 280 | 260 |
| 500 | 300 | 280 | 270 | 240 |

(3.5.2) Bottom surface of work-piece:

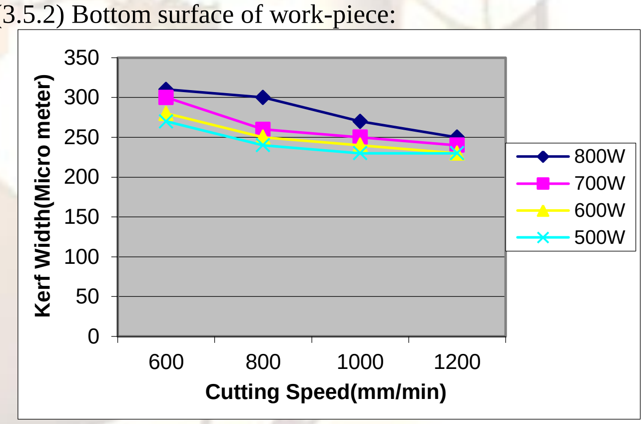


Figure 3.10 Kerf widh Vs Cutting speed for P = 102KPa, e=4mm, S.S. (Bottom Surface)

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 800 | 310 | 300 | 270 | 250 |
| 700 | 300 | 260 | 250 | 240 |
| 600 | 280 | 250 | 240 | 230 |
| 500 | 270 | 240 | 230 | 230 |

**3.6. Experiment –3 (HAZ -Heat Affected Zone in μm)**

Material – Stainless Steel; Thickness – 4 mm;

Cutting Speed – 1350 mm/min

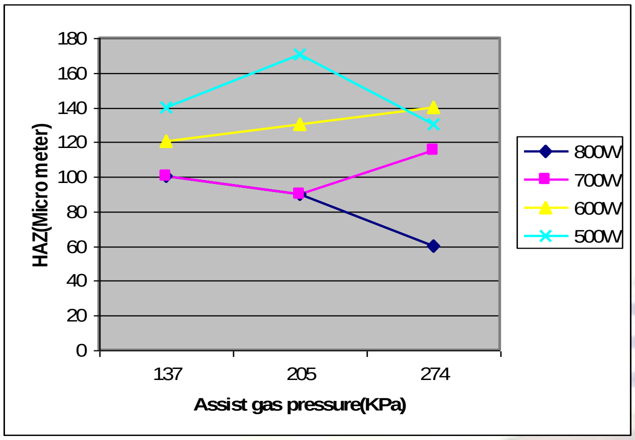


Figure 3.11 HAZ Vs Assist gas pressure for V=1350mm/min, e=4mm, S.S.

| Laser Power (Watt) | Pressure (KPa) | | |
|---|---|---|---|
| | 137 | 205 | 274 |
| 800 | 100 | 90 | 60 |
| 700 | 100 | 90 | 115 |
| 600 | 120 | 130 | 140 |
| 500 | 140 | 170 | 130 |

Material –Stainless Steel; Thickness – 4 mm;
Pressure – 102KPa

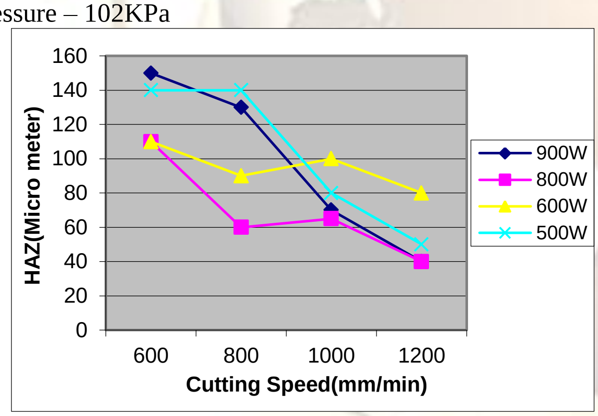


Figure 3.12 HAZ Vs Cutting speed for P = 102KPa, e=4mm, S.S.

| Laser Power (Watt) | Cutting Speed (mm/min) | | | |
|---|---|---|---|---|
| | 600 | 800 | 1000 | 1200 |
| 900 | 150 | 130 | 70 | 40 |
| 800 | 110 | 80 | 90 | 70 |
| 600 | 110 | 90 | 100 | 80 |
| 500 | 150 | 140 | 80 | 50 |

## Conclusion:

The kerf width generally increases with increase in assist gas pressure and laser power and decrease in cutting speed.

By actual ready of S.S. material of thickness 4mm in which kerf width increase with increase in assist gas pressure and laser power and decrease in cutting speed.

Size of HAZ increases with an increase in laser power, but reduces with an increase in cutting speed.

## IV. COMPARISON OF QUERRY'S MODEL AND MIYAZAKI'S MODELS FOR PROCESS PARAMETERS:

There are three classes of through cuts. In class I cut, the kerf width at bottom is greater than that of top surface and also cuts were obtained with massive dross attached at the bottom edges and surrounding area. In class II cuts also obtained with massive dross attached at the bottom edges and surrounding area. To achieve class III cuts are very difficult, because class III cuts are very accurate. For getting class III cuts with optimize process parameters, here considering the comparison of two models given by Querry and Miyazaki. For this comparison all reading are taken from the previous experimental data.

Querry's model:

$$V = 7430\, e^{-1.06}\, P^{\,0.63}$$

Miyazaki model:

$$V = 3500\, e^{-0.56}\, P^{\,0.5}$$

Where,
V = Cutting speed
e = Material thickness
P = Laser power supply (kW)

**Table. (4.1)**

| Thick -ness (mm) | Assist oxygen pre. (kPa) | Laser Power (W) | Cutting Speed (mm/min) | Querry model | Miyazaki model |
|---|---|---|---|---|---|
| 2 | 10 | 600 | 1500 | 2593 | 1839 |
| 3 | 10 | 700 | 2000 | 1857 | 1582 |
| 4 | 10 | 800 | 1200 | 1489 | 1440 |

For analysis, if cutting speed and energy consumption (laser energy input) are considered as economic measures, and cut quality is the technological performance measure, the combinations of process parameters, which may be used for good quality cuts, are given in Table (4.1). This recommendation is also consistent with that derived from the energy efficiency analysis presented above. The calculated cutting speeds for a given laser power and assist gas pressure from the two empirical models (curve fitted from experimental data) in the literature for sheet metals are also obtained for comparison. It is apparent that Querry's model can give cutting speeds to obtain class III cuts for the materials. But Miyazaki's model may be more applicable because all calculated cutting speeds are lower than that of Querry's model. Nevertheless, higher productivity can be achieved by using the recommendation from this study.

## V. COMPARISON OF PROCESS PARAMETER FOR M.S. AND S.S

- From the observed results, we can conclude that, for the same Laser Power, Kerf Width in M.S. is greater than that of the S.S.
- At same Laser Power, Kerf width in M.S. for top surface is comparatively greater than that of the S.S. by varying the Assist gas pressure at constant Cutting Speed.
- At same Laser Power, Kerf width in M.S. for bottom surface is comparatively greater than that of the S.S. by varying the Assist gas pressure at constant Cutting Speed.
- At same Laser Power, Kerf width in M.S. for top surface is comparatively greater than that of the S.S. by varying the Cutting Speed at constant Assist gas pressure.
- At same Laser Power the HAZ in M.S. and S.S. is nearly same by varying Assist gas pressure at constant Cutting Speed.
- At same Laser Power the HAZ in S.S. is comparatively greater than that of M.S. by varying Cutting Speed at constant Assist gas pressure.

## VI. CONCLUSION

- For the same Laser Power, Kerf width in M.S. is greater than that of S.S.
- At the same Laser Power. Kerf width in M.S. for top surface is comparatively greater to the tune of 23% than that of the S.S. when the Assist gas pressure is varying, keeping cutting speed constant.
- At the same Laser Power, Kerf width in M.S. for bottom surface is comparatively greater to the tune of 28% than that of the S.S. when the Assist gas pressure is varying, keeping cutting speed constant.
- At the same Laser Power, Kerf width in M.S. for top surface is comparatively greater to the tune of 47% than that of the S.S. when the Cutting speed is varying, keeping Assist gas pressure constant.
- At the same Laser Power, Kerf width in M.S. for bottom surface is comparatively greater to the tune of 28% than that of the S.S. when the Cutting speed is varying, keeping Assist gas pressure constant.
- At same Laser Power the HAZ in M.S. and S.S. is nearly same when Assist gas pressure is varying, keeping Cutting speed constant.
- At same Laser Power the HAZ in S.S. is comparatively greater than that of M.S. when Cutting speed is varying, keeping Assist gas pressure constant.

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