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OPTIMIZATION OF HIGH POWER CO_2 LASER MACHINING CENTRE'S MACHINING PARAMETERS BY EXPERIMENTAL ANALYSIS FOR FINE QUALITY CUT

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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. To check surface roughness identified Ra value for fine quality cut by using measuring instrument and make comparison for different thickness sheet.

Keywords- HAZ, Laser Cutting, Kerf Width, Surface Roughness, Ra Value, Laser Cutting 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

EXPERIEMENT-1

Table 1 General data of process parameter

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

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 1.

From above data it can be seen that

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

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

EXPERIMENT - 2

To see effect of variation of laser power on cutting speed at constant assistant gas pressure for M.S. sheet
Material – Mild Steel
Assist gas pressure – 10 KPa

1. **Results at 2 mm thickness**

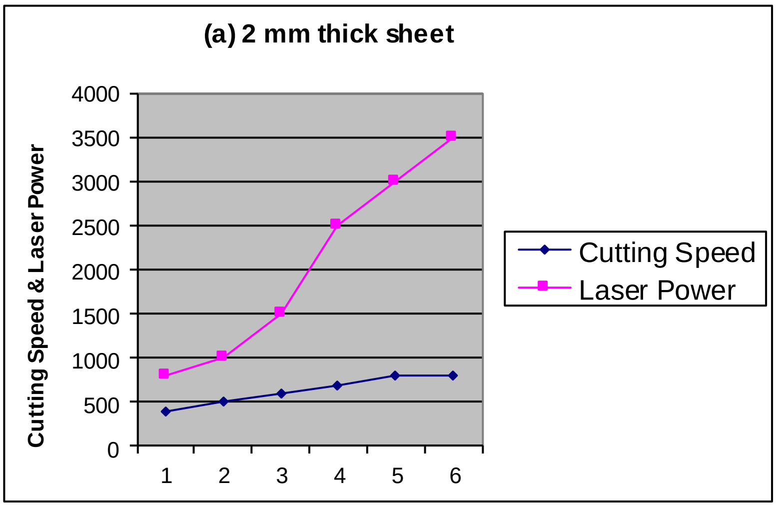


Figure 1 Cutting Vs Laser Power for 2mm M.S. Sheet

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

2. Result at 3 mm thickness

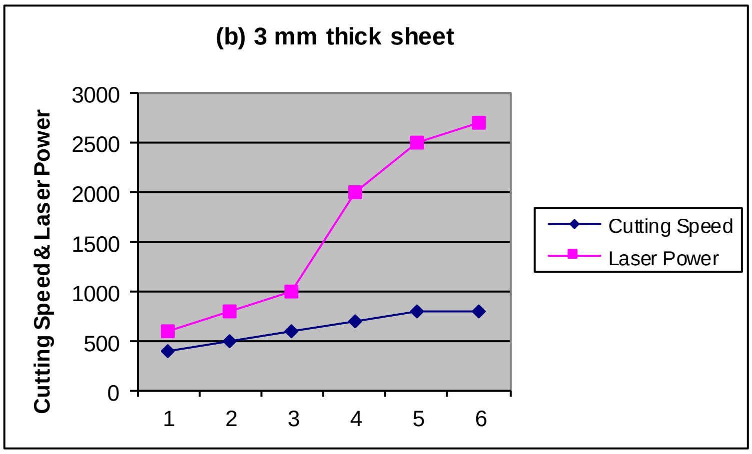


Figure 2 Cutting Vs Laser Power for 3mm M.S. Sheet

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

3. Results at 4 mm thickness

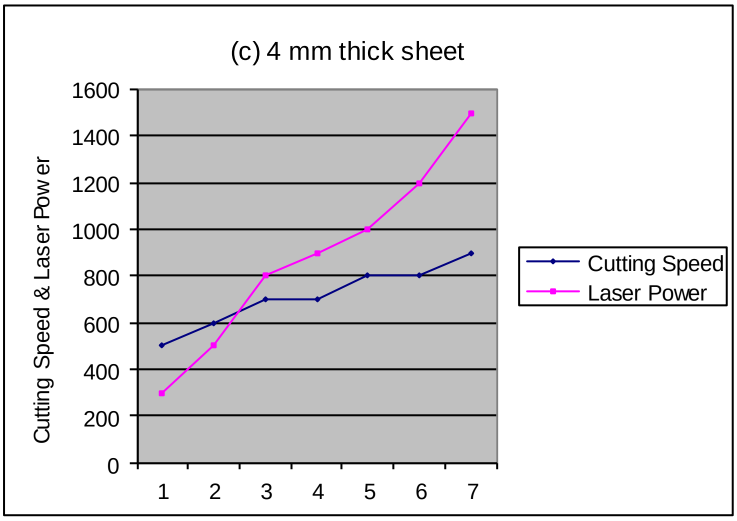


Figure 3 Cutting Vs Laser Power for 4mm M.S. Sheet

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

RELATION BETWEEN CUTTING SPEED AND MATERIAL THICKNESS
EXPERIMENT – 1

To see effect of variation of work piece thickness on cutting speed by keeping laser power constant on S.S. Material.

(A) Result at 400 Watt Laser Power

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

(B) Result at 500 Watt Laser Power

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

(C) Result at 700 Watt Laser Power

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

EXPERIMENT – 2

To see effect of variation of work piece thickness on cutting speed by keeping laser power constant on M.S. Material.

(A) Result at 400 Watt Laser Power

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

(B)Result at 500 Watt Laser Power

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

(C) Result at 700 Watt Laser Power

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

EXPERIMENT – 3

To see effect of variation of work piece thickness on laser power by keeping cutting speed constant on S.S. Material.

(A) Result at 1000 mm/min Cutting speed

Thickness (mm)	Power (Watt)
2	300
3	400
4	450

(B) Result at 1500 mm/min Cutting speed

Thickness (mm)	Power (Watt)
2	400
3	500
4	600

From above experimental data, we can see that the cutting speed decrease with increase in material thickness at constant power supply for both M.S. and S.S.

III. 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 then 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 2 Comparison of Model for fine cut quality

Thickness (mm)	Assist Oxygen Pressure (KPa)	Laser Power (W)	Cutting Speed (mm/min)	Querry's 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 5.2. 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 then that of Querry's model. Nevertheless, higher productivity can be achieved by using the recommendation from this study.

IV. EFFECT OF LASER POWER AND CUTTING SPEED ON KERF WIDTH AND HAZ

To see effect of variation of laser power and cutting speed on kerf width and HAZ (Hear Affected Zone) for both M.S. and S.S. and compared these data for optimization.

For M.S. material

EXPERIMENT –1

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

(1) **Top surface of work-piece:**

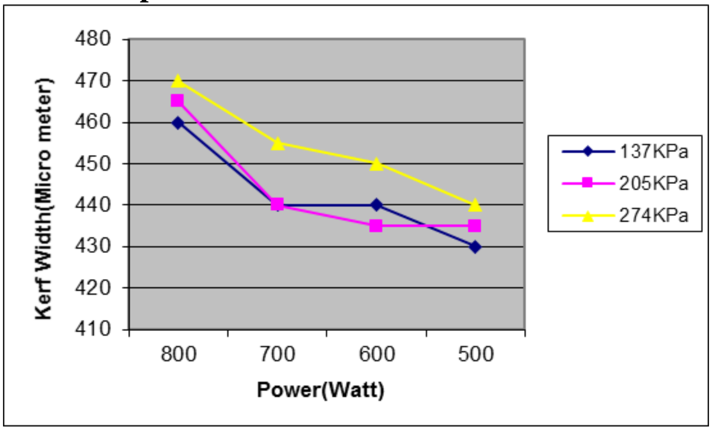


Figure 4 Kerf width Vs Laser Power for V=1350 mm/min, e = 4mm, M.S. (Top Surface)

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

(2) Bottom surface of work-piece:

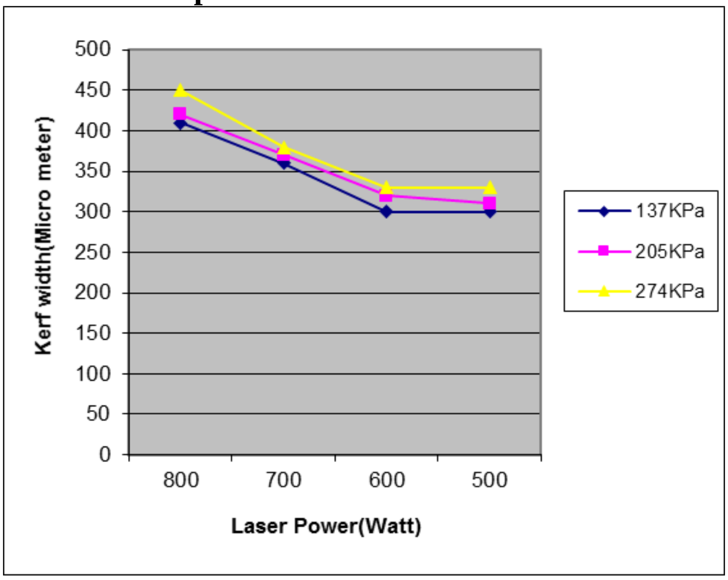


Figure 5 Kerf width Vs Laser Power for V=1350 mm/min, e = 4mm, M.S. (Bottom Surface)

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

EXPERIMENT –2
Material – Mild Steel
Thickness – 4 mm
Pressure – 102KPa

(1)Top surface of work-piece:

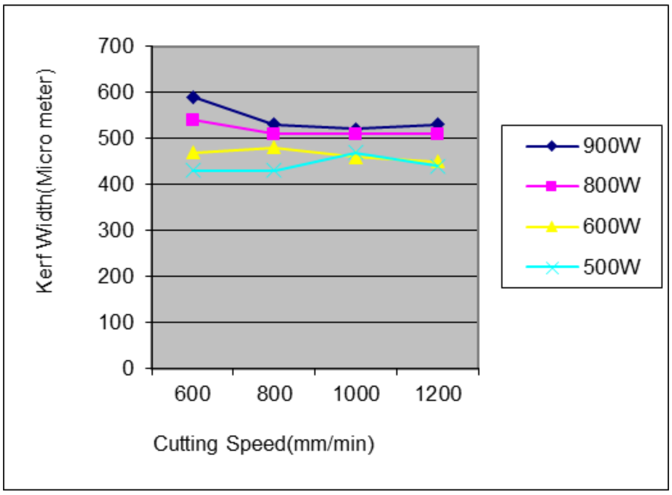


Figure 6 Kerf width Vs Laser Power for P=102KPa, e = 4mm, M.S. (Top Surface)

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

(1) Bottom surface of work-piece:

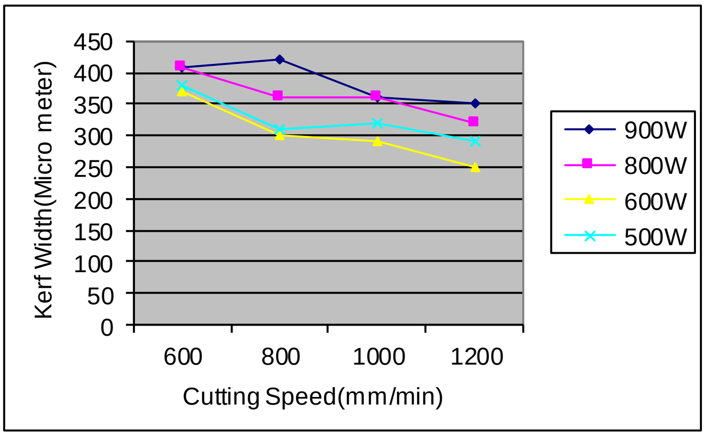


Figure 7 Kerf width Vs Laser Power for P=102KPa, e = 4mm, M.S. (Bottom Surface)

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

Experiment –3
Material – Mild Steel
Thickness – 4 mm
Cutting Speed – 1350 mm/min

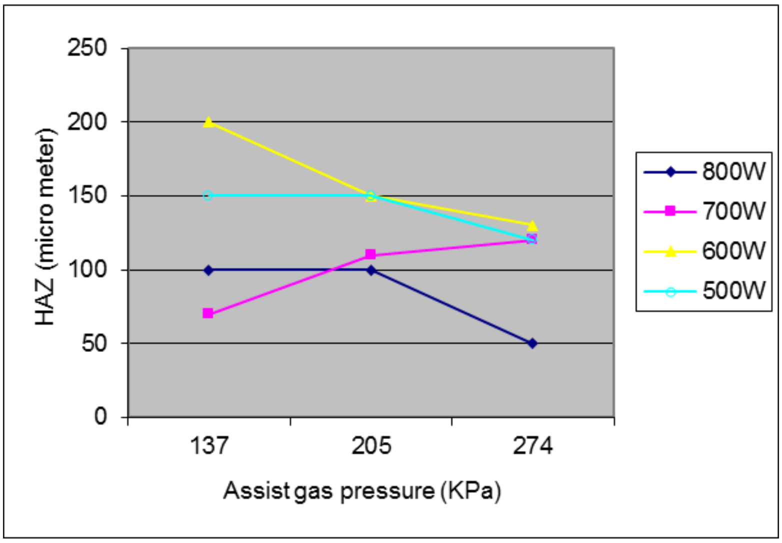


Figure 8 HAZ Vs Assist gas pressure for V=1350mm/min, e = 4mm, M.S.

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

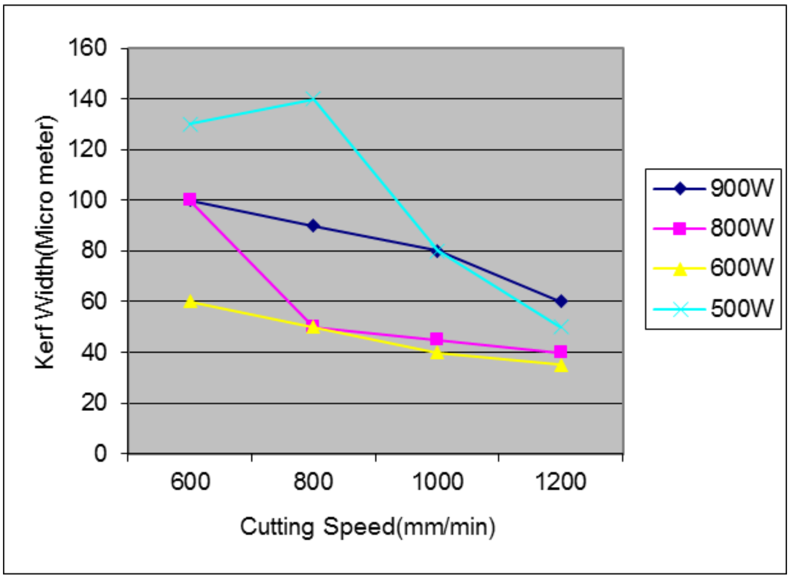


Figure 9 HAZ Vs Cutting speed for P=102KPa, e = 4mm, M.S.

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

From above table it can be seen that

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.

For S.S. material

EXPERIMENT –1

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

(1) Top surface of work-piece:

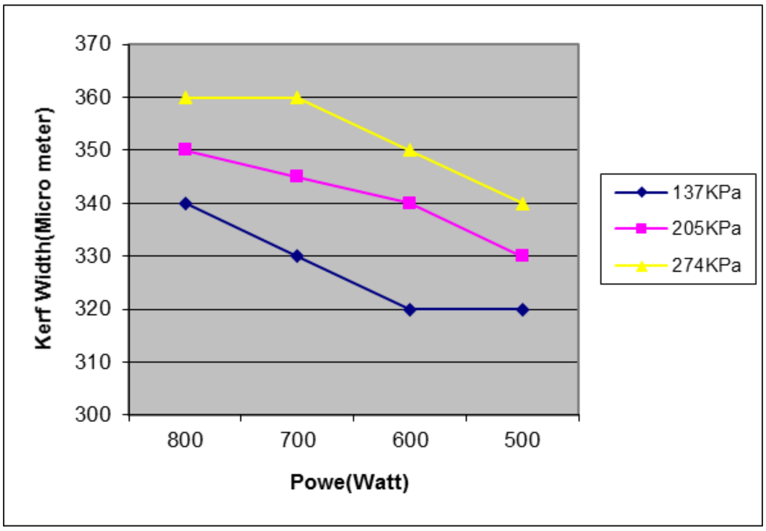


Figure 10 Kerf width Vs Laser Power for V=1350mm/min, e = 4mm, S.S. (Top Surface)

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

(2) Bottom surface of work-piece:

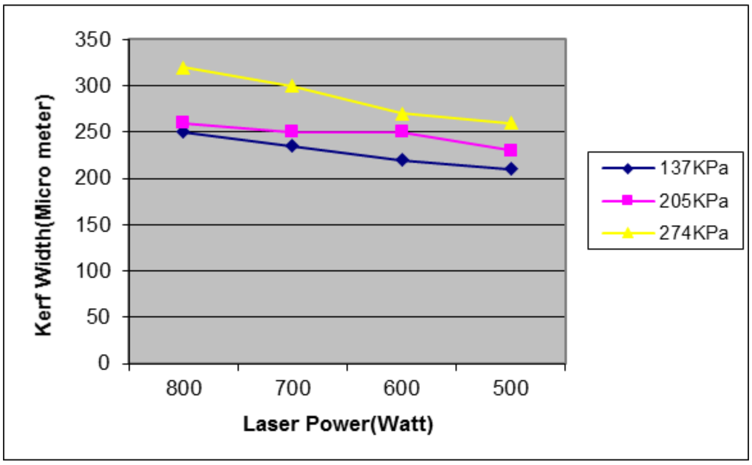


Figure 11 Kerf width Vs Laser Power for V=1350mm/min, e = 4mm,S.S.

(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

EXPERIMENT –2

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

(1) Top surface of work-piece:

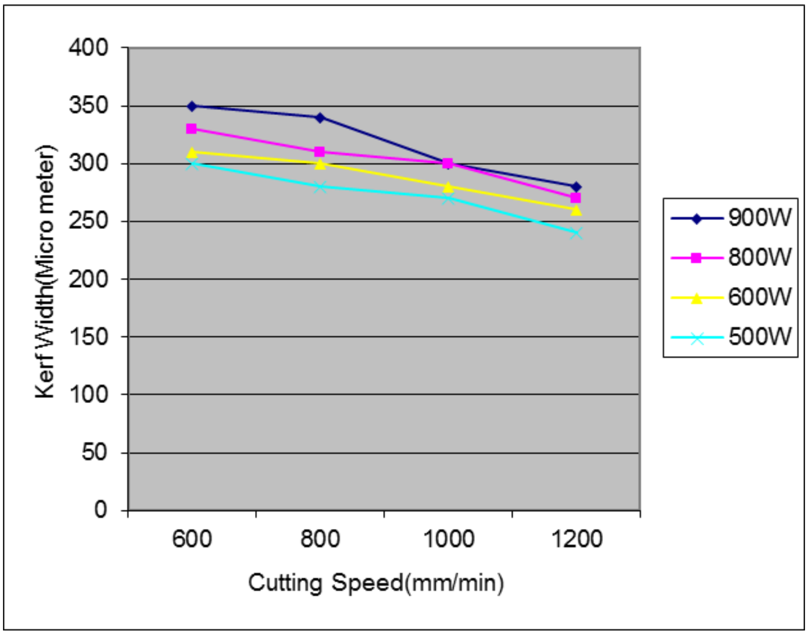


Figure 12 Kerf width Vs Laser Power for P=102KPa, e = 4mm, S.S. (Top Surface)

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

(2) Bottom surface of work-piece:

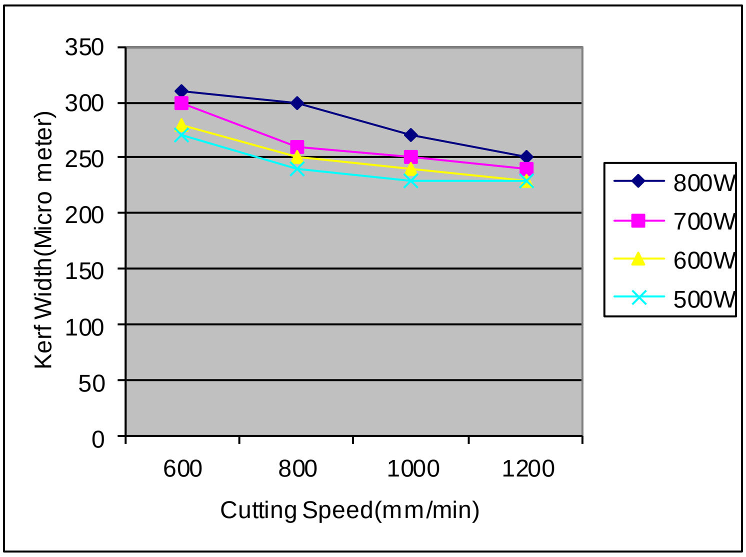


Figure 13 Kerf width Vs Laser Power for P=102KPa, e = 4mm, S.S. (Bottom Surface)

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

EXPERIMENT –3
Material – Stainless Steel
Thickness – 4 mm
Cutting Speed – 1350 mm/min

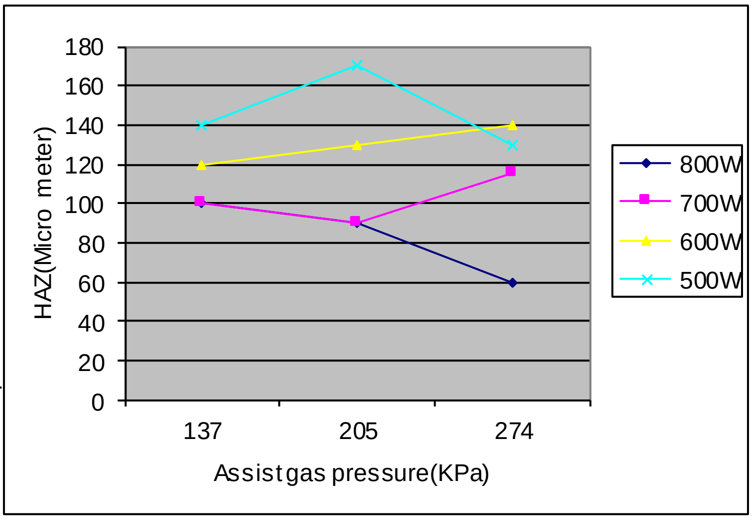


Figure 14 HAZ Vs Assist gas pressure for V=1350mm/min, e = 4mm, S.S.

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

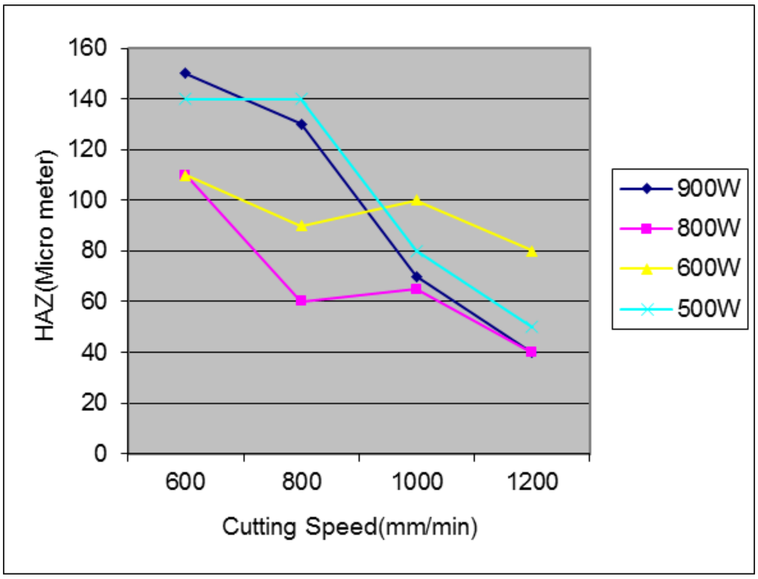


Figure 15 HAZ Vs Cutting speed for P=102KPa, e = 4mm, S.S.

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

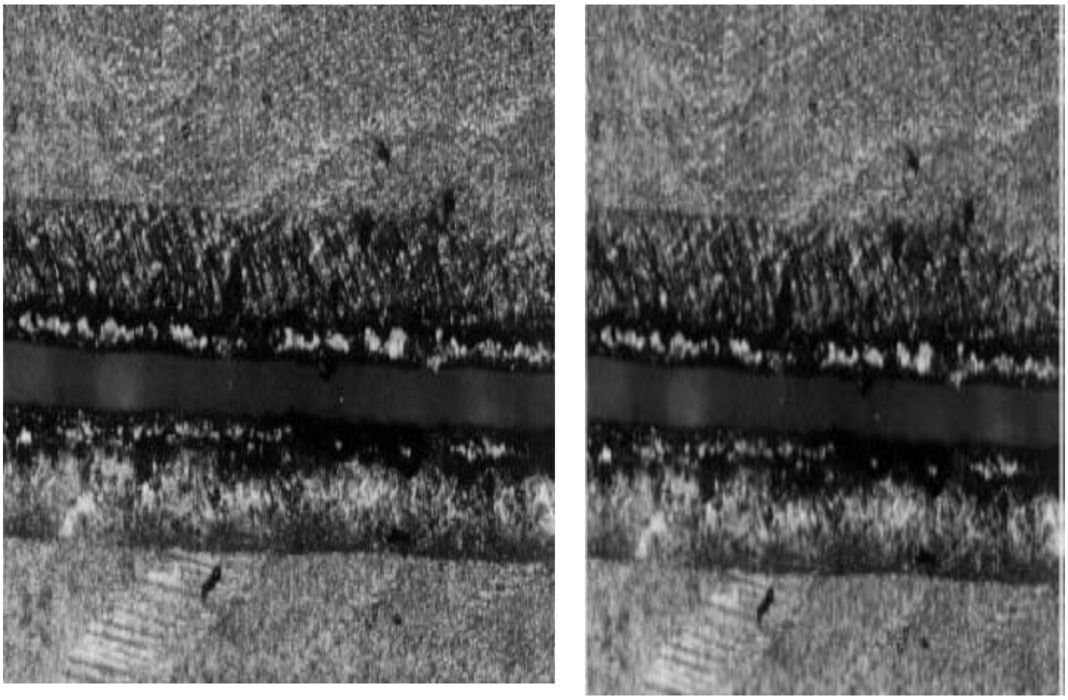
From above table it can be seen that

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.

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

VI. MICROSCOPIC DATA OF HAZ AND KERF WIDTH



(a) Top surface **(b) Bottom surface**

Figure 16 Kerf produced by CO_2 laser on 4mm specimen P=800 W,

V= 1350 mm/min, Pr = 137 KPa

When examining the HAZ and dross deposition, it is found that for all the cuts using low cutting speeds, there was severe thermal damage to work piece. A moderate case is shown in Figure 16 (a) and (b). The molten material is drawn towards the sides of the cuts (the cooler zone) and is propelled downwards along a kerf walls by the gas jet together with the molten substrate. The melt eventually deposits at the exit to form excessive burrs, as shown in Figure 16. Slage can also be seen deposited in the surrounding area of the exit kerf. There was no marked difference in quality between the kerfs for different cutting speeds in this range, possibly because of small spacing between the speeds.

By contrast, cutting with high speeds has resulted in high quality cuts with minimum HAZ. By properly selecting the process parameters, the oxides presented on the outlet face can also be minimized to form class III cuts.

VII. SURFACE ROUGHNESS READING OF FINE QUALITY CUT SHEET

Table 3 Cutting conditions

	Condition 1 (2mm)	**Condition 2 (3mm)**
Cutting speed [mm/min]	3000	2600
Power [W]	700	700
Gas pressure [KPa]	10	10

After cutting a plate with the condition of Table 3, we used an instrument of stylus type (Surftest SV-600, Mitutoyo) for the measurement of a surface roughness. The measurement data of cutting face is calculated by the average value through 5 times of cutting for data reliability. The results of surface roughness are listed in Table 4. From Table 4, each surface roughness is different according to each cutting condition. This clearly shows that we need to obtain the optimal cutting condition using experiments.

Table 4 Results of cutting conditions

Thickness	**Results [µm]**	
	Condition 1	**Condition 2**
2mm	2.901	3.112
3mm	3.258	3.001

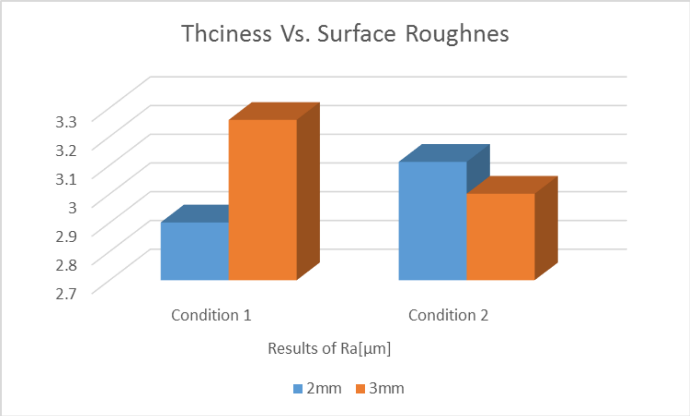


Figure Thickness Vs. Surface Roghness

% Error in Surface Roughness for 2mm = (3.112-2.901)/3.112 = 0.067

% Error in Surface Roughness for 3mm = (3.258-3.001)/3.258 = 0.078

Average Surface Roughness for fine quality cut = (0.067 + 0.078)/2 = 0.0725 µm

VIII. 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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