

Comprehensive Analysis of CO₂ Laser Cutting Process for AISI 304 Stainless Steel

S.Saravanakumar¹, T.Sathishkumar², A.Muthukumar³, Dr.M.Sivaraja⁴

¹ Assistant Professor, ² Lecturer, ⁴ Principal,

N.S.N. College of Engineering and Technology, Karur, Tamilnadu, India.

³ Associate Professor, Cheran College of Engineering, Karur, Tamilnadu, India

E-Mail: ¹saravana.hitz@live.com, ²sathishqkumar@hotmail.com

Abstract— Laser cutting of sheet metal has become an economically viable method of production through advances in technology. The quality of laser cut is of the utmost importance in laser cutting process. CO₂ laser machine has been used in industry for many applications such as laser cutting, laser engraver and laser marking. Laser cutting process is one of the famous applications of laser machine in industry. Laser beam usually used to cut small and precise products for assembly parts. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut has been rise as critical issues in industry due to the improper setting of cutting parameters. All cutting parameters might have significant influence on the resulting quality of work. In general, cutting parameters are adjusted and tuned to provide the quality of cut desired. But this consumes exhaustive amounts of time and effort. Therefore, it is important to investigate the impact of cutting parameters on quality of cut.

The aim of this study is to relate the CO₂ laser cutting parameters namely Laser Power, Gas Pressure and Cutting Speed to the quality of cut of Stainless Steel Sheet. The quality parameters considered include the measurement of Outlet Diameter, Inlet Diameter and the Operation Cost. The effects of each cutting parameters on quality of cut was establish and the interactions between the cutting parameters were investigated. Design of Experiment was used by implementing Design Expert Software to identify the main effects and interactions of the parameters. Once the best value is find out the other quality parameter like Surface Roughness, Kerf Width and Heat Affected Zone are examined.

Keywords – AISI 304 SS, Laser Cutting, Laser Power, Gas Pressure, Cutting Speed, Inlet Dia, Outlet Dia, Operation Cost.

I. INTRODUCTION

CO₂ Laser machine has been used in industry for many applications such as laser cutting, laser engraver and laser marking. Laser cutting process is one of the famous applications of laser machine in industry. Laser beam usually used to cut small and precise products for assembly parts. The finished product of laser cutting process does not need any further finishing process. However, poor quality of cut has been rise as critical issues in industry due to the improper setting of cutting parameters. In order to solve this problem, a research study on the impact of cutting parameters on quality of cut was carried out. In this research, the main objective will focus on the impact of the cutting parameters of a specify machine on the quality of cut on AISI 304 SS sheet.

II. PROBLEM STATEMENT

Quality of cut has been a critical issue in laser cutting process. For stainless steel cutting such as AISI 304 (L) SS sheet, when the profile cut is a hole the required outer diameter, inner diameter measured is found to be unsatisfactory for the customer. The edges will always be brown or yellow, and it produces hydrochloric acid during the cutting, which will eat up everything inside the laser and in the exhaust system. Currently, there are some problems with the laser cutting process which require immediate attention.

III. PARAMETERS INVOLVED

The main objectives of this project is to find out the optimum

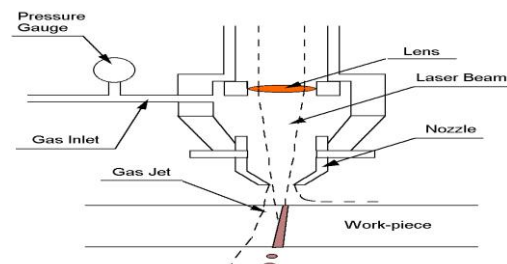
- i. Laser power in Watts
- ii. Laser cutting speed in mm/min
- iii. Laser gas pressure in Mpa

Such that the operation cost involved is minimum. Once the new specimen is prepared it is been examine under Tool Makers Microscope and the following factor are compared with specimen that is prepared on experimental run.

- i. Inlet Diameter in mm
- ii. Outlet Diameter in mm
- iii. Cutting Cost in Rs/hr

IV. CO₂ LASER CUTTING PROCESS

Carbon dioxide lasers are the highest-power continuous wave lasers that are currently available. The laser creates a beam of light that is used to cut through the material, so there is no part of the laser system in contact with the material.



The laser beam must first penetrate the material at a certain point, before a contour can be cut. The piercing can be done quickly with full laser power or slowly using the so- called “ramp”. When creating a start hole in the ramp mode, the laser output is gradually increased, and then it is held constant until the start hole has been formed and finally the output is again slowly reduced.

Using high laser power, the material is heated, melted and partly vaporized. The material is blown out of the Kerf. The cutting flow of gas, which aids the removal of melting, is emitted together with the laser beam out of the nozzle. The Kerf is created by moving the work piece or the cutting head. Both the piecing and the laser cutting can be aided by adding a gas and thereby influence the cutting results. The choice of piercing gas or cutting gas depends on which material is being machined and level of quality needed for the work piece.

v. QUALITY OF CUT

Quality of the cut is satisfied only when the following three factors are satisfied they are

- i. Geometry Factor (Inner, Outer diameter)
- ii. Cost Factor (Operation Cost)
- iii. Other Quality Factors (HAZ, Surface Roughness, Kerf Width)

Quality of Cut on Geometry Factor:

The geometry factor includes measurement of the outer diameter, the inner diameter, length, breath, arc and straight cut after the cutting operation is performed. The outer diameter is the diameter of the hole on the upper surface of the work piece where the laser beam hit the surface at first. The inner diameter is the diameter of the hole on the lower surface of the work piece where the laser beam leaves the work piece.

Quality of Cut on Cost Factor:

Laser cutting operating costs can be estimated as cutting per hour or per unit length. The laser system used in this work utilized CO₂ using a static volume of laser gases of approximately 7.5 liters every 72 h. For this laser system with 3 KW maximum output power the operating costs is calculated as follows.

Cost Calculation:

$$\begin{aligned}
 \text{Laser Electrical Power} &= 22 \text{ KVA} \times 0.8 \times \text{Rs.}10 \times \frac{P}{0.5} \\
 &= \frac{22 \times 0.8 \times 10 \times P}{1.5} \\
 &= \text{Rs. } 117.30 P \\
 \text{Chiller Electrical Power} &= 12 \text{ KVA} \times 0.8 \times \text{Rs. } 10 \\
 &= 12 \times 0.8 \times 10 \\
 &= \text{Rs. } 96 \text{ /-} \\
 \text{Motion Controller Power} &= 0.5 \text{ KVA} \times 0.8 \times \text{Rs. } 10 \\
 &= 0.5 \times 0.8 \times 10 \\
 &= \text{Rs. } 40 \text{ /-} \\
 \text{Exhaust Power System} &= 0.9 \text{ KVA} \times \text{Rs. } 10 \\
 &= 0.9 \times 10 \\
 &= \text{Rs. } 9 \text{ /-} \\
 \text{Laser Gas} &= \frac{\text{Rs.}8500 \text{ / bottle}}{1500 \text{ l / bottle}} \times \frac{7.5 \text{ l}}{72 \text{ hrs}}
 \end{aligned}$$

$$\begin{aligned}
 &= 5.66 \times 0.104 \\
 &= \text{Rs. } 0.589 \text{ /-} \\
 \text{Gas Bottle Rental} &= \frac{\text{Rs.}1500}{720 \text{ hrs}} \\
 &= \text{Rs. } 20.80 \text{ /-} \\
 \text{Compressed Nitrogen} &= 0.8 f \\
 \text{Nozzle Tip} &= \frac{\text{Rs.}600}{200 \text{ hrs}} \\
 &= \text{Rs. } 3 \text{ /-} \\
 \text{Exhaust System} &= \frac{\text{Rs.}420}{100 \text{ hrs}} \\
 &= \text{Rs. } 4.20 \text{ /-} \\
 \text{Focus lens} &= \frac{\text{Rs.}1500 \text{ / lens}}{1000 \text{ hrs}} \\
 &= \text{Rs. } 15 \text{ /-} \\
 \text{Maintenance \& Labor} &= \frac{12 \text{ hrs}}{2000 \text{ hrs}} \times \text{Rs. } 4750 \text{ /hr} \\
 &= 0.006 \times 4750 \\
 &= \text{Rs. } 24.9 \text{ /-} \\
 \text{Total Cost} &= \text{Rs. } 117.30 P + \text{Rs. } 96 + \text{Rs. } 40 + \text{Rs. } 9 + \\
 &\quad \text{Rs. } 0.589 + \text{Rs. } 20.80 + 0.8 f + \text{Rs. } 3 + \\
 &\quad \text{Rs. } 4.20 + \text{Rs. } 15 + \text{Rs. } 24.9 \\
 \text{Total Cost} &= \frac{213.489 + 0.8 f + 117.3 P}{0.051 \times 2000} \\
 \text{Flow Rate (f)} &= 492 \times d^3 \times (P_g + 1)
 \end{aligned}$$

$$d = \text{Diameter of Nozzle} = 2 \text{ mm}$$

$$P_g = \text{Gas Pressure in bar}$$

$$P = \text{Power in Watts}$$

$$f = \text{Flow Rate (Gas) in Lit/Sec}$$

$$\text{Power Factor} = 0.8$$

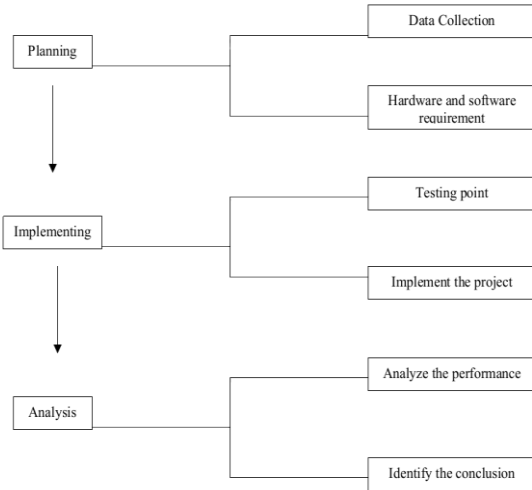
VI. MEASURING TECHNIQUES

In order to attain good cutting results, measurement of work piece parameters after the laser cutting process is done and checked for quality of cut. The work piece parameters include measurement of Inner diameter, Outer diameter and the Taper angle. Along with the work piece parameter the effect of process parameter which includes Kerf width, Surface roughness and HAZ over the quality of cut is measured. The work piece parameter and effect of process parameter over the work piece after laser cutting is measured using two types of instrument and they are,

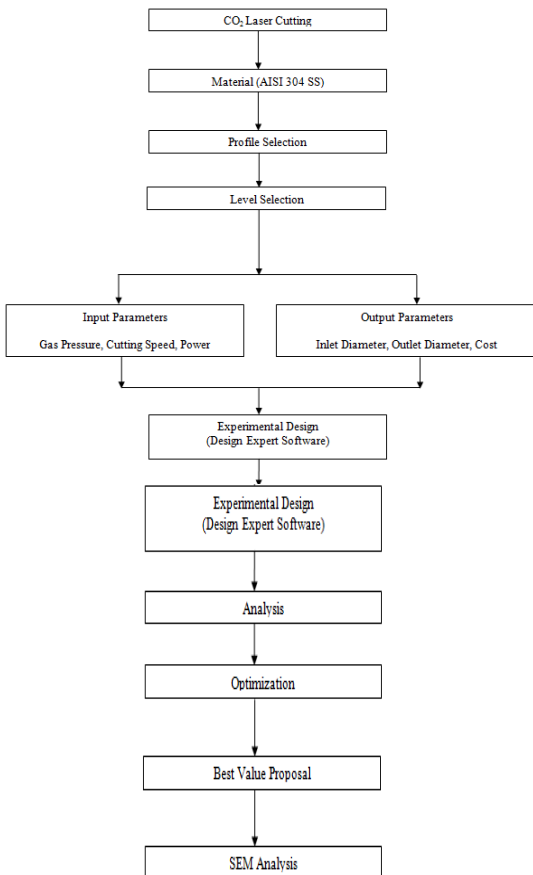
- a. Tool Markers Microscope WM2.
- b. Marvision MMS20 SEM Microscope.

VII. METHODOLOGY

In order to evaluate this project, the methodology based on System Development Life Cycle (SDLC), generally three major step, which is planning, implementing and analysis.



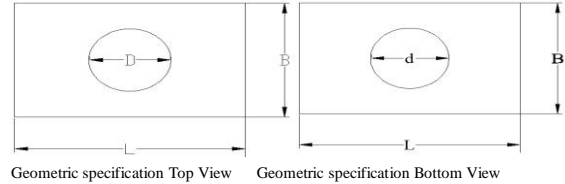
Methodology Flow Chart:



VII. PROFILE SPECIFICATION

The diagram below specifies the geometry value of the profile that is to be cut using the CO2 laser. In the

diagram the D specifies the outer diameter, d specifies the inner diameter and “ α ” specifies the taper angle which occurs when there is change in value of the outer diameter and inner diameter. The change in inner and outer diameter occurs when the quality of cut is poor. The required value of cut is D = 10 mm , d = 10 mm, B= 9mm.



VIII. LEVEL SELECTION

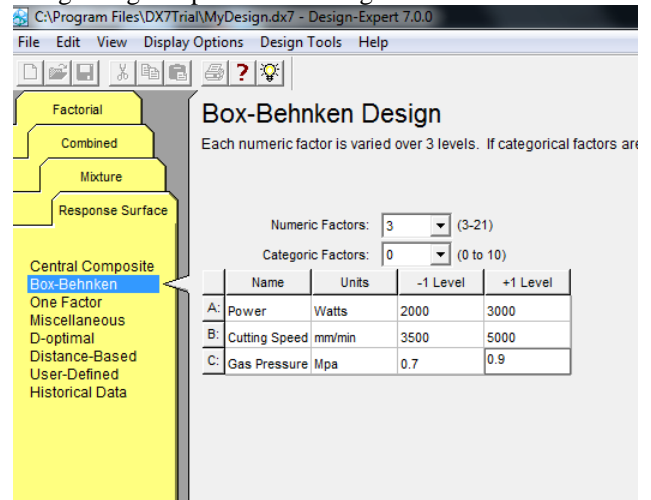
Gas Pressure = 0.7 Mpa to 0.9 Mpa.

Cutting Speed = 3500 mm/min to 5000 mm/min.

Laser power = 2000 W to 3000 W.

IX. EXPERIMENT DESIGN

The experiment was designed based on a three level Box-Behnken design with full replication. Laser power, cutting speed and gas pressure are input parameters of the CO₂ laser beam cutting process. The inlet diameter D, Outlet diameter d and Cutting Cost are the response measured. The step involved in generating the table of run using Design-Expert software is given below.



From the previous equation of the cost factor is calculated for the different table of run. The table below gives us the cost incurred in running the experiment to prepare sample with laser cutting operation at different levels of input parameters that is obtained in Design expert software.

Experiment No	Power in Watts	Cutting Speed in mm/min	Gas Pressure in Mpa	Flow Rate in Lit/hr	Cutting Cost in Rs/hr
1	2500	3500	0.7	15744	128.45
2	3000	4250	0.9	19680	159.90
3	2500	3500	0.9	19680	159.32
4	2000	5000	0.8	17712	143.31
5	2500	4250	0.8	17712	143.89
6	3000	5000	0.8	17712	144.46
7	2000	4250	0.9	19680	158.75
8	3000	4250	0.7	15744	129.03
9	2500	4250	0.8	17712	143.89
10	2500	4250	0.8	17712	143.89
11	3000	3500	0.8	17712	144.46
12	2500	4250	0.8	17712	143.89
13	2500	4250	0.8	17712	143.89
14	2500	5000	0.9	19680	159.32
15	2500	5000	0.7	15744	128.45
16	2000	4250	0.7	15744	127.88
17	2000	3500	0.8	17712	143.31

Cutting Cost for different Specimen.

X. MEASUREMENT OF GEOMETRIC PARAMETERS (D & d)

The tool makers microscope WM2 is a robust and easy to operate device for the universal use in the workshop. This microscope is used to measure the inner diameter d, outer diameter D and taper angle α . The out of the reading which include the measurement of inner and outer diameter that is measured are obtained digitally in Tool Markers Microscope WM2. The measured value D & d of different specimen that is obtained is shown in the table below.

Specimen No	Power in Watts	Cutting Speed in mm/min	Gas Pressure in Mpa	Inlet Diameter in mm (D)	Outlet Diameter in mm (d)	Cutting Cost Rs / hr
1	2000	3500	0.8	10.09	9.89	143.31
2	3000	3500	0.8	10.1	9.9	144.46
3	2000	5000	0.8	10.09	9.88	143.31
4	3000	5000	0.8	10.1	9.89	144.46
5	2000	4250	0.7	10.1	9.9	127.87
6	3000	4250	0.7	10.14	9.94	127.87
7	2000	4250	0.9	10.1	9.9	158.74
8	3000	4250	0.9	10.14	9.93	159.89
9	2500	3500	0.7	10.1	9.89	128.45
10	2500	5000	0.7	10.12	9.92	128.4
11	2500	3500	0.9	10.11	9.91	159.32
12	2500	5000	0.9	10.1	9.89	159.32
13	2500	4250	0.8	10.11	9.91	143.88
14	2500	4250	0.8	10.11	9.91	143.88
15	2500	4250	0.8	10.11	9.92	143.31
16	2500	4250	0.8	10.11	9.92	143.88
17	2500	4250	0.8	10.12	9.93	143.88

D, d & Cutting Cost for different Specimen.

X. RESPONSE ANALYSIS

The response which includes measurement of inlet diameter D, outlet diameter d, and cutting cost is analyzed using the design expert software. The Design expert software is used carried out the following analysis (i). ANOVA analysis, (ii). Analysis of response with that of input parameter, (iii). Obtaining final equation in terms of actual factors and (iv). Analysis of Experimental value with that of Theoretical value.

a. Analysis of Inlet Diameter, D

Response 1 Inlet Diameter

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	2.821E-003	9	3.135E-004	3.95	0.0418	significant
A-Power	1.250E-003	1	1.250E-003	15.77	0.0054	
B-Cutting Speed	1.250E-005	1	1.250E-005	0.16	0.7032	
C-Gas Pressure	1.250E-005	1	1.250E-005	0.16	0.7032	
AB	0.000	1	0.000	0.000	1.0000	
AC	0.000	1	0.000	0.000	1.0000	
BC	2.250E-004	1	2.250E-004	2.84	0.1359	
A ²	2.132E-005	1	2.132E-005	0.27	0.6201	
B ²	9.161E-004	1	9.161E-004	11.55	0.0115	
C ²	4.424E-004	1	4.424E-004	5.58	0.0502	
Residual	5.550E-004	7	7.929E-005			
Lack of Fit	4.750E-004	3	1.583E-004	7.92	0.0370	significant
Pure Error	8.000E-005	4	2.000E-005			
Cor Total	3.376E-003	16				

ANOVA Analysis for Inlet Diameter, D

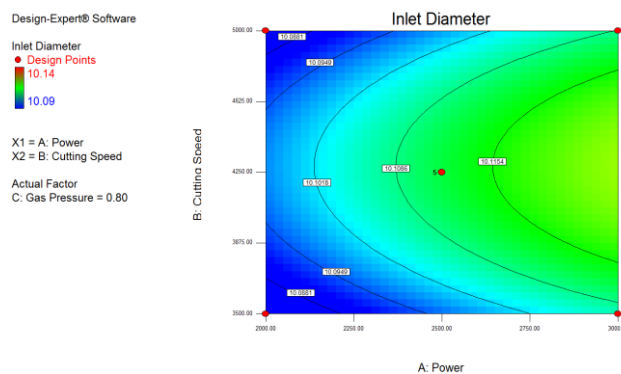
The Model F-value of 3.95 implies the model is significant. There is only a 4.18% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 7.92 implies the Lack of Fit is significant. There is only a 3.70% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.

Analysis inlet diameter, D vs input parameter

The Analysis of Inlet diameter D, with that of cutting speed, Power and Gas pressure is carried out using the Design Expert software. The Graph so obtain is shown below in the figure. From the graph it is noted that when the Power is increased, the diameter values are increased. So, the factors are mainly depends upon the Power value.



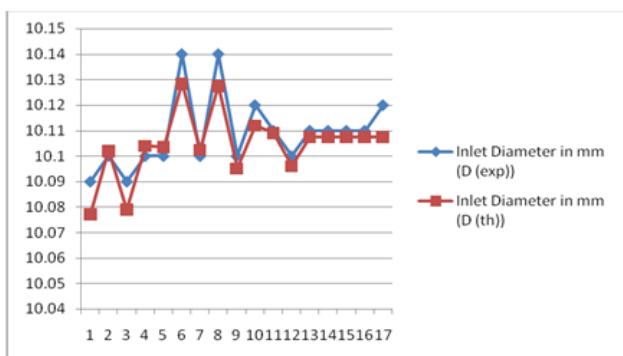
Analysis Inlet Diameter, D Vs Input Parameter

The experimental value and the theoretical value is been tabulated and graph is drawn as shown below.

Specimen No	Power in Watts	Cutting Speed in mm/min	Gas Pressure in Mpa	Inlet Diameter in mm (E _{experimental})	Inlet Diameter in mm (T _{theoretical})
1	2000	3500	0.8	10.09	10.08
2	3000	3500	0.8	10.1	10.10
3	2000	5000	0.8	10.09	10.08
4	3000	5000	0.8	10.1	10.10
5	2000	4250	0.7	10.1	10.10
6	3000	4250	0.7	10.14	10.13
7	2000	4250	0.9	10.1	10.10
8	3000	4250	0.9	10.14	10.13
9	2500	3500	0.7	10.1	10.10
10	2500	5000	0.7	10.12	10.11
11	2500	3500	0.9	10.11	10.11
12	2500	5000	0.9	10.1	10.10
13	2500	4250	0.8	10.11	10.11
14	2500	4250	0.8	10.11	10.11
15	2500	4250	0.8	10.11	10.11
16	2500	4250	0.8	10.11	10.11
17	2500	4250	0.8	10.12	10.11

Experimental value and Theoretical value For Inlet Diameter, D

From the graph it is clearly understand that the theoretical value is nearer to the required value than the experimental value and hence the final equation for D in terms of actual factor satisfy the requirement.



Comparison of Theoretical and Experimental Inlet Diameter, D

The final equation for “D” in terms of actual factor D, with that of cutting speed, Power and Gas pressure is carried out using the Design Expert software. The equation so obtain is given below,

$$\begin{aligned}
 \text{Inlet Diameter} = & \\
 & +9.83853 \\
 & +7.00000\text{E-}005 * \text{Power} \\
 & +3.04556\text{E-}004 * \text{Cutting Speed} \\
 & -1.22750 * \text{Gas Pressure} \\
 & +0.000000 * \text{Power} * \text{Cutting Speed} \\
 & +0.000000 * \text{Power} * \text{Gas Pressure} \\
 & -1.00000\text{E-}004 * \text{Cutting Speed} * \text{Gas Pressure} \\
 & -9.00000\text{E-}009 * \text{Power}^2 \\
 & -2.62222\text{E-}008 * \text{Cutting Speed}^2 \\
 & +1.02500 * \text{Gas Pressure}^2
 \end{aligned}$$

b. Analysis of Outlet Diameter, d

Response 2 Outlet Diameter

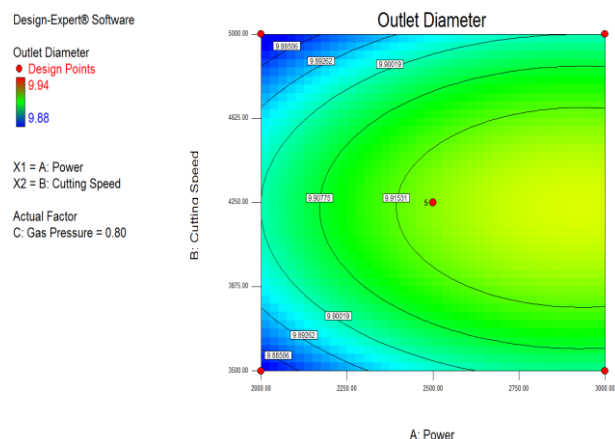
ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	4.001E-003	9	4.445E-004	4.41	0.0315	significant
A-Power	1.013E-003	1	1.013E-003	10.05	0.0157	
B-Cutting Speed	1.250E-005	1	1.250E-005	0.12	0.7350	
C-Gas Pressure	5.000E-005	1	5.000E-005	0.50	0.5038	
AB	0.000	1	0.000	0.000	1.0000	
AC	2.500E-005	1	2.500E-005	0.25	0.6336	
BC	6.250E-004	1	6.250E-004	6.21	0.0415	
A ²	1.779E-004	1	1.779E-004	1.77	0.2255	
B ²	1.946E-003	1	1.946E-003	19.33	0.0032	
C ²	1.516E-004	1	1.516E-004	1.51	0.2596	
Residual	7.050E-004	7	1.007E-004			
Lack of Fit	4.250E-004	3	1.417E-004	2.02	0.2531	not significant
Pure Error	2.800E-004	4	7.000E-005			
Cor Total	4.708E-003	16				

ANOVA Analysis for Outlet Diameter, d

From the following graph it is noted that when the Power is increased, the diameter values are increased. So, the factors are mainly depends upon the Power value.



Analysis Outlet Diameter, d Vs Input Parameter

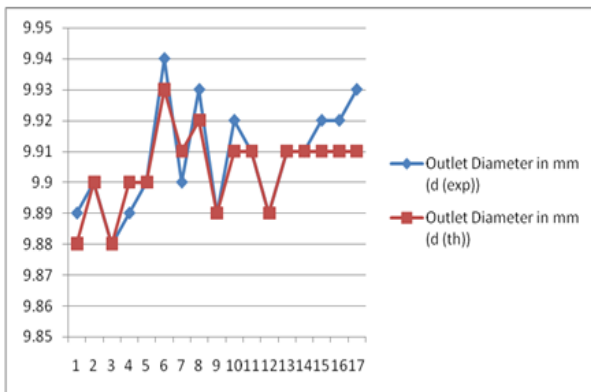
The experimental value and the theoretical value is been tabulated and graph is drawn as shown below.

Specimen No	Power in Watts	Cutting Speed in mm/min	Gas Pressure in Mpa	Outlet Diameter in mm (d _{experimental})	Outlet Diameter in mm (d _{theoretical})
1	2000	3500	0.8	9.89	9.88
2	3000	3500	0.8	9.9	9.9
3	2000	5000	0.8	9.88	9.88
4	3000	5000	0.8	9.89	9.9
5	2000	4250	0.7	9.9	9.9
6	3000	4250	0.7	9.94	9.93
7	2000	4250	0.9	9.9	9.91
8	3000	4250	0.9	9.93	9.92
9	2500	3500	0.7	9.89	9.89
10	2500	5000	0.7	9.92	9.91
11	2500	3500	0.9	9.91	9.91
12	2500	5000	0.9	9.89	9.89
13	2500	4250	0.8	9.91	9.91
14	2500	4250	0.8	9.91	9.91
15	2500	4250	0.8	9.92	9.91
16	2500	4250	0.8	9.92	9.91
17	2500	4250	0.8	9.93	9.91

Experimental value and Theoretical value For Outlet Diameter, d

From the following graph it is clearly understand that the theoretical value is nearer to the required value

than the experimental value and hence the final equation for d in terms of actual factor satisfy the requirement.



Comparison of Theoretical and Experimental Outlet Diameter, d

The experimental value that is measured and is compared with that of theoretical value which is been calculated. The theoretical value of Inlet diameter is calculated using the following formula,

$$\begin{aligned} \text{Outlet Diameter} = & \\ & +8.75328 \\ & +1.92500\text{E-}004 * \text{Power} \\ & +4.56556\text{E-}004 * \text{Cutting Speed} \\ & -0.15167 * \text{Gas Pressure} \\ & +0.000000 * \text{Power} * \text{Cutting Speed} \\ & -5.00000\text{E-}005 * \text{Power} * \text{Gas Pressure} \\ & -1.66667\text{E-}004 * \text{Cutting Speed} * \text{Gas Pressure} \\ & -2.60000\text{E-}008 * \text{Power}^2 \\ & -3.82222\text{E-}008 * \text{Cutting Speed}^2 \\ & +0.60000 * \text{Gas Pressure}^2 \end{aligned}$$

c. Analysis of Cutting Cost

Response 3 Cutting Cost

ANOVA for Response Surface Quadratic Model

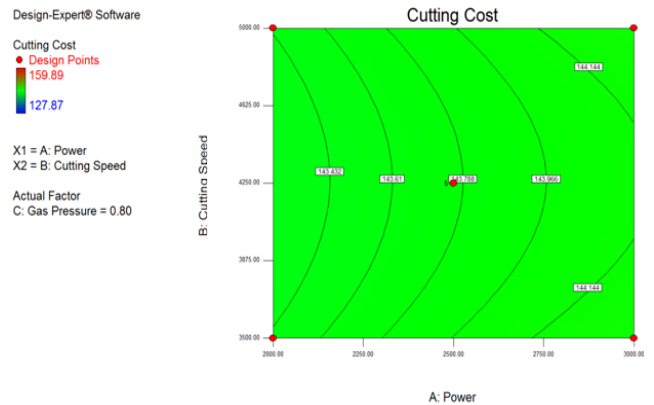
Analysis of variance table (Partial sum of squares - Type III)

Source	Sum of Squares	df	Mean Square	F Value	p-value	Prob > F
Model	1945.18	9	216.13	2622.97	< 0.0001	significant
A-Power	1.49	1	1.49	18.06	0.0038	
B-Cutting Speed	3.125E-004	1	3.125E-004	3.793E-003	0.9526	
C-Gas Pressure	1943.14	1	1943.14	23581.97	< 0.0001	
AB	0.000	1	0.000	0.000	1.0000	
AC	0.33	1	0.33	4.01	0.0852	
BC	6.250E-004	1	6.250E-004	7.585E-003	0.9330	
A ²	0.027	1	0.027	0.33	0.5830	
B ²	0.17	1	0.17	2.03	0.1969	
C ²	0.036	1	0.036	0.44	0.5275	
Residual	0.58	7	0.082			
Lack of Fit	0.32	3	0.11	1.63	0.3176	not significant
Pure Error	0.26	4	0.065			
Cor Total	1945.75	16				

ANOVA Analysis for Cutting Cost

The Analysis of Inlet diameter d, with that of cutting speed, Power and Gas pressure is carried out using the

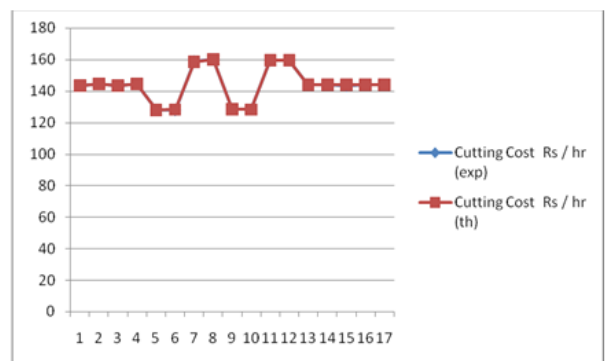
Design Expert software. The Graph so obtain is shown below in the figure.



Analysis of Cutting Cost Vs Input Parameter

Specimen No	Power in Watts	Cutting Speed in mm / min	Gas Pressure in Mpa	Cutting Cost in Rs/hr (experimental)	Cutting Cost in Rs/hr (theoretical)
1	2000	3500	0.8	143.31	143.48
2	3000	3500	0.8	144.46	144.35
3	2000	5000	0.8	143.31	143.47
4	3000	5000	0.8	144.46	144.34
5	2000	4250	0.7	127.87	127.88
6	3000	4250	0.7	127.87	128.18
7	2000	4250	0.9	158.74	158.48
8	3000	4250	0.9	159.89	159.92
9	2500	3500	0.7	128.45	128.33
10	2500	5000	0.7	128.4	128.29
11	2500	3500	0.9	159.32	159.47
12	2500	5000	0.9	159.32	159.49
13	2500	4250	0.8	143.88	143.79
14	2500	4250	0.8	143.88	143.79
15	2500	4250	0.8	143.31	143.79
16	2500	4250	0.8	143.88	143.79
17	2500	4250	0.8	143.88	143.79

Experimental value and Theoretical value for Cutting Cost



Comparison of Theoretical and Experimental Cutting Cost

From the graph it is clearly understand that the theoretical value and the experimental values are nearer and there is no much variation between them.

XI. OPTIMIZATION

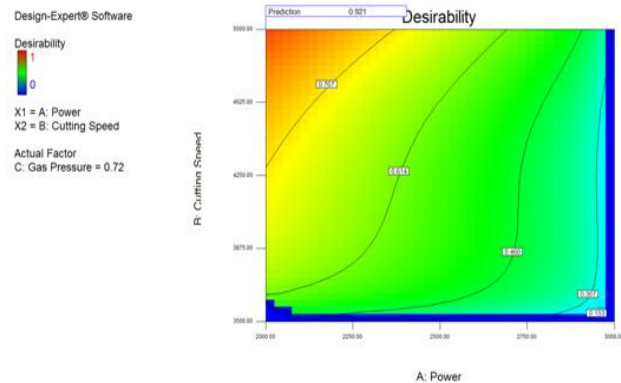
The optimized solution so obtain using the Design Expert software is shown below.

Number	Power	Cutting Speed	Gas Pressure	Inlet Diameter	Outlet Diameter	Cutting Cost	Desirability	
1	2000.00	5000.00	0.72	10.0961	9.8903	131.875	0.921	Selected
2	2000.00	5000.00	0.72	10.0964	9.89056	131.689	0.921	
3	2000.00	5000.00	0.73	10.0954	9.88966	132.342	0.921	
4	2000.35	5000.00	0.73	10.0957	9.88993	132.155	0.920	
5	2000.00	5000.00	0.72	10.0971	9.89111	131.301	0.920	
6	2000.00	4999.99	0.72	10.0974	9.89139	131.108	0.920	
7	2000.00	5000.00	0.73	10.0944	9.88872	133.038	0.920	
8	2000.00	5000.00	0.71	10.0989	9.89273	130.185	0.919	
9	2000.00	5000.00	0.74	10.0927	9.88716	134.227	0.917	
10	2000.00	5000.00	0.74	10.0919	9.88638	134.844	0.915	
11	2000.00	5000.00	0.70	10.1017	9.89508	128.633	0.914	
12	2000.00	5000.00	0.75	10.091	9.88552	135.547	0.912	
13	2000.00	4929.37	0.73	10.0966	9.89209	132.853	0.899	
14	2000.00	4964.32	0.76	10.09	9.88522	137.344	0.892	
15	2000.00	4810.09	0.70	10.1071	9.90266	127.961	0.855	
16	2189.43	5000.00	0.70	10.1089	9.9052	128.148	0.827	

16 Solutions found

The optimized value is
 Power = 2000 Watts
 Cutting Speed = 5000 mm/min
 Gas Pressure = 0.72 Mpa.

Desirability Value:



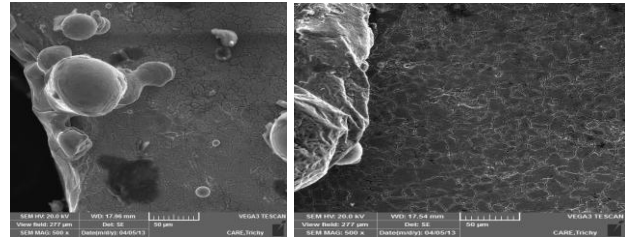
Desirability Factor Graph

XII. SEM ANALYSIS

The new specimen is prepared based on the optimized value. The cutting speed is set as 5000 mm/min, the Power is taken as 2000 Watts, and the Gas pressure is taken as 0.72 Mpa. Once the new specimen is prepared it is been examine under SEM microscope and the following factor are compared with specimen that is prepared on experimental run.

i. Heat affected zone

Effect of Power and Cutting Speed on the width of HAZ:



The heat-affected zone (HAZ) is the area of base material, either a metal or a thermoplastic, which has had its microstructure and properties altered by heat intensive cutting operations. The heat from the laser cutting process and subsequent re-cooling causes this change from the interface to the termination of the sensitizing temperature in the base metal. It is found that increase in Cutting Speed and a decrease in power results in a decrease in the width of HAZ.

XIII. CONCLUSION

The optimized value is Power = 5000 Watts, the Cutting Speed = 2000 mm/min, and Gas Pressure = 0.72 Mpa is founded using the design expert software. The cost involved during the operation when the optimized condition is Rs.131.87/hr. This optimized value improves the required quality parameter like Inlet diameter, Outlet diameter and Cutting Cost. The Specimen is examine under SEM microscope and the Effect of Power and Cutting Speed on kerf width, Effect of Power and Cutting Speed on the width of HAZ and, Effect of power and Cutting Speed on surface roughness is observed and the following factor is concluded.

Power had a major effect on the kerf width, while feed rate played a minor role. Decreasing power and increasing feed rate generally led to a decrease in HAZ. At low power levels, increasing feed rate led to a slight decrease in HAZ. At high power levels, increasing feed rate led to a slight increase in HAZ.

Feed rate has a major effect on surface roughness and striation frequency. Increasing feed rate generally led to increasing surface roughness and striation frequency. An optimum feed rate, for which surface roughness is minimum, could be identified. Power has a small effect on surface roughness, and no effect at all on striation frequency.

References

- [1] W.M. Steen, Laser Material Processing, Springer, Germany, 1991.
- [2] F.O. Olsen, Investigations in optimizing the laser cutting process, in: Lasers in Materials Processing, Conference Proceedings — American Society for Metals, Los Angeles, USA, 1983, pp. 64–80.
- [3] N. Rajendran, M.B. Pate, The effect of laser beam velocity on cut quality and surface temperature, American Society of Mechanical Engineers, Heat Transfer Division 104 (1988) 121–127. [4] R. Neimeyer, R.N. Smith, D.A. Kaminski, Effects of operating parameters on surface quality laser cutting of mild steel, Journal of Engineering for Industry 115 (1993) 359–366.

- [4] W.M. Steen, J.N. Kamalu, in: M. Bass (Ed.), *Laser Cutting, Laser Materials Processing*, vol. 3, North Holland, New York, 1983, pp. 17–111.
- [5] I. Decker, J. Ruge, U. Atzert, Physical models and technological aspects of laser gas cutting, *Proceedings of SPIE — The International Society of Optical Engineering, Industrial Applications of High Power Lasers.*, Linz, Austria 455 (1984) 81–87.
- [6] A. Ivarson, J. Powell, J. Kamalu, C. Magnusson, The oxidation dynamics of laser cutting of mild steel and the generation of striations on the cut edge, *Journal of Materials Processing Technology* 40 (1994) 359–374.
- [7] W.K. Hamoudi, The effects of speed and processing gas on laser cutting of steel using a 2 kW CO₂ laser, *International Journal for Joining of Materials* 9 (1) (1996) 31–36.
- [8] H. Kaebernick, A. Jeromin, P. Mathew, Adaptive control for laser cutting using striation frequency analysis, *Annals of CIRP — Manufacturing Technology* 47 (1) (1998) 137–140.
- [9] S. Biermann, R. Nuss, M. Geiger, Analytical studies on laser cut surfaces, *SPIE*, in: *Seventh International Symposium on Gas Flow and Chemical Lasers*, vol. 1031, 1988, pp. 586–591.
- [10] R. Nagarajan, Parametric study of the effect of laser cutting variables on the cut quality, Master thesis, Wichita State University, Wichita, Kansas, 2000.
- [11] U. Diltthey, M. Faerber, J. Weick, Laser cutting of steel—cut quality depending on cutting parameters, *Welding in the World* 30 (9/10) (1992) 275–278.
- [12] S.-L. Chen, Analysis and modeling of reactive three-dimensional high-power CO₂ laser cutting, *Proceedings of the Institution of Mechanical Engineers Part B* 212 (1998) 113–128