OPTIMIZATION OF CO2 LASER CUTTING PARAMETERS FOR MINIMUM KERF WIDTH DURING THE CUTTING OF AISI 304L STEEL

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Abstract

Laser cutting is a non-contact type machining process which does not involve any mechanical cutting forces hence no tool wear. In this process of machining, the workpiece material is locally melted by the focused laser light. In the present work, the effect of CO2 laser cutting process parameters has been optimized for minimum kerf widthusing Taguchi methodology based on L_{16} orthogonal array. An attempt has also been made to investigate the effect of laser cutting parameters on kerf width. The entire laser cutting experiments have been carried out on AISI304L stainless steel. The laser power, cutting speed, focal point position and gas pressure have been considered as a process parameters while upper kerf width as a response. The result revealed that minimum value of kerf width has been achieved at lowest level of laser power, lowest level of gas pressure, highest level of cutting speed and highest level of focal point position.

Keywords:CO2 laser cutting, AISI304L, Laser power, Gas pressure, Focal point position and optimization.

I. INTRODUCTION AND LITERATURE REVIEW

Now a days, laser cutting is a popular cutting process, which finds wide range of application in various manufacturing industries due to its advantages of high cut quality and cost efficiency through mass- production. Also, Laser cutting is a non-contact type machining process which does not involve any mechanical cutting forces hence no tool wear. In this process of machining, the workpiece material is locally melted by the focused laser light (1). The melt is then blown away with the aid of assist gas, which flow coaxially with the laser beam, forming a kerf(2).In metal cutting procedures, different types of assist gases are used such as oxygen, nitrogen etc (3-4).

In any manufacturing process, it is required to investigate the effect of input parameters on responses in order to achieve the better product quality at minimum cost. Laser cutting requires high investment and offers poor efficiency. Therefore, It is required to select the optimum combination of process parameters for obtain the high production rate at low cost with an acceptable level of quality of cut parts. These parameters affect the special microscopic and macroscopic characteristics of the cut parts, as signified by the kerf width, the width of the heat affected zone and the surface roughness after processing(5). Extensive research studies have been carried out to investigate the effect of parameters and optimize the parameters to improve the performance of laser cutting process.

Dilthey et al. (6) revealed that during the cutting stainless steel, proper adjustment of focus position and gas jet is requires in order to obtaining dross free cutting. It has also been found that the corrosion resistance is at risk when cutting stainless steel with oxygen.

Chen (7) investigated the effects of gas composition on the CO2 laser cutting during the cutting of mild steel sheet of thickness 3mm. The oxygen, argon, nitrogen and helium gas mixtures have been used for the investigation. It has been observed that high purity of oxygen provide high performance laser cutting.

Chen (8) experimentally investigated the effect of high-pressure assistant gas flow on CO2 laser cutting on side-burning effect during the cutting of 3mm thick mild steel plate. It has been revealed that side-burning effect always appears on the top of the cut surface using oxygen.

Kaebernick et al. (9) developed kerf width prediction model in terms of laser parameters. An attempt has also been made to investigate the effect of laser cutting parameters on kerf width. The result revealed that the initially kerf width increase as cutting speed increases. After certain value of cutting speed, kerf width continuously decreases with increase in cutting speed.

Mathew et al. (10) optimized the laser cutting parameters (speed, pulse energy, pulse duration, pulse repetition rate and gas pressure) for minimum HAZ and the taper of cut surface using response surface methodology. All the laser cutting operations have been carried out using pulsed Nd:YAG laser on fibre reinforced plastic composite sheet of 2 mm thickness. The result revealed that most of the factors in their middle range are the optimal parameter ranges.

Bagger and Olsen (11) optimized the pulsed mode laser cutting parameters (laser power and cutting speed) for multi-performance (squareness, surface roughness and dross attachment of laser cut blanks) during the cutting of medium strength steel (GA 260) having thickness of 1.8 mm. The optimal cutting condition has been obtained at 2.0kW power and 3.5 m/min cutting speed settings for the tested material.

Yilbas (12) experimentally investigated the effect of laser power, energy coupling factor and cutting speed on kerf width size. The results revealed that increase in laser power and energy coupling factor increase the kerf width size.

Rajaram et al. (13) investigated the effect of laser cutting parameters (cutting speed and laser power) on laser cut quality during the CO2 laser cutting of 4130 steel. It has been found that the kerf and HAZ width were influenced significantly by laser power, while cutting speed played a minor role.

Ghany and Newishy (14) investigated the effect of laser parameters (laser power, pulse frequency, cutting speed and focus positions) on surface roughness and kerf width during the cutting of 1.2mm austenitic stainless steel sheets using pulsed and continuous wave (CW) Nd:YAG laser beam with nitrogen and oxygen as assistant gases. It has been found that laser cutting quality depends mainly on the laser power, pulse frequency, cutting speed and focus positions. Although, nitrogen produced brighter and smoother cut surfaces with smaller kerf as compared to oxygen.

Lamikiz et al. (15) investigated the effect of laser cutting parameters (laser power, gas pressure, cutting speed and focus position) on quality and geometry of cutting during the cutting of different type of AHSS sheet steels. It has been revealed that at higher cutting speed, laser power should be increased to 300W to avoid the risk of the appearance of pitting.

Uslan (16) investigated the effect of laser cutting parameters (laser power intensity, cutting speed and focus position) on kerf width. It has been found that increasing the laser power intensity enhances the kerf width size and small variation in laser power results in a large variation in the kerf size.

Almeida et al. (17) employed factorial design to investigate the effects of pulse energy, overlapping rate and type of assist-gas on the surface roughness and dross formation (edge irregularity) during the Nd:YAG laser cutting of pure titanium and titanium alloy (Ti–6Al–4V). The result revealed that surface roughness increases with increase in pulse energy while intermediate value of pulse energy increases the dross quantity. Also, use of nitrogen assist gas increases surface hardness due to the formation of nitride (TiN) while a mixture of helium and argon gases reduces the irregular edges and also eliminates the nitride formation.

Ghany et al. (18) experimentally investigated the effects of laser cutting parameters (laser power, cutting speed, focus position, different gas types and pressures) on attached dross, kerf width and surface roughness during the cutting of zinc coated steel material. The resultreveals that zinc coated steel material could be cut using Nd:YAG laser with laser powers less than 400W and speeds of up to 6 m/min.

Radovanovic and Dasic (19) investigated the effect of sheet thickness and laser power on surface roughness of cut part during the laser cutting of mild steel sheet. The result revealed that surface roughness increases with increase in the sheet thickness, but decreases with increasing the laser power.

Dubey and Yadava (20) used Taguchi methodology to optimize laser cutting process parameters for kerf width, kerf deviation and kerf taper during the cutting of nickel-based super alloy sheets using Nd:YAG laser.

Yilbas (21)investigated the effect of laser cutting parameters on kerf size variations during the cutting of thick sheet metals using factorial design. It has been found that laser output power and oxygen gas pressure have significant effect on the percentage of kerf width variation.

Eltawahni et al. (22) investigated the effect of laser cutting parameters on quality of cut using response surface methodology. An attempt has also been made to optimize the laser cutting parameters for good quality of cut during the cutting of medium density fiberboard. The result revealed that the higher cutting speed does not always improve the efficiency of the LBC.

Prajapati et al. (23) used Taguchi methodology to investigate the effect of CO2 laser cutting parameters (laser power, gas pressure, cutting speed and thickness of work piece) on surface roughness of cut pieces during the laser cutting of mild steel and hardox-400. The cutting speed has been found most significant parameter that affects the surface roughness of cut pieces followed by thickness of plate.

Patel et al. (24) used response surface methodology to optimize process parameters (gas pressure, cutting speed, stand of distance and laser power) for optimum value of metal removal rate and kerf width during the laser cutting of SS410 steel. An attempt has also been made to investigate the effect of process parameters on responses. As the gas pressure and cutting speed increase, the surface roughness decreases while increase in stand of distance and laser power, surface roughness also increases. On the other hand, MRR increase with increase in gas pressure, cutting speed, stand of distance and laser power.

Abhimanyu and Satyanarayana(25) investigated the effect of laser cutting process parameters on edge surface roughness and surface hardness during the pulsed CO2 laser cutting of mild steel sheet using design of experiments. The laser power, cutting speed and material thickness have been considered as process parameters.

Argade et al. (26) optimized the laser process parameters (cutting speed, input power and gas pressure) for minimum value of surface roughness and kerf width during the CO2 laser cutting of stainless steel SS 409 using Taguchi methodology. The result revealed that surface roughness increases with increase in laser power and cutting speed while decreases with increase in gas pressure. On the other hand, kerf width increases with increase in laser power and gas pressure and decrease in cutting speed.

The review of the research presented above reveals that work has been carried out to investigate the effect of laser cutting parameters on surface roughness, kerl width etc. during the cutting of various metals and non metals. In the present work, Taguchi methodology based on L_{16} orthogonal array based has been used to investigate the effect of laser cutting parameters (laser power, cutting speed, focal point position and gas pressure) on the upper kerf width during the cutting of AISI304L stainless steel. An attempt has also been made to optimize the laser cutting parameters for minimum upper kerf width.

II. EXPERIMENTAL DETAILS AND DATA COLLECTION

In order to accomplish the objective of present research, proper selection of cutting parameters, range of parameters, proper experimentation and measurement are required.

A.Selection of level of process parameters and design of experiment

In the present research L_{16} orthogonal array based Taguchi methodology has beenusedto achieve the objective of present research. Table 1 shows the process parameters and there levels while table 2 shows the design matrix according to L_{16}(4 factors and 4 levels) orthogonal array based Taguchi methodology with for the experimentation.

Table 1. process parameters and there levels

Input parameters			**3**	**4**
Laser power (kW)	1	1.25	1.5	1.75
Cutting speed (mm/min)	600	1200	1800	2400
Gas pressure (Bar)	4	8	12	16
Focal point position	-4	-3	-2	-1

B. Experimentation and measurement

To achieve the goal of present research, a CO2 laser-machine (Truflow 4000) operating in CW mode with maximum output power of 3 kW at a wavelength of 10.6 μm, has been used for the experimentation. Nitrogen gas was supplied coaxially as an assist gas with different pressures. The material used in the experiment was AISI 316L steel (Austenitic stainless steel) in the form of sheet of dimensions of 400mm x 400mm x 4 mm. All the sixteen laser cutting operation has been carried out on this sheet with different combination of laser parameters according to design matrix. An optical microscope has been used to measure upper kerf width. The measurements have been repeated at three different locations of the cut workpiece. Finally, mean of all three upper kerf width values has been considered for the particular trial. The table 2 shows the final values of kerf width along with run order.

Table 2. Design matrix according to L_{16} orthogonal array

S.No.	Cutting speed (V)	Laser power (L)	Nitrogen pressure (P)	Focal point position (F)	Kerf width (mm)
1	600	1	4	-4	0.331
2	600	1.25	6	-3	0.356
3	600	1.5	8	-2	0.383
4	600	1.75	10	-1	0.408
5	1200	1	6	-2	0.293
6	1200	1.25	4	-1	0.258
7	1200	1.5	10	-4	0.381
8	1200	1.75	8	-3	0.346
9	1800	1	8	-1	0.261
10	1800	1.25	10	-2	0.306
11	1800	1.5	4	-3	0.233
12	1800	1.75	6	-4	0.278
13	2400	1	10	-3	0.263
14	2400	1.25	8	-4	0.248
15	2400	1.5	6	-1	0.196
16	2400	1.75	4	-2	0.181

III. RESULTS AND DISCUSSION

In the present work, for kerf width, the smaller the better S/N ratio has been applied to optimize the laser cutting parameters for minimum upper kerf width. The S/N ratio for smaller the better is used for situation where the target value is zero, such as computer response time, automotive emission, corrosion, surface roughness, tool wear, tool vibration etc. The equation for smaller the better ratio is

$$(S/N)_{SB} = -10 \log \left[(\Sigma y^2)/N \right] \quad (1)$$

The negative sign is used to ensure that the target value gives the best value for the response variable and therefore robust design. Mean standard deviation is given to display the relationship to the loss function. The table 3 shows the values of S/N ratio along with experimental values of kerf width.

Table 3. values of S/N ratio

S.No	Kerf width (mm)	S/N ratio
1	0.331	9.60344
2	0.356	8.971
3	0.383	8.336025
4	0.408	7.786797
5	0.293	10.66265
6	0.258	11.76761
7	0.381	8.3815
8	0.346	9.218478
9	0.261	11.66719
10	0.306	10.28557
11	0.233	12.65288
12	0.278	11.1191
13	0.263	11.60089
14	0.248	12.11097
15	0.196	14.15488
16	0.181	14.84643

A.Analysis of Variance (ANOVA)

The ANOVA for S/N ratio for kerf width has been carried out for a significance level of α = 0.05, i.e. for a confidence level of 95%. The ANOVA is based on the three assumptions. To check the first assumption of ANOVA i.e population normality, the normal probability plot of residuals is shown in figure 1. If the distribution of residuals is normal, the plot will resemble a straight line. The figure displays that the residuals generally fall on a straight line implying that the errors are distributed normally.

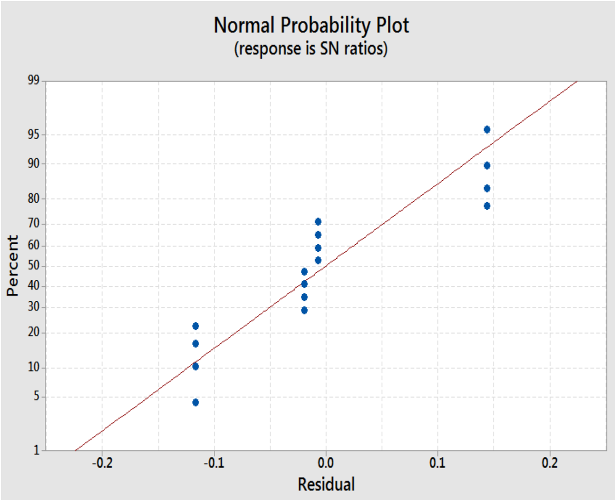

Fig.1. Normal probability plot of residuals for S/N ratio

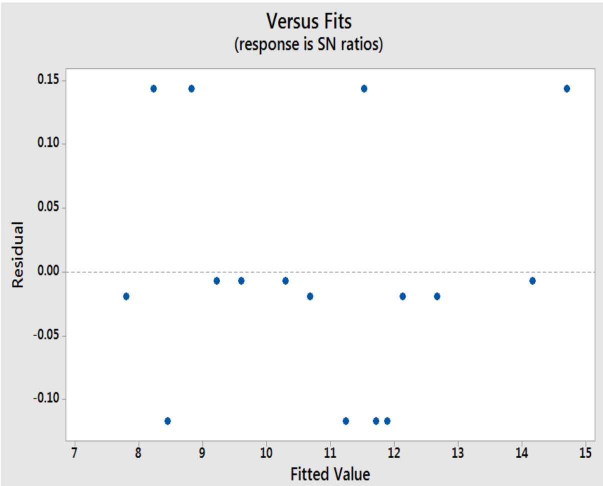

Fig.2. Plot of residuals v/s predicted S/N ratio

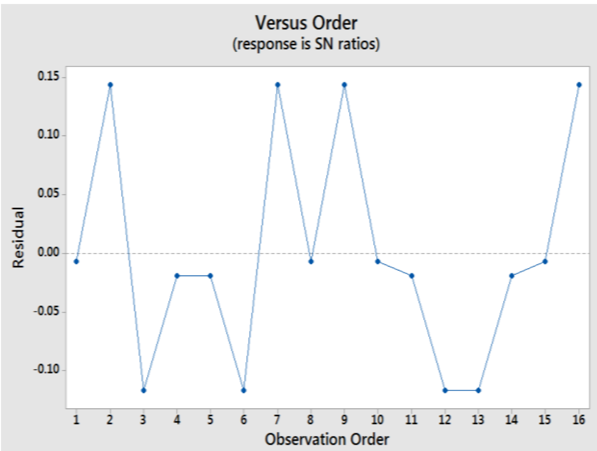

Fig.3. Plot of residuals v/s order for S/N ratio

The second assumption i.e assumption of constant variance can be checked with residuals versus fits plot. The figure.2 represents residuals versus the predicted S/N ratio of kerf width plot. The figure shows that there is no obvious pattern and it shows unusual structure. This implies that there is no reason to suspect any violation of the independence or constant variance assumption. The third assumption of independence can be checked with residuals versus order plot. The figure3 represents residuals versus order plot for S/N ratio for kerf width. The figure shows that plot have no obvious pattern. Thus, independence assumptions are satisfied

The table 4, shows that the value of “Prob. > *F*” for cutting speed is less than 0.0001 which is less than 0.05, that indicates the speed is significant. In the same manner, the value of “Prob. > *F*” for main effect of gas pressure and focal point position are less than 0.05 so these terms are significant model terms. From the table it is also clear that cutting speed is the most dominating factor (70.26 % contribution) that affects the kerf width followed by gas pressure (25.48 %), focal point position (3.95 %) and laser power (0.09 %).

Table 4. Resulting ANOVA table for S/N ratio

Source	DF	Sum of square	Mean square	F value	P value	% Contribution
Cutting speed	3	44.79	14.93	322.3	0.0001	70.26
Laser power	3	0.060	0.020	0.433	0.745	0.09
Gas pressure	3	16.25	5.416	116.9	0.001	25.48
Focal point position	3	2.52	0.84	18.13	0.02	3.95
Residual Error	3	0.139	0.046			
Total	15	63.76				

Table 5 presents the difference between the maximum and the minimum value of the S/N ratio for kerf width values. The most effective factor affecting performance characteristics is obtained by comparing these values. From the table it is also clear that cutting speed is the most dominating factor that affects the kerf width followed by gas pressure, focal point position and laser power. From the table 5 it is also clear that the minimum kerf width is obtained at first level of cutting speed, 4Th level of laser power, 4th level of gas pressure and 1st level of focal point position i.e $V_1L_4P_4F_1$.

Table 5. Response table for S/N ratio (minimum is best) for kerf width

Level	Cutting speed	Laser power	Gas pressure	Focal point position
1	**8.674**	10.884	12.218	**10.304**
2	10.008	10.748	11.227	10.611
3	11.431	10.881	10.33	11.033
4	13.178	**10.743**	**9.514**	11.344
Delta	4.504	0.141	2.704	1.04
Rank	1	4	2	3

B.Effect of laser cutting parameters on kerf width

The figure 4 shows the effect of laser cutting parameters on kerf width.From the figure it is clear that as the kerf width is increases with increase in laser power and gas pressure (12,16,21), while kerf width decreases with increase in cutting speed and focal point position (12,16).

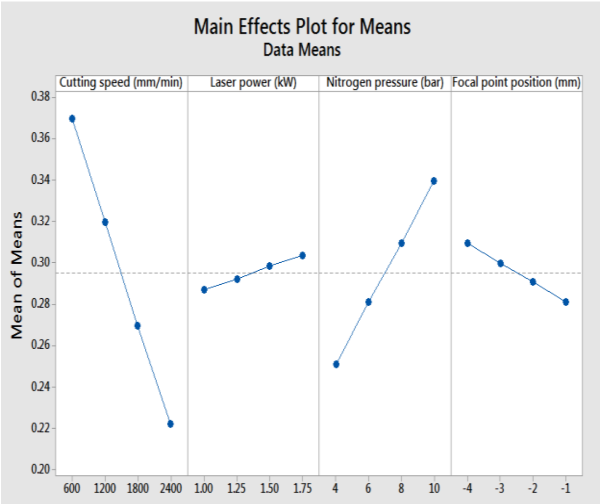

Fig.4. Effect of laser cutting parameters on kerf width

IV. CONCLUSION

The following points can be concluded from the present research within the factors limits.

1. The kerf width is increases with increase in laser power and gas pressure.
2. The kerf width decreases with increase in cutting speed and focal point position.
3. The minimum value of kerf width has been achieved at $V_4L_1P_1F_4$.
4. The cutting speed has been found most dominating factor that affects the kerf width followed by gas pressure, focal point position and laser power.

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