EXPERIMENTATION AND PARAMETRIC ANALYSIS OF LASER CUTTING PROCESS ON LOW CARBON STEEL

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ABSTRACT

Laser cutting process is a relatively new machining technique, which is extensively used in many industrial applications. Parameters which affect on quality of laser cutting are Laser power, Cutting speed, and Gas pressure. It's effect observe on Surface roughness, Kerf width and Taper angle. Laser cutting process on low carbon steel is rarely found in previous research work. This research include Experimentation and Parametric analysis on Low carbon steel.

These study conclude that the kerf width is affected to kerf angle thus ultimately concentration on reduce kerf width leads to good surface qualities. While studying the effect of the cutting parameters on the surface roughness, it was observed that both the cutting speed and the laser power play equally important roles in the effect on the surface roughness. The role of the gas pressure given is less crucial to the same extent. Through use of response surface methodology, engineer can predicted and visualize manipulate range of process parameters for this particular work material. Also it has been given intermediate value of process parameters which carried out the accurate study.

Key words: *Laser cutting process, Low carbon steel*

I. INTRODUCTION

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The initial foundation of the laser theory was laid by Einstein.
Cutting is the most widely practiced industrial application of laser among the machining operations. The advantages of laser cutting over other techniques are: flexibility, scope of automation, ease of control over depth of cut, cleanliness, noncontact processing, speed, amenability to a wide variety of materials (ductile/brittle, conductor/non-conductor, hard/soft), negligible heat affected zone. Following figure shows laser cutting process.

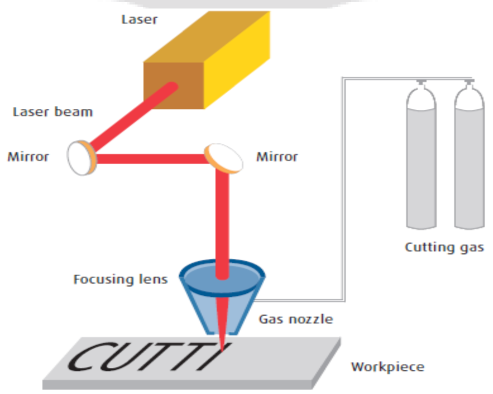

Figure 1: Schematic diagram of laser cutting process [8]

II. LITERATURE REVIEW

Various researchers are working on laser cutting process to cut various materials. They are working on various parameters.

Serkan Apay and Behcet Gulenc[3] used Surface coating operations which is important place in metal technologies. The work of surface coating operations is to improve and enhance the inferior properties of a surface through its modification. The low-carbon AISI 1015 steel was coated with cobalt-base alloy Stellite 6 welding wire by microlaser welding. After coating, the microstructures of the coated surface cross-sections were examined. The microstructure, hardness and wear resistance of the surface-alloyed layer were investigated using optical microscopy, scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), X-ray diffraction analysis and pin-on-disk tests. The Stellite coating alloy to the diffusion from chrome and cobalt AISI 1015 steel was examined by means of the line analysis method and element mapping analyses. AISI 1015 low-carbon steel was coated with cobalt- base Stellite 6 alloy welding wire by using microlaser welding. Structural steels can be coated with Stellite alloys by the method of microlaser welding in one pass under normal atmospheric conditions without taking any measure and without a pre-annealing thermal process.

G. R. Fayaz and A. Ebrahimi [4] used model to multilayer laser solid freedom fabrication process for material properties of low carbon steel 1015 for workpiece and cobalt which allow stellite 21 with 1.5wt.% nano CeO2 as the powder particles. Transient heat transfer and mass transfer equations in laser solid freeform fabrication process are solved by Finite Element Method (FEM). In this approach, the geometry of the deposited material, temperature and thermal stress fields across the process area are predicted. For each layer the clad height is computed. The results for powders with and without nano CeO2 are compared. For a specific point and time, the stress due to heat expansion and contraction is obtained. The addition of nano CeO2 into the power, the maximum stress and the melt pool temperature increase but the crack formation decreases.

H.A. Eltawahni[5] discussed laser cutting is a popular manufacturing process utilized to cut various types of materials economically. The width of laser cut or kerf, quality of the cut edges and the operating cost are affected by laser power, cutting speed, assist gas pressure, nozzle diameter and focus point position as well as the work-piece material. CO2 laser cutting of stainless steel of medical grade AISI316L has been investigated.
Design of experiment (DOE) was implemented by applying Box–Behnken design to develop the experiment lay-out. The aim of this work is to relate the cutting edge quality parameters namely: upper kerf, lower kerf, the ratio between them, cut section roughness and operating cost to the process parameters which are mentioned above. Then, an overall optimization routine was applied to find out the optimal cutting setting that would enhance the quality or minimize the operating cost. To determine the relationship between the process parameters and the edge quality features mathematical models were developed. Also, process parameters effects on the quality features have been defined.

R. Adalarasan et.al[6] proposed the second generation metal matrix composites (MMCs) which find wide applications in aerospace and automotive industries. For cutting these advanced materials and obtaining a good surface texture is challenge. The present study reports the application of non-contact type (thermal energy based) pulsed CO2 laser cutting process on $Al6061/SiCp/Al_2O_3$ composite. The process parameters in laser cutting influence the kerf width, surface finish and cut edge slope. These quality characteristics were observed for the various combinations of cutting parameters like laser power, pulsing frequency, cutting speed and assist gas pressure. The cutting trials were designed according to Taguchi's L18 orthogonal array and a hybrid approach of grey based response surface methodology (GRSM) was disclosed for predicting the optimal combination of laser cutting parameters. A substantial improvement in the surface finish was observed in the responses obtained with the optimal setting of parameters. The atomic force microscopy (AFM) images and P-profile graphs of the cut surface were also observed to study the surface finish and texture.

III. METHODOLOGY

A. Introduction of Material

AISI 1015 carbon steel can be used in forged, cold headed or cold formed parts which are low strength with wear resistant and hard surfaces. Before applying heat treatment, its hardness was 111 BHN and after heat treatment hardness of material was 320 BHN.

B. SELECTION OF PROCESS PARAMETERS

Table 1: Range of process parameters

Parameters	**Unit**	**Level 1**	**Level 2**	**Level 3**
Laser Power	Watt (1000)	750	850	950
Cutting Speed	mm/min	4000	4500	5000
Gas Pressure	Bar	3	5	7
Fixed Parameters				
Nozzle Diameter	1.5 mm			
Stand of Distance	2 mm			
Pulse Width	80%			
Modulation Frequency	800 Hz			
Material Thickness	10 mm			

C. DESIGN OF EXPERIMENT

Design of experiment is a series of tests in which purposeful changes are made to the input variables of a system or process and the effect on response variables are measured. Full factorial design is used for simultaneous study of several factor effects on the process. By varying levels of factors simultaneously we can find optimal solution. Responses are measured at all combinations of the experimental factor levels.

D. RESPONSE SURFACE METHODOLOGY

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables).

IV. EXPERIMENTAL RESULTS AND DISCUSSION

An experiment was conducted at CENTRAL INSTITUTE OF PLASTIC ENGINEERING AND TECHNOLOGY, G.I.D.C Vatva, Ahmedabad and results are recorded in a table as shown below.

Table 2: Experiment Reading

Sr. No.	Laser power (watt)	Cutting speed (mm/min)	Gas pressure (Bar)	Surface roughness (µm)	Kerf width (mm)	Taper angle[°]
1	750	4000	3	3.24	0.0064475	0.0154
2	750	4000	5	3.12	0.0087920	0.021
3	750	4000	7	3.11	0.0100480	0.024
4	750	4500	3	3.18	0.0050659	0.0121
5	750	4500	5	3.14	0.0077035	0.0184
6	750	4500	7	3.07	0.0084152	0.0201
7	750	5000	3	3.14	0.0046472	0.0111
8	750	5000	5	3.11	0.0068661	0.0164
9	750	5000	7	3.04	0.0075779	0.0181
10	850	4000	3	3.35	0.0162861	0.0389
11	850	4000	5	3.21	0.0290555	0.0694
12	850	4000	7	3.17	0.0364659	0.0871
13	850	4500	3	3.21	0.0148208	0.0354
14	850	4500	5	3.18	0.0250363	0.0598
15	850	4500	7	3.13	0.0339120	0.081
16	850	5000	3	3.17	0.0130624	0.0312
17	850	5000	5	3.11	0.0241989	0.0578

18	850	5000	7	2.98	0.0335352	0.0801
19	950	4000	3	3.64	0.0326979	0.0781
20	950	4000	5	3.58	0.0406107	0.097
21	950	4000	7	3.51	0.0519147	0.124
22	950	4500	3	3.29	0.0297253	0.071
23	950	4500	5	3.24	0.0364659	0.0871
24	950	4500	7	3.19	0.0473093	0.113
25	950	5000	3	3.26	0.0280507	0.067
26	950	5000	5	3.23	0.0309813	0.074
27	950	5000	7	3.11	0.0424528	0.1014

A. Main effects plot of surface roughness

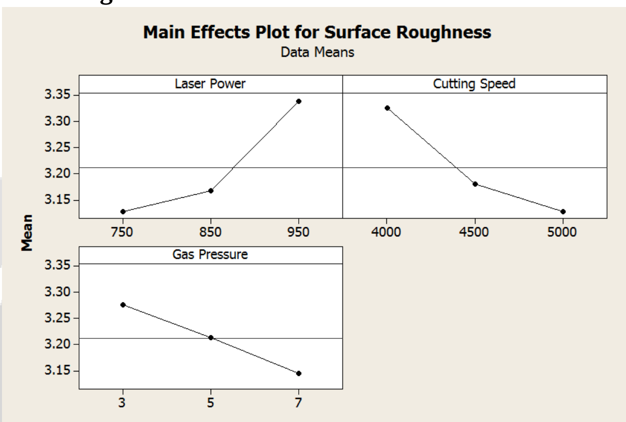

Figure 2: Effect of control factor on Surface roughness

From the Figure 2, it has been Conclude that the Optimum combination of each process parameter for lower surface roughness is meeting at low laser power [A1], high cutting speed [B3] and high gas pressure [C3].

B. Main effects plot of kerf width

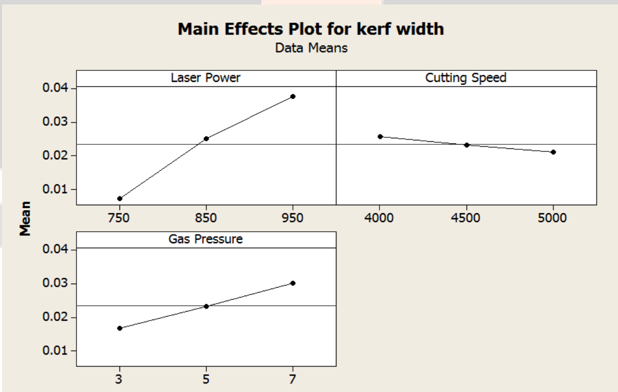

Figure 3: Effect of control factor on Kerf width

From the Figure 3, it has been Conclude that the Optimum combination of each process parameter for low kerf width value is meeting at laser power [A1], cutting speed [B3] and gas pressure [C1].

C. Main effects plot of taper angle

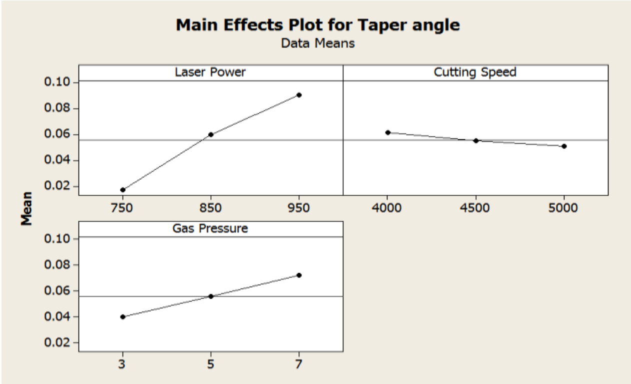

Figure 4: Effect of control factor on Taper angle

From the Figure 4, it has been Conclude that the Optimum combination of each process parameter for low taper angle is meeting at laser power[A1], cutting speed[B3] and gas pressure[C1].

D. Analysis of Variance for Surface roughness

Table 3: ANOVA: Surface Roughness versus Laser Power, Cutting Speed and Gas Pressure

Factor	Type	Levels	Values
Laser Power	fixed	3	750, 850, 950
Cutting Speed	fixed	3	4000, 4500, 5000
Gas Pressure	fixed	3	3, 5, 7

Analysis of Variance for Surface Roughness

Source	DF	SS	MS	F	P
Laser Power	2	0.226341	0.113170	18.46	0.000
Cutting Speed	2	0.188474	0.094237	15.37	0.000
Gas Pressure	2	0.076096	0.038048	6.21	0.008
Error	20	0.122630	0.006131		
Total	26	0.613541			

R-Sq = 80.01%   R-Sq(adj) = 74.02%

From ANOVA result, it is observed that the Laser power, Cutting speed and Gas pressure of cutting influencing parameter for Surface roughness as they are all less than 0.05 p. Thus it can be concluded that the effect of all cutting parameters are significant.
The confidence level (CL) used for investigation is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in surface roughness is explained by the input factor. R-Sq= 80.01 % which indicate that the model is able to predicate the response with high accuracy.

E. Analysis of Variance for Kerf width

Table 4: ANOVA: Kerf width versus Laser Power, Cutting Speed and Gas Pressure

Factor	Type	Levels	Values
Laser Power	fixed	3	750, 850, 950
Cutting Speed	fixed	3	4000, 4500, 5000
Gas Pressure	fixed	3	3, 5, 7

Analysis of Variance for kerf width

Source	DF	SS	MS	F	P
Laser Power	2	0.00423142	0.00211571	143.24	0.000

Cutting Speed	2	0.00009399	0.00004700	3.18	0.063
Gas Pressure	2	0.00081124	0.00040562	27.46	0.000
Error	20	0.00029540	0.00001477		
Total	26	0.00543205			

R-Sq = 94.56%   R-Sq(adj) = 92.93%

From ANOVA result, it is observed that the Laser power, Cutting speed and Gas pressure of cutting influencing parameter for Kerf width as they are all less than 0.05 p. The confidence level (CL) is taken 95% for this investigation.

F. Analysis of variance for Taper angle

Table 5: ANOVA: Taper angle versus Laser Power, Cutting Speed and Gas Pressure

Factor	Type	Levels	Values
Laser Power	fixed	3	750, 850, 950
Cutting Speed	fixed	3	4000, 4500, 5000
Gas Pressure	fixed	3	3, 5, 7

Analysis of Variance for Taper angle

Source	DF	SS	MS	F	P
Laser Power	2	0.0241407	0.0120703	143.24	0.000
Cutting Speed	2	0.0005362	0.0002681	3.18	0.063
Gas Pressure	2	0.0046282	0.0023141	27.46	0.000
Error	20	0.0016853	0.0000843		
Total	26	0.0309904			

R-Sq = 94.56%   R-Sq(adj) = 92.93%

The confidence level (CL) is taken 95% for this investigation. The parameter R-Sq described the amount of variation observed in cutting forces is explained by the input factor. R-Sq= 94.56% which indicate that the model is able to predicate the response with high accuracy.

V. RESPONSE SURFACE METHODOLOGY

A. Response Surface analysis for Surface roughness

Response surface plot is one of the best method to represent the Experimental data.

Figure 5 shows Surface plot of Surface roughness for interaction of laser power and cutting speed, when gas pressure taken as hold value. This surface plot indicates that surface roughness decrease in cutting speed from 4000 to 5000 mm/min, whereas surface roughness increase in laser power increase from 800 to 960 Watt.

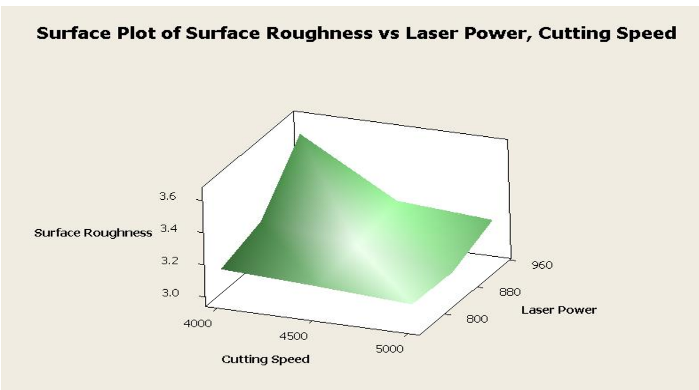

Figure 5: Surface plot for Surface roughness vs. Laser power and Cutting speed

Figure 6 shows Surface plot of Surface roughness for interaction of cutting speed and gas pressure, when laser power taken as hold value. This surface plot indicates that surface roughness decreases with gas pressure from 3 to 7.5 bar, whereas surface roughness decrease with increase cutting speed from 4000 to 5000 mm/min. It also shows that influence of cutting speed is significant.

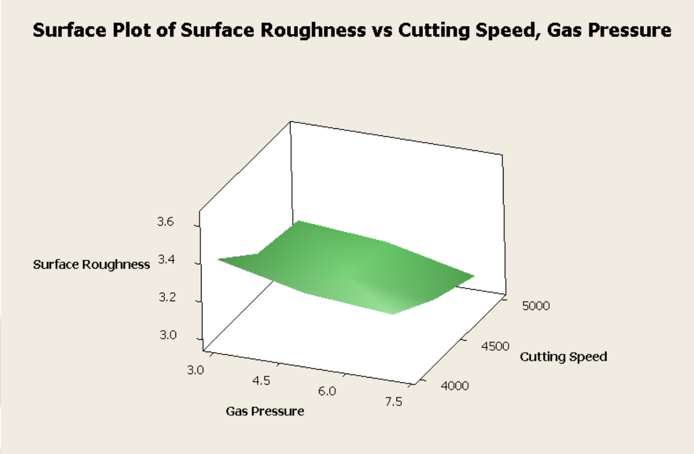

Figure 6: Surface plot for Surface roughness vs. Cutting speed and Gas pressure

Figure 7 shows Surface plot of Surface roughness for interaction of gas pressure and laser power, when cutting speed taken as hold value. This surface plot indicates that surface roughness increases with increase laser power from 800 to 960 watt, wheareas decreases in gas pressure from 3.00 to 7.5 bar. But influence of laser power on surface roughness is more significant compare to gas pressure parameter.

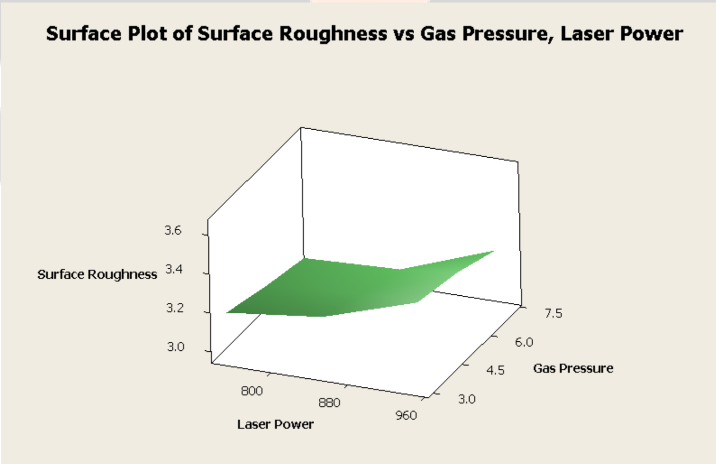

Figure 7: Surface plot for Surface roughness vs. Gas pressure and Laser power

Optimization of Process parameters for Surface roughness

Large number of conflicting factors and complex Machining phenomena in cutting process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will minimize the surface roughness with the use of response optimizer in response surface methodology shown in Table 6.

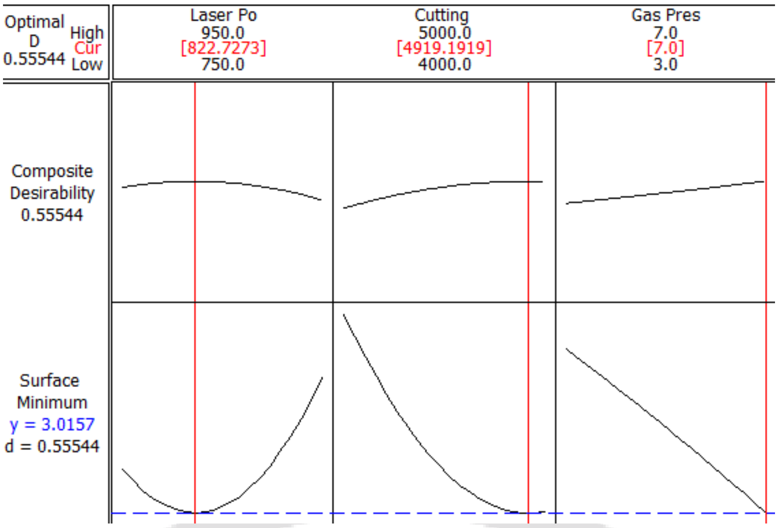

Table 6: Response optimization Surface roughness parameter

Response	Goal	Optimal condition	Target	Upper	RSM predicated	Experimental
Surface roughness	Minimize	Laser power: 822.72 watt Cutting speed : 4919.19 mm/min Gas pressure : 7 bar	2.98	3.66	3.0157	3.09

For Minimizing the Surface roughness, the optimum value of 822.72 watt, 4919.19 mm/min and 7 bar are laser power, cutting speed and gas pressure as respectively. And experimental surface roughness value is 3.09µm.

B. Response Surface analysis for Kerf width

Figure 8 shows Surface plot of Kerf width for interaction of laser power and cutting speed, when gas pressure taken as hold value. This surface plot indicates that kerf width decrease in cutting speed from 4000 to 5000 mm/min., whereas kerf width increase in laser power increase from 800 to 960 watt. It also shown that influence of laser power is comparatively more significant.

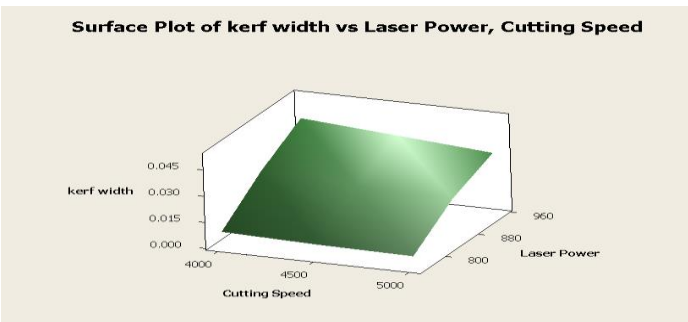

Figure 8: Surface plot for Kerf width vs. Laser power and Cutting speed

Figure 9 shows Surface plot of Kerf width for interaction of cutting speed and gas pressure, when laser power as hold value. This surface plot indicates that kerf width slightly effect with gas pressure from 3 to 7.5 bar whereas kerf width decrease with increase speed from 4000 to 5000 mm/min. It also shows that influence of speed is significant.

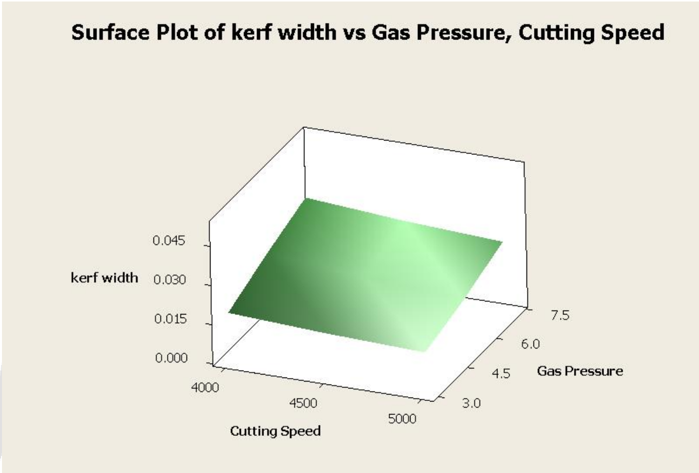

Figure 9: Surface plot for Kerf width vs. Cutting speed and Gas pressure

Figure 10 shows Surface plot of Kerf width for interaction of gas pressure and laser power, when cutting speed taken as hold value. This surface plot indicates that kerf width decrease with after laser power 880 watt. And increase with gas pressure from 3 to7.5 bar. But influence of gas pressure on kerf-width is less significant compare to laser power parameter.

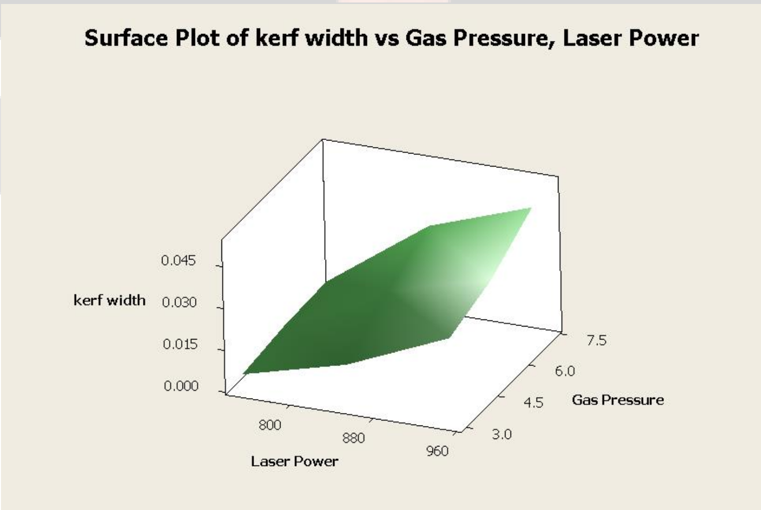

Figure 10: Surface plot for Kerf width vs. Gas pressure and Laser power

Optimization of Process parameters for Kerf width

Large number of conflicting factors and complex Machining phenomena in cutting process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will minimize the kerf width with the use of response optimizer in response surface methodology shown in Table 7.

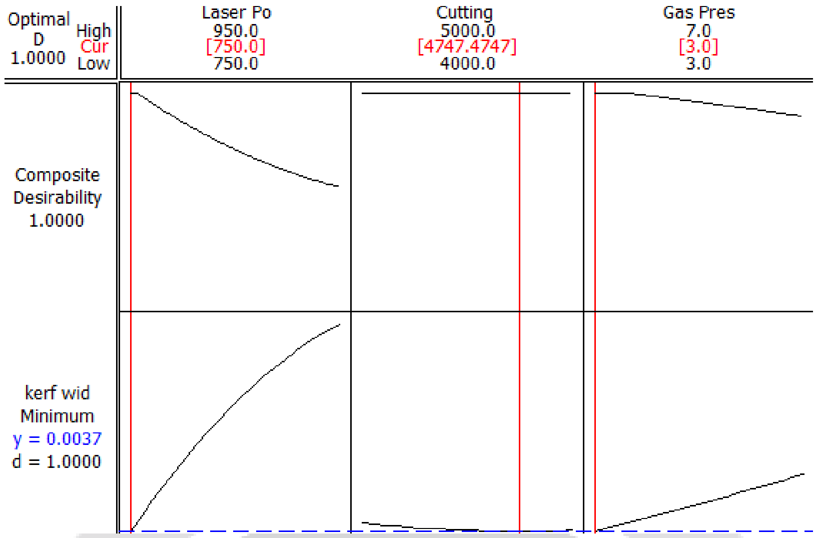

Table 7: Response optimization Kerf width parameters

Response	Goal	Optimal condition	Target	Upper	RSM predicated	Experi-mental
Kerf width	Minimize	Laser power: 750 watt Cutting speed: 4747.47 mm/min Gas pressure : 3 bar	0.0046472	0.0519146	0.0037244	0.004021

For minimizing the kerf width, the optimum value of laser power, cutting speed and gas pressure as 750 watt, 474747 mm/min and 3 bar respectively. And experimental kerf width value is 0.31 mm.

C. Response Surface analysis for Taper angle

Figure 11 shows Surface plot of Taper angle for interaction of laser power and cutting speed, when gas pressure taken as hold value. This surface plot indicates that Taper angle decrease with cutting speed increase from 4000 to 5000 mm/min. It also shown that influence of laser power is comparatively more significant.

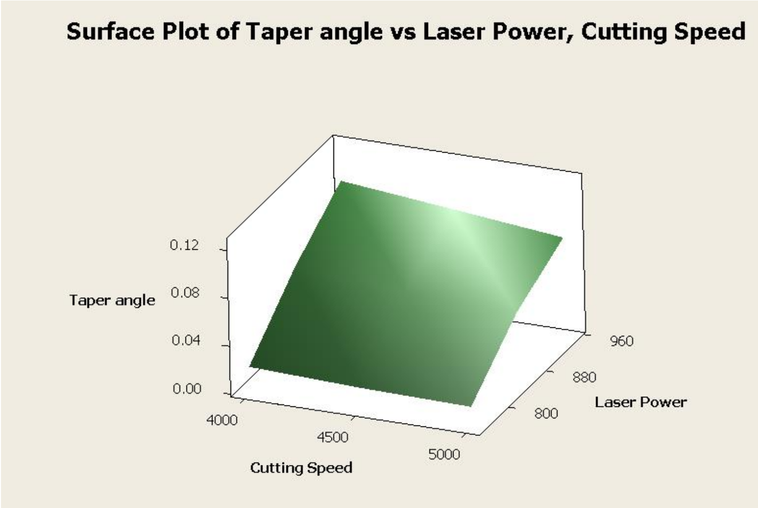

Figure 11: Surface plot for Taper angle vs. Laser power and Cutting speed

Figure 12 shows Surface plot of Taper angle for interaction of Cutting speed and gas pressure, when laser power taken as hold value. This surface plot indicates that Taper angle does not effect by gas pressure, but slightly variation through cutting speed.

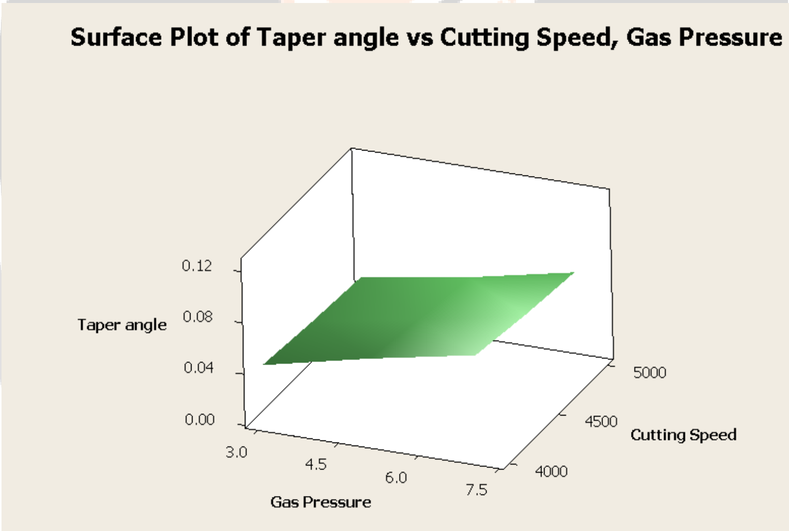

Figure 12: Surface plot for Taper angle vs. Cutting speed and Gas pressure

Figure 13 shows Surface plot of Taper angle for interaction of Laser power and gas pressure, when cutting speed taken as hold value. This surface plot indicates that Taper angle increases with increases in laser power from 800 to 960 watt, and slightly affected by gas pressure. But influence of gas pressure on Taper angle is less significant compare to laser power parameter.

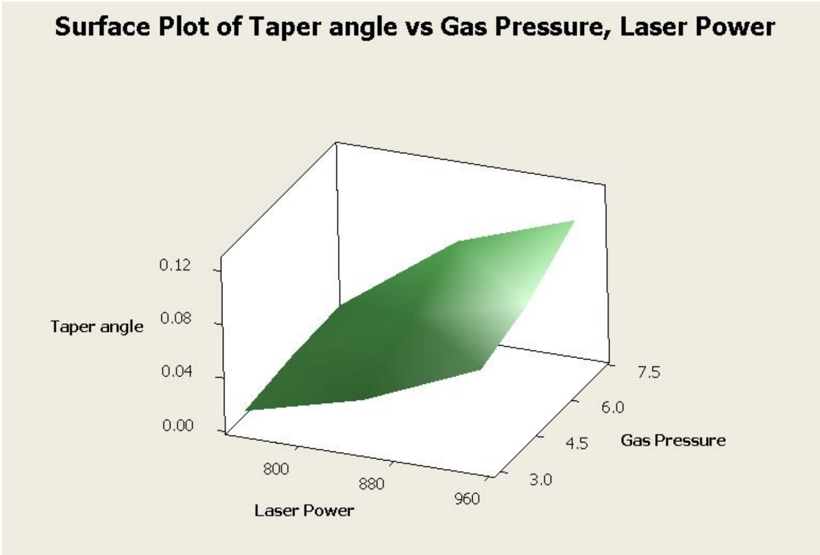

Figure 13: Surface plot for Taper angle vs. Laser power and Gas pressure

Optimization of Process parameters for Taper angle

Large number of conflicting factors and complex Machining phenomena in cutting process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will minimize the taper angle with the use of response optimizer in response surface methodology shown in Table 8.

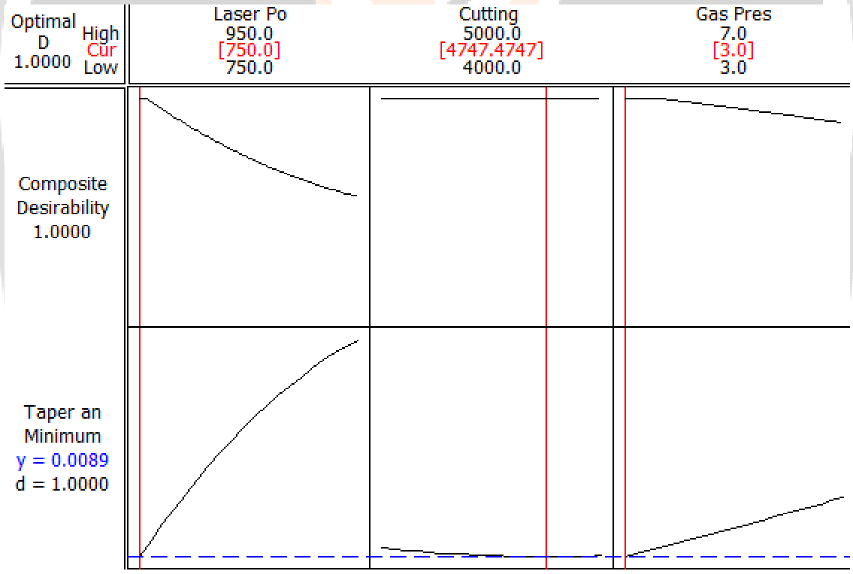

Table 8: Response optimization Taper angle Parameters

Response	Goal	Optimal condition	Target	Upper	RSM predicated	Experimental
Taper angle	Minimize	Laser power : 750 watt Cutting speed : 4747.4747 mm/min Gas pressure : 3 bar	0.0111	0.124	0.0088959	0.008314

For Minimizing the Taper angle, the optimum value of 750 watt, 4747.4747 mm/min and 3 bar are laser power, cutting speed and gas pressure as respectively. And experimental surface roughness value is 0.008314.

VI. CONCLUSION

The AISI1015 has been laser cutted by laser cutting machine. The conclusions relevant to this investigation are outlined below:

- The surface roughness increase with increase laser power from 750 to 950 watt, when the other two parameter are kept constant as well as surface roughness decrease with increase cutting speed and gas pressure 4000 to 5000 mm/min and 3 to 7 bar.
- While studying the effect of the cutting parameters on the kerf width and taper angle, it was observed that both the gas pressure and the laser power play equally important roles in the effect on the kerf width. The role of the cutting speed given is not crucial to the same extent. The optimum condition for machining to reduce kerf width would be A1 B3 C1. The cutting speed kept at 5000 mm/min, the laser power kept at 750 watt and the gas pressure kept at 3 bar.
- These study conclude that the kerf width is affected to kerf angle thus ultimately concentration on reduce kerf width leads to good surface qualities.
- The optimum condition for machining to reduce surface roughness would be A1 B3 C3. The cutting speed kept at 5000 mm/min, the laser power kept at 750 watt and the gas pressure 7 bar.
- While studying the effect of the cutting parameters on the surface roughness, it was observed that both the cutting speed and the laser power play equally important roles in the effect on the surface roughness. The role of the gas pressure given is less crucial to the same extent.
- Through use of response surface methodology, engineer can predicted and visualize manipulate range of process parameters for this particular work- material. Also it has been given intermediate value of process parameters which carried out the accurate study.

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