An Investigation of Laser Machining for Thick Stainless Steel on Surface Roughness Parameter

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ABSTRACT

Laser machining is a widely used thermal advanced machining process capable of high accuracy cutting of almost any material with complex geometries. Stainless steel is an significant engineering material that is difficult to machine by conventional methods because of the high melting point and low viscosity. However, it is suitable to be machine by laser. The main aim of this work is to do parametric analysis of process parameters of fiber laser cutting system on surface characteristics of the cut section in the cutting of 20mm Stainless Steel (SS) sheet. In this work, the laser cutting parameters such as laser power, cutting speed and gas pressure are analyzed and optimized with consideration of workpiece surface roughness. Design of experiments (DOE), ANOVA and Response Surface Methodology (RSM) approaches are used to analyze the laser cutting variables and find out the optimum value for surface roughness. The critical analysis of various theoretical and experimental models used to describe the performance analysis of laser machining process. By studying, it is observed that the laser power has more effect on responses rather than cutting speed and gas pressure.

Keywords*: Laser machining, surface roughness, DOE*

1. INTRODUCTION

In today's environment, manufacturing industries are facing fierce competition in changing markets. Customer demands for higher quality at lower costs. In addition, demands for shorter delivery time are putting extra pressure on manufacturing industries. The manufacturer having responsibility of ensuring customer requirements; comply with specification, and ensuring quality, all within compressed time limits. Keeping these limitations in mind present research work is made to focus on one of the prominent machining technique sheet metal cutting process. LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. The most important applications of laser is laser cutting. The effect of machining difficult to machine materials by other mechanical machining processes is more as it causes less material removal rate and low tool life. Laser beam machining is the machining processes involving a laser beam as a heat source. Laser machining, being a non-contact process, does not involve any mechanical cutting forces and tool wear. In this process, the workpiece material is locally heated by the determined laser source. The melt is then blown out of the material with the help of assist gas that flows throughout the material with the laser beam [1]. In metal machining operations, in general, oxygen or nitrogen is used while argon or helium is used for wood or plastic cutting. It was shown that the laser cutting quality depends on the laser power, cutting speed, gas pressure, beam diameter, beam incident angle, stand-off distance, pulse frequency and focus positions [2]. From papers [3-5], it was found that the most significant cutting parameters are cutting speed, gas pressure and laser power which has more effect on cutting quality. A few of experimental investigation has been undertaken with intend of analyzing the effect of these three process parameters on cut surface quality. Different researchers used various optimizing methods for optimizing cutting parameters [6-11]. In this research paper, the cutting parameters such as laser power, cutting speed and gas pressure were analyzed and optimized with consideration of surface roughness with help of DOE, ANOVA and RSM on stainless steel thick material.

2. EXPERIMENTAL SETUP

The experiments were conducted on Bystronic 4020 laser cutting machine, at Kakade Lasers, Pune. This machine used a 10.6 µm wavelength CO_2 laser with a nominal power output of 6000W at pulsed mode. Focal length of lens used was 127 mm, nozzle diameter (2.0 mm), and material thickness (20 mm) were kept constant throughout the experimentation. A 20 mm thick Stainless steel-304 was used as workpiece material. Technical Specification of laser cutting machine 4020 is given in Table 1. SS-304 has selected as workpiece material due to lower carbon content. SS-304 is used in high-temperature applications and widely used material for sheet metal working for various industrial and household applications like screws, machinery parts and fabrication of electronics components. The chemical composition of the SS-304 is provided in Table 2. In this study, the cutting parameters such as laser power, cutting speed and gas pressure were analyzed and optimized with consideration of workpiece surface roughness as output parameter.

Parameter	**Range**	**Parameter**	**Range**
Laser type	Ytterbium fiber	Frequency	50-60 Hz
Mode of operation	CW	Laser source weight	330 kg
Polarization	Random	Laser cooling water flow rate	6 Lit/min
Nominal output power	6000 Watt	Laser cooling water temperature	18-26 C
Emission wave length	1070-1080 µm	Operation voltage three phase	400-460 volt
Switch ON/OFF	80 µsec	Operating current	8 A
Output fiber core diameter	150 µm	Starting current	18 A
Fiber length	10 m	Work table	3000 X 1500 mm

Table-1: Technical Specification of laser cutting machine

C	Cr	Ni	Mn	Si	P	S	Fe
0.08	18-20	8-10.5	2.0	1.0	0.045	0.030	Balance

Table-2: Chemical composition of the SS-304

Design of experiment approach, ANOVA and Response Surface Methodology were used to study cutting parameters with consideration of workpiece surface roughness and identify the optimized parameter regions. RSM also gives the relation between interaction of two cutting variable and surface roughness. The values of the parameters that have varied during the execution of experiments are shown in Table 3.

Symbol	Cutting Factors	Level 1	Level 2
A	Laser power (watt)	5000	5500
B	Cutting speed (mm/min)	210	230
C	Gas pressure (bar)	8	12

Table-3: Laser cutting variables and their levels

3. ANALYSIS AND DISCUSSION OF EXPERIMETNAL RESULT

A series of experiments were performed under the experimental plan to analyze the influence of the process parameters upon processed surface roughness and to obtain a complex relationship to show roughness variation according to these parameters. Statistical software Design-Experts [12] was used to code the variables and to establish the design matrix as shown in Table 4.

		Factor 1	Factor 2	Factor 3	Response 1
Std	**Run**	**A:Laser Power kW**	**B:Gas Pressure Bar**	**C:Cutting speed mm/min**	**Surface Roughness micron**
1	13	5250	10	220	5.878
2	14	5250	10	220	6.484
3	4	5500	12	220	5.255
4	8	5500	10	230	6.562
5	1	5000	8	220	6.647
6	5	5000	10	210	5.235
7	2	5500	8	220	5.356
8	10	5250	12	210	6.242
9	3	5000	12	220	6.349
10	7	5000	10	230	6.182
11	15	5250	10	220	6.266
12	16	5250	10	220	6.513
13	6	5500	10	210	7.216
14	12	5250	12	230	6.853
15	9	5250	8	210	6.566
16	17	5250	10	220	6.322
17	11	5250	8	230	5.563

Table-4: Experimental data

	Sum of		Mean	F	p-value	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Model	0.45	9	0.050	7.28	0.0079	significant
A-Laser Power	0.068	1	0.068	9.94	0.0161	
B-Gas Pressure	0.094	1	0.094	13.84	0.0075	
C-Cutting speed	1.422E-005	1	1.422E-005	2.085E-003	0.9649	
AB	0.075	1	0.075	10.94	0.0130	
AC	0.026	1	0.026	3.82	0.0915	
BC	0.026	1	0.026	3.83	0.0912	
A^2	0.056	1	0.056	8.26	0.0238	
B^2	0.053	1	0.053	7.74	0.0272	
C^2	0.054	1	0.054	7.91	0.0261	
Residual	0.048	7	6.822E-003			
Lack of Fit	0.037	3	0.012	4.76	0.0830	Non significant
Pure Error	0.010	4	2.614E-003			
Cor Total	0.49	16				

Table-5: ANOVA for response surface quadratic model

Applying the ANOVA on the experimental data, the obtained influence of each parameter and the adequacy of the data are obtained. The summary of the analysis is shown in Table 5. This table shows the degrees of freedom (DF), sum of squares (SS), mean squares (MS), F-values (F-VAL.) and probability (P-VAL.) in addition to the percentage contribution (Contr. %) of each factor and different interactions. The Model F-value of 7.28 implies the model is significant. There is only a 0.79% chance that an 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, B, AB, A^2, B^2, C^2 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 4.76 implies there is 8.30% chance that a "Lack of Fit F-value" this large could occur due to noise. Lack of fit is bad -- we want the model to fit.

Std. Dev. 0.083, R-Squared 0.9035, Mean 2.45, Adj R-Squared 0.7794, C.V. % 3.37, Pred R-Squared-0.2392, PRESS 0.61, Adeq Precision 11.906. A negative "Pred R-Squared" implies that the overall mean may be a better predictor of your response than the current model."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 11.906 indicates an adequate signal. This model can be used to navigate the design space.

- Final Equation in Terms of Coded Factors:

Surface roughness = +2.51 + 0.092 * A + 0.11 * B - 1.33E-003 * C - 0.14 * AB - 0.081 * AC + 0.081 * BC -0.12 * A^2 - 0.11* B^2 + 0.11* C^2

- Final Equation in Terms of Actual Factors:

Surface roughness = - 41.73630 + 29.64182 * Laser Power + 1.15916 * Gas Pressure - 36.89512 * Cutting speed - 0.27314 * Laser Power * Gas Pressure - 3.22972 * Laser Power * Gas Pressure + 0.40405 * Gas Pressure * Cutting speed - 1.85112 * Laser Power^2 - 0.027988 * Gas Pressure^2 + 11.31756 * Cutting speed^2

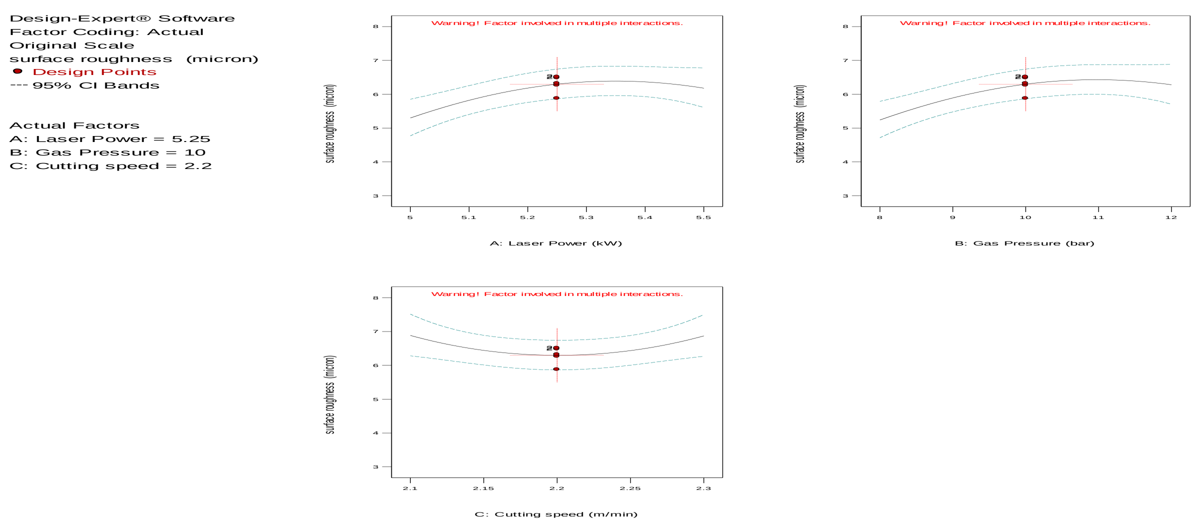

Fig-1: Individual effects of all three parameters on surface roughness of SS 304 for 20 mm

The individual effect of all three parameters laser power, gas pressure and cutting speed on surface roughness are shown in Fig-1. Effect of increase in laser power and gas pressure causes increase in surface roughness at a specific point and then it decreases slightly. When cutting speed increases there is also increase in surface roughness of the material which is not desirable.

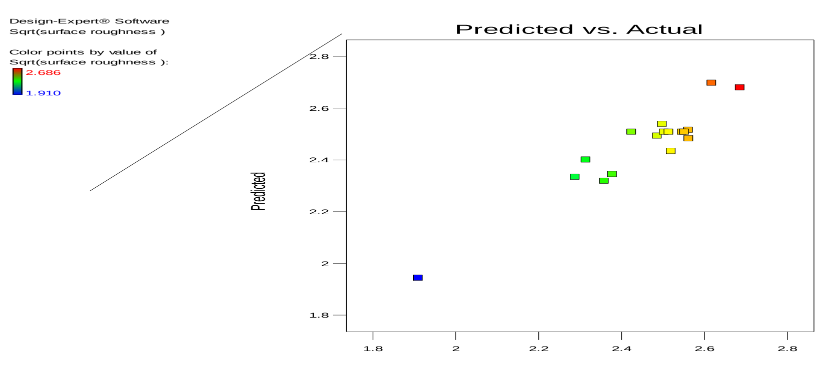

Fig-2: Graph of predicted vs actual surface roughness values of SS 304 with 20 mm

The relationship between the actual and predicted values of experiment is shown in Fig-2. It was observed that the developed model is adequate and predicted results are in good agreement with the experimental results.

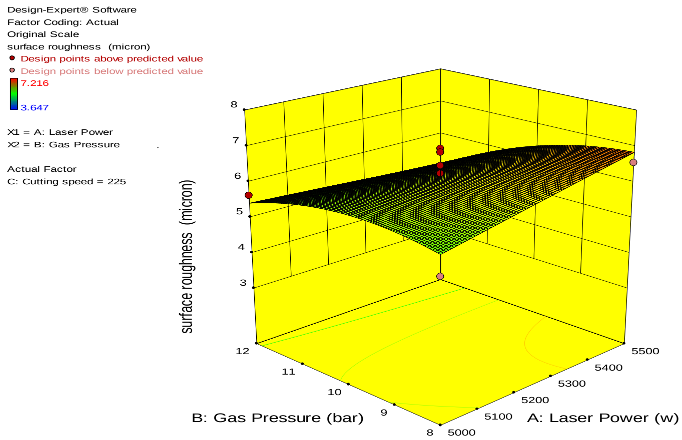

Fig-3: Interaction effect of cutting parameters on surface roughness

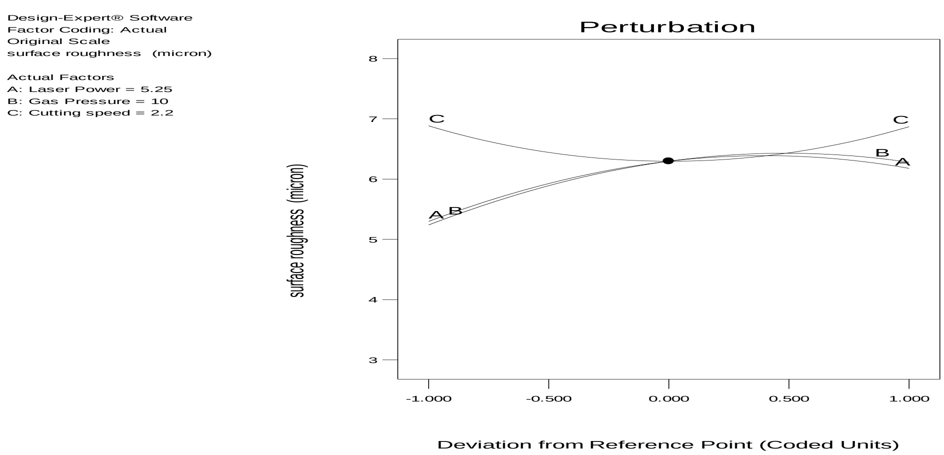

Fig-4: Perturbation plots representing the effect of process parameters on surface roughness of SS 304 for 20 mm

Fig-3 shows a contour surface of the response (i.e. surface roughness) versus laser power and cutting speed, while keeping gas pressure fixed at 10 bar. The increase in laser power increases surface roughness slightly and then decreases and similar effect is also observed with increase in gas pressure. With higher cutting speed, it causes increases in surface roughness as shown Fig-4 for perturbation plots representing the effect of process parameters on surface roughness.

4. CONCLUSION

In this paper, the complete analysis of the influence process parameters on the laser cutting process has performed with laser cutting machine. After DOE analysis total 17 run have identified for experiment with sheet metal operation (20 mm thick) SS 304 as workpiece material. The optimal values of these parameters have defined with the aim of achieving the required surface roughness. It has found that the laser power is most significant compare to cutting speed and gas pressure. Laser power and gas pressure has identified most significant interactive parameter with highest F value of 7.74. By using regression analysis method, the optimized value of parameters found as power 5000 W, gas pressure 10 bar and cutting speed 210 mm/min for the minimum value of surface roughness 5.235 µm. Based on these results, the optimal cutting condition, at which the surface roughness is minimized and both the delayed cutting phenomenon is estimated to improve both the quality of the cut section and the cutting efficiency.

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