Effect of Fiber Laser Machining for Surface Roughness of Thick Stainless Steel

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ABSTRACT

The use of stainless steel (SS) in the recent years has grown worldwide. A wide spectrum of industries rely on stainless steel including constructions, automotive and much more. Different shapes like plate, bars, sheets and tubing can be manufactured using stainless steel for using industrial and domestic settings. It cannot be easily cut by laser cutting process. In this research work effect of fiber laser cutting for SS has been considered. Fiber laser has capacity to cut hard materials due to its higher efficiency, better beam quality, reliability and ease of beam delivery through optical fiber. In this study, the laser cutting parameters such as laser power, cutting speed and gas pressure are analyzed and optimized with consideration of work piece surface roughness. Surface roughness is considered as one of the performance parameter. The variation in laser cut quality with varying process parameters are studied with the design of expert software. Response surface methodology (RSM) is used by implementing three levels box- behnken design for optimization. It is observed that surface roughness can be optimized effectively by using this approach.

Keywords: ***Surface roughness, Box- Behnken, Laser cutting***

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1. INTRODUTION

LASER is an acronym for light amplification by stimulated emission of radiation. It was first suggested by Albert Einstein in 1916. Laser cutting is a two dimensional cutting process which removes the material by focusing a highly intense laser beam on the work piece. It has ability to produce highly quality cuts at optimum production cost [1]. In last few years fiber lasers have proven themselves as the preferred laser source in industrial applications. Small size, maintenance free operation, thermal and electrical efficiency combined with outstanding beam quality has made the fiber laser effective choice for cutting. It is a reliable technique used in many industries for production. Laser cutting is known by localized heating, melting and vaporization. The cost of difficult to cut material by traditional method is high because of less removal of material. In this technique highly intense monochromatic beam is used to cut hard materials. Generally, fiber laser operating machines are used to cut because of its high focus ability [2]. The important factors that affect the cutting process are gas pressure, feed rate, cutting speed, type of assist gas and flow, and focus position. Multiple interaction effects between these factors further complicate cutting process making it difficult to develop relationships between process factors and performance characteristics. The effects of these factors on the laser cutting performances such as cut quality characteristics, productivity and operational costs have been widely studied. Stainless steel has wide applications in the home, industry, hospitals, food processing, aerospace, construction etc. Cutting of thick stainless steel sheets is the basic requirement in fabrication work of the various components [5]. Fiber laser cutting of stainless steel 304 offers several advantages over conventional cutting methods. The laser cutting parameters used for this experiment are laser power, cutting speed and gas pressure as these parameters affect cutting quality in laser cutting process and the cut qualities were analyzed by measuring the surface roughness[1-2]. Some experimental investigation has been conducted by analyzing the effect of these parameters on cut surface quality. In this research paper process parameters were analyzed and optimized with consideration of response surface methodology by using design of expert (DOE) software. Response surface methodology is used by implementing three level box behnken design to optimize the variation of cut quality [2].

1.1 EXPERIMENTAL SETUP

The experiments were conducted on Bystronic 4020 fiber laser machine at Kakade lasers, Pune. We have selected 16 mm thick SS 304 sheet as work piece material. Technical specifications of laser machine are given in table 1. The 17 samples of 30 mm X 30 mm cross-section and 16 mm thickness were cut. SS304 was selected as work piece material because of low carbon which decreases carbide specifications. Also, it has higher operating temperature application.

Table 1 Specifications of machine

Laser cutting system	**Bysprint 4020**
Nominal Sheet size	X-4000 mm , Y-2000 mm
Cutting Area	X-4064 mm, Y-2032 mm
Maximum Positioning speed parallel axis x, y	100 mm
Maximum simultaneously positioning speed	140 mm
Positioning accuracy Pa	±0.1
Repeatability Ps	±.05
Maximum work piece weight	1580
Machine weight	15000
Operation via panel	Byvision touch screen and manual control unit

2. DESIGN OF EXPERIMENT (DOE)

Design of experiment (DOE) is the method of planning and conducting experiments in a systematic way to study any process or system using statistical analysis [3]. It is used for collecting an appropriate set of experimental data to be used for statistical analysis in order to draw inferences about the process or system. In the current study response surface methodology (RSM) was applied for the above mentioned process parameters, using statistical software, Design-expert v10.

2.1 RESPONSE SURFACE METHODOLOGY (RSM)

Implementation of RSM requires the following steps like selection of parameters with major effects, selection of proper experimental design, fitting of adequate mathematical model, checking the quality of the fitted model and evaluation of its prediction behaviour with respect to the experimental data. RSM is applied to predict the parametric relationship from the responses obtained in a series of experiments by fitting a polynomial equation with experimental data. The input parameters are known as factors and output variables are termed as responses. If all independent variables or factors are measurable and can be repeated with negligible error, the nature of relationship between the factors and responses i.e. the response surface can be expressed by the following equation 1:

$$y=f\ (x_1, x_2, x_3,.........x_p) \qquad 1$$

where p is the number of independent variables. Usually a second order polynomial is used as a functional relationship between the independent variables and the response surface to optimize the responses in RSM, as presented in equation 2:

$$Y=b_o+ \Sigma b_i x_i+ \Sigma b_{ii} x_{ii}^2+ \Sigma b_{ij} x_i x_j \qquad 2$$

The coefficients b_0, bi, bii, bij are determined using regression analysis. Fitting the response surface most efficiently requires proper selection of the design of experiments (DOE) that helps in choosing proper experimental array to carry out within the process window [11-12]

2.2 BOX BEHNKEN DESIGN

Various complex experimental designs like three level factorial design, central composite design (CCD), Box-Behnken design (BBD) and Doehlert design are used to generate response surface. In this study Box-Behnken method was chosen due to the shorter range of process parameters and less experimental runs. BBD is also reported to be more efficient compared to CCD and three level full factorial designs [6], where efficiency is defined as the ratio of number of coefficients present in regression model and number of experiments conducted. Another advantage of Box-Behnken design is that, it does not contain combination of factors at which all the factors are simultaneously at their highest or lowest level, thus can avoid experiments under the extreme conditions [6]. The experimental runs were conducted as per the design matrix given by the software. Second order polynomials were fitted to the experimental data, and stepwise regression method was used to find out the significant model terms and the final regression equation. Afterwards the same software was used to generate different response plots and to carry out numerical optimization to find out the set of process parameters at which the desired cut quality can be achieved.

3. ANALYSIS AND DISCUSSIONOF EXPERIMENTAL RESULTS

The experimental data generated by DOE software is shown in Table 2.

Table 2 Observation Table

		Factor 1	Factor 2	Factor 3	Response 1
Run	Std	A:Laser Power (W)	B:Gas Pressure (Bar)	C:Feed Rate (mm/min)	Top Surface (microns)
1	1	6000	12	250	2.325
2	14	5000	13	250	6.322
3	5	5000	10	250	6.125
4	2	6000	12	250	2.714
5	6	5000	13	250	6.424
6	15	5000	16	250	6.156
7	7	5000	10	250	6.011
8	16	6000	13	300	3.993
9	8	5000	13	250	6.422
10	9	5500	13	275	3.748
11	10	5500	16	300	6.547
12	13	5500	13	275	4.712
13	11	5500	16	250	4.125
14	12	5500	13	275	4.461
15	4	6000	12	250	2.826
16	17	6000	16	275	3.524
17	3	6000	12	250	2.789

In Table 2, readings of 17 samples are taken by varying cutting parameters such as laser power, gas pressure and feed rate. These readings are taken as given by the design matrix in DOE software.

Table 3 ANOVA for response surface quadratic model

Source	Sum of Squares	Df	Mean Square	F Value	P – value Prob> F	
Model	2.09	6	0.35	66.17	< 0.0001	significant
A-Laser Power	0.19	1	0.19	35.46	0.0001	
B-Gas Pressure	0.083	1	0.083	15.65	0.0027	
C-Feed Rate	3.351E-003	1	3.351E-003	0.64	0.4440	
AB	0.014	1	0.014	2.70	0.1312	
AC	0.048	1	0.048	9.07	0.0131	
BC	0.084	1	0.084	15.84	0.0026	
Residual	0.053	10	5.276E-003			
Lack of Fit	6.790E-003	2	3.395E-003	0.59	0.5763	not significant
Pure Error	0.046	8	5.746E-003			
Cor Total	2.15	16				

In table 3 the Model F-value of 66.17 implies the model is significant. There is only a 0.01% 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, AC, BC 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 0.59 implies the Lack of Fit is not significant relative to the pure error. There is a 57.63% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.
The "Pred R-Squared" of 0.8998 is in reasonable agreement with the "Adj R-Squared" of 0.9607; i.e. the difference is less than 0.2."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 19.659 indicates an adequate signal. This model can be used to navigate the design space.

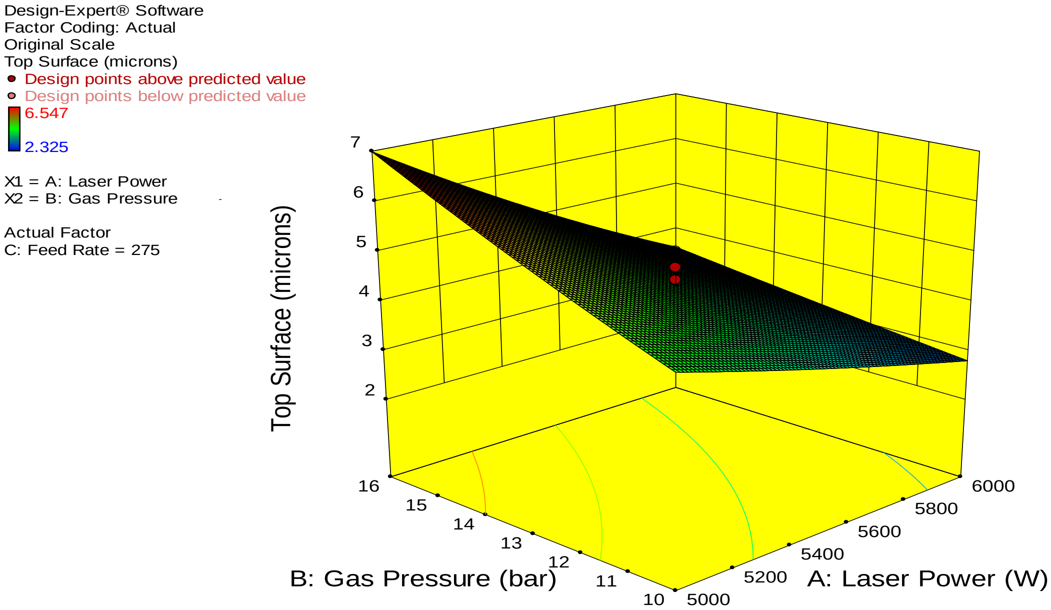

Fig.1 Interaction effect of cutting parameters on surface Roughness

In fig.1, Graph shows that with increase in laser Power, surface roughness values decreases and as gas pressure increases, surface roughness values increases.

- Final Equation in Terms of Coded Factors:

Sqrt(Top Surface) = 2.08067 + -0.293305 * A + 0.190987 * B + 0.0341278 * C + -0.0779132 * AB + 0.165156 * AC + 0.241325 * BC

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

- Final Equation in Terms of Actual Factors:

Surface roughness = 31.8772 + -0.00354479 * Laser Power + -0.535515 * Gas Pressure + -0.113133 * Feed Rate + -5.19422e-005 * Laser Power * Gas Pressure + 1.32125e-005 * Laser Power * Feed Rate + 0.00321767 * Gas Pressure * Feed Rate

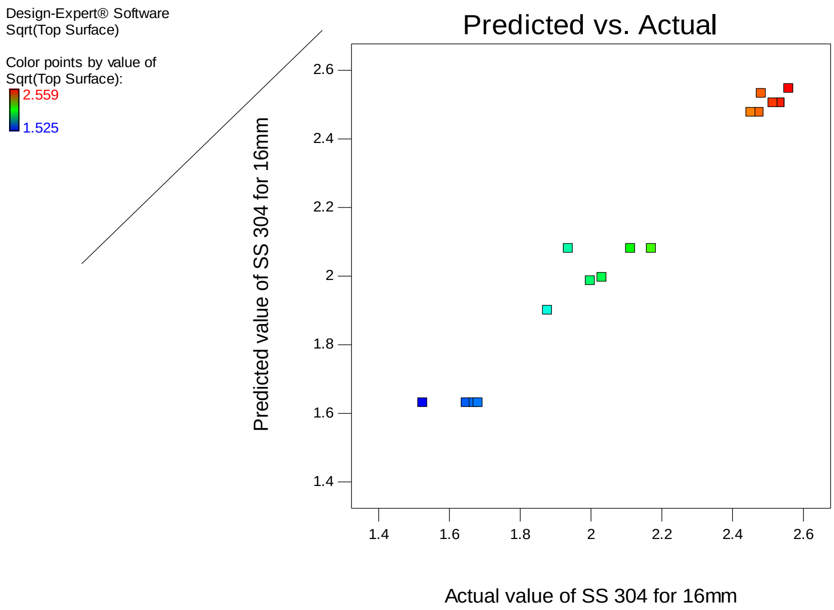

Fig.2 Graph of Predicted VS Actual Roughness Values

In fig.2 graph represents predicted Vs actual surface roughness value. The straight line represents predicted value and other points represent actual value. It concludes that the actual values are closer to predicted values of surface roughness.

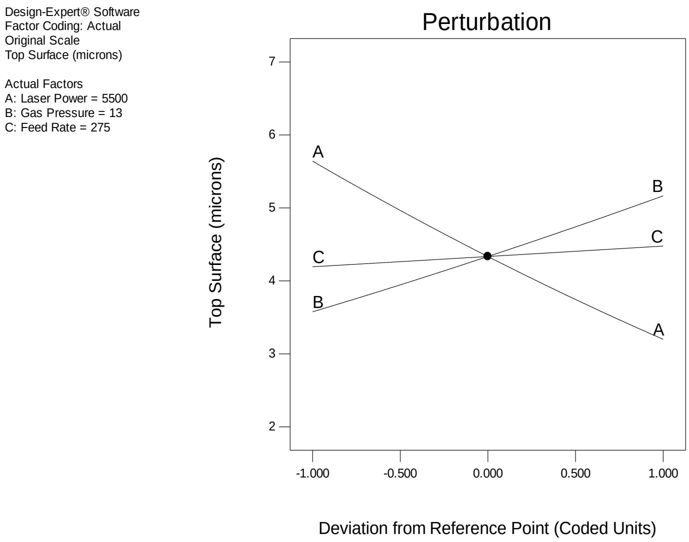

Fig.3 Graph showing deviation from reference point

In fig.3 the graph shows relation between cutting parameters. The middle point represents the mean value of all the cutting parameters. The AA, BB and CC lines represent the variation of the parameters laser power, feed rate and gas pressure accordingly.

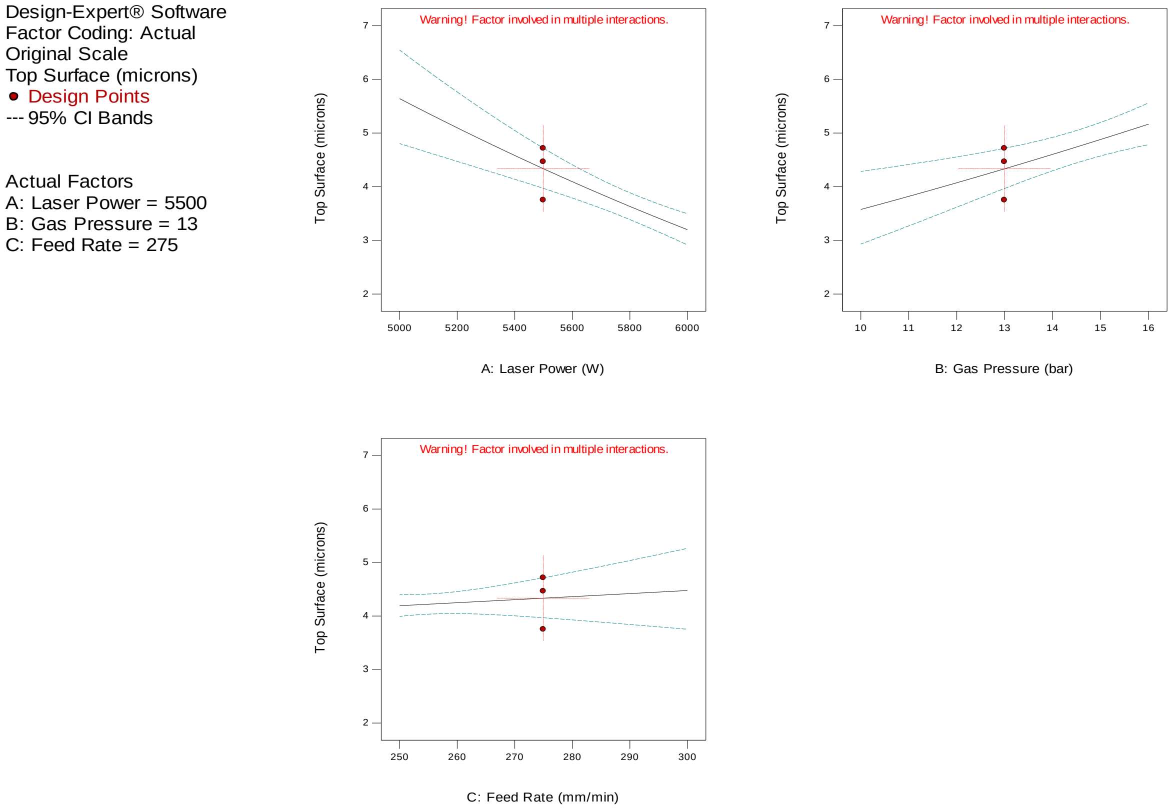

Fig.4 Graph showing variation of roughness values with respect to cutting parameter

In fig.4 the graph shows individual variation of the parameters with respect to surface roughness readings of the top surface. For example we can see that as the laser power increases the values of surface roughness start to diminish.

3. CONCLUSION

In this paper, the complete analysis of the influence of process parameters, i.e. laser power, feed rate and gas pressure, on the laser cutting process was performed with Fiber laser cutting machine Bysprint 4020, 6KW laser power. After DOE analysis, total 17 run were identified for experiment with sheet metal SS 304 (16 mm thick) as work piece material. The optimal values of these parameters were defined with the aim of achieving the required surface roughness. It was found that the laser power is most significant compared to cutting speed and gas pressure. As we can see surface roughness decreases with increase in laser power whereas it increases with increase in gas pressure. Laser power and gas pressure were identified as the most significant interactive parameter with highest F value of 0.64. By using regression analysis method, the optimized value of parameters found as power 1.46 kW, gas pressure 0.70 bar and cutting speed 2.00 m/min for the minimum value of surface roughness 2.18179 µm. Based on these results, the optimal cutting condition, at which the surface roughness is minimized is recognised. Also, delayed cutting phenomenon is estimated to improve both the quality of the cut section and the cutting efficiency.

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