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Effect of Co_2 Laser Machining for Surface Roughness of Thick Stainless Steel

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ABSTRACT

Metal cutting is one of the most significant manufacturing processes in the area of material removal application. Metal cutting is defined as the removal of metal from a workpiece in order to obtain a finished product with desired attributes of size, shape, and surface roughness. In this high speed cutting operations, laser cutting is widely used. In this research work effect of fibre laser cutting of Stainless Steel grade 304 is considered. The fiber laser is more compact, has better performance characteristics and permits cutting thin (upto 4 mm) sheetswith higher speed. In this study, the laser cutting parameters such as laser power, cutting speed and gas pressure are analysed and optimized with consideration of work piece surface roughness. Three factors that one must consider for dimensional accuracy are kerf width, HAZ and quality of surface finish. Among various process variables, surface finish is central to determining the quality of a workpiece. Surface roughness is harder to attain and track than physical dimensions are, because relatively many factors affect surface finish. The effect of varying process parameters on the quality of laser cut are studied with the design of expert software. Response surface methodology (RSM) is used by implementing box-behnken design for optimization. Surface roughness can be optimized effectively by using this approach.

***Keywords*:*Surface roughness, Laser cutting, DOE*.**

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1. INTRODUCTION

Laser is acronym for Light Amplification by Stimulated Emission of Radiation. The world's first laser was demonstrated by Maiman using a ruby crystal (1960). Laser material processing has become popular due to several unique advantages of laser namely, high productivity, easy of automation, non-contact processing, improved product quality, highest material utilization and minimum heat affected zone. A laser can produce a coherent, convergent, and monochromatic beam of electro-magnetic radiation with wavelength ranging from ultraviolet to infrared [1]. Laser cutting, being a non-contact process, does not involve any mechanical cutting forces and tool wear. In this process, the workpiece material is locally melted by the focused laser light. In metal cutting 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].In present paper cutting of widely used industrial application material is selected.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 [3]. According to various experiments carried out in previous work, it was found that the most significant cutting parameters are cutting speed, gas pressure and laser power which has more effect on cutting quality [4-5]. Surface finish is central to determining the quality of a workpiece. In this paper, cutting parameters such as laser power, gas pressure and cutting speed were analysed and optimized with consideration of workpiece surface roughness with help of DOE.

2. EXPERIMENTAL SETUP

The experiments were conducted on Bystronic 4020 fiber laser machine at Kakade lasers, Pune. We have selected 25 mm thick SS 304 sheet as workpiece material. Technical specifications of laser machine are given in table 1. The 17 samples of 30 mm X 30 mm cross-section and 25 mm thickness were cut. SS304 was selected as workpiece material because of low carbon which decreases carbide specifications. Also, it has higher operating temperature application and widely utilized material for sheet metal operation for various industrial and household applications like screws, machinery parts, car headers, and fabrication of electronics components.

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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 workpiece weight	1580
Machine weight	15000
Operation via panel	Byvision touch screen and manual control unit

Table-1:Specifications of machine

2.1Design Of Experiment (DOE)

Design of experiment (DOE) is the method of planning and conducting experiments in a systematic way to study any processor system using statistical analysis [4]. 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.

2.2Response 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 behavior with respect to the experimental data. The input parameters are known as factors and output variables are termed as responses.

2.3 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. Box Behnken method has already been used for the optimization of cut quality in laser cutting of different materials, due to its various advantages over the other existing designs. 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, 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. The experimental runs were conducted as per the design matrix given by the software.

2.4 Factors With Level Value

The range of process parameters and experimental design levels are given in table 2

Factors	Level 1	Level 2
Laser power (watt)	5500	6000
Cutting speed (mm/min)	150	200
Gas pressure (bar)	8	12

Table-2:Factors with level value

3. ANALYSIS AND DISCUSSIONOF EXPERIMENTAL RESULTS

The experimental data generated by DOE according to levels entered are given in table 3.

		Factor 1	Factor 2	Factor 3	Response 1

Std	Run	A:Laser Power	B:Cutting speed	C:Gas pressure	surface roughness (top portion)
		Watt	mm/min	bar	Microns
9	1	5250	100	10	9.847
8	2	5500	125	14	5.895
12	3	5250	150	14	9.658
7	4	5000	125	14	10.547
14	5	5250	125	12	9.581
15	6	5250	125	12	9.458
17	7	5250	125	12	9.478
1	8	5000	100	12	9.847
4	9	5500	150	12	6.658
6	10	5500	125	10	7.547
3	11	5000	150	12	12.325
2	12	5500	100	12	7.512
10	13	5250	150	10	9.514
16	14	5250	125	12	9.871
13	15	5250	125	12	9.784
11	16	5250	100	14	8.474
5	17	5000	125	10	10.355

Table-3:Observation Table

Surface roughness for all trial runs is measured with profile meter named as SJ-201 (surface roughness tester).

Analysis of variance table [Partial sum of squares - Type III]						
	Sum of		**Mean**	**F**	**p-value**	
Source	**Squares**	**df**	**Square**	**Value**	**Prob> F**	
Model	1.11	9	0.12	165.56	< 0.0001	Significant
A-Laser Power	0.86	1	0.86	1146.97	< 0.0001	
B-Cutting speed	0.016	1	0.016	21.14	0.0025	
C-Gas Pressure	0.030	1	0.030	40.71	0.0004	
AB	0.071	1	0.071	95.15	< 0.0001	
AC	0.030	1	0.030	40.75	0.0004	
BC	0.016	1	0.016	20.96	0.0025	
A^2	0.072	1	0.072	96.37	< 0.0001	
B^2	1.582E-003	1	1.582E-003	2.12	0.1889	
C^2	0.017	1	0.017	22.30	0.0022	
Residual	5.229E-003	7	7.469E-004			
Lack of Fit	1.688E-003	3	5.628E-004	0.64	0.6302	not significant
Pure Error	3.540E-003	4	8.851E-004			
Cor Total	1.12	16				

Table-4:Show ANOVA for surface roughness of SS 304 for 25 mm.

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The Model F-value of 165.56 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, C, AB, AC, BC, A^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 0.64 implies the Lack of Fit is not significant relative to the pure error. There is a 63.02% 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. Std. Dev. 0.027, R-Squared 0.9953, Mean 3.02, Adj R-Squared 0.9893, C.V. % 0.90, Pred R-Squared 0.9709, PRESS 0.033, Adeq Precision 50.731.The "Pred R-Squared" of 0.9709 is in reasonable agreement with the "Adj R-Squared" of 0.9893;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 50.731 indicates an adequate signal. This model can be used to navigate the design space.

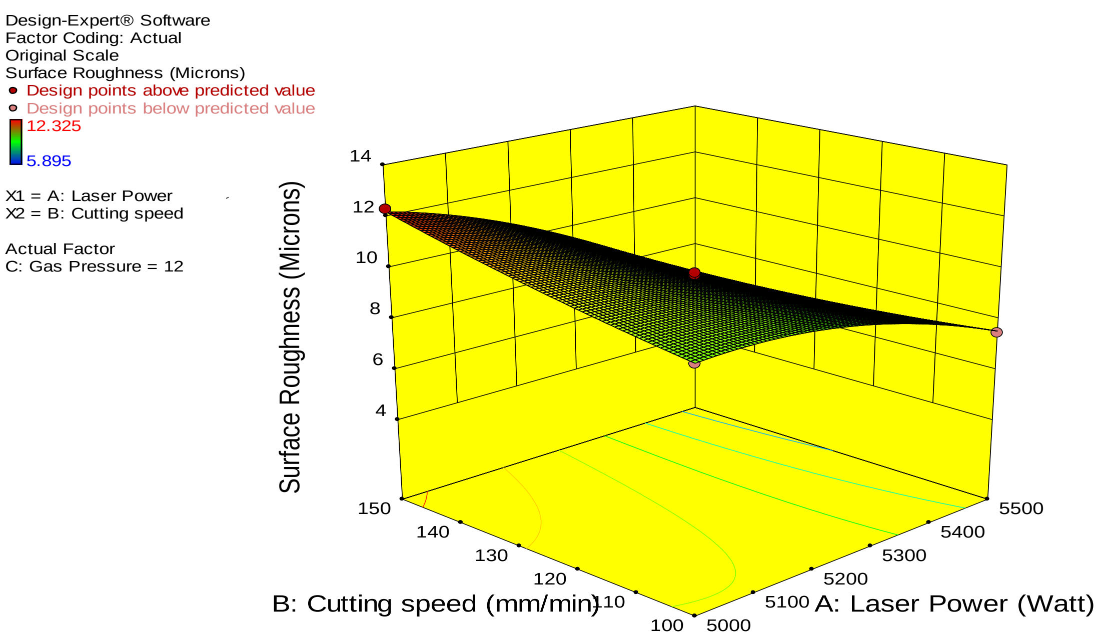

Fig-1: Interaction effect of cutting parameters on surface roughness

In fig-1, graph shows that with increase in laser power, the value of surface roughness decreases and as cutting speed increases, value of surface roughness increases.

Final Equations in terms of coded factors

Surface Roughness = 3.10382 - 0.327246*A + 0.0444269*B - 0.0616558*C - 0.133299*AB - 0.0872285*AC + 0.0625586*BC - 0.130752* A^2 + 0.0193836* B^2 - 0.0628985*C^2

Final Equations in terms of actual factors

Surface Roughness = -72.4279 + 0.0254168 * Laser Power + 0.0909811 * Cutting speed + 1.10607 * Gas Pressure - 2.13279e-005 * Laser Power * Cutting speed - 0.000174457 * Laser Power * Gas Pressure + 0.00125117 * Cutting speed * Gas Pressure - 2.09202e-006 * Laser Power^2 + 3.10137e-005 * Cutting speed^2 - 0.0157246 * Gas Pressure^2

The equation in terms of actual factors can be used to make predictions about the response forgiven levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the interceptis not at the centre of the design space.

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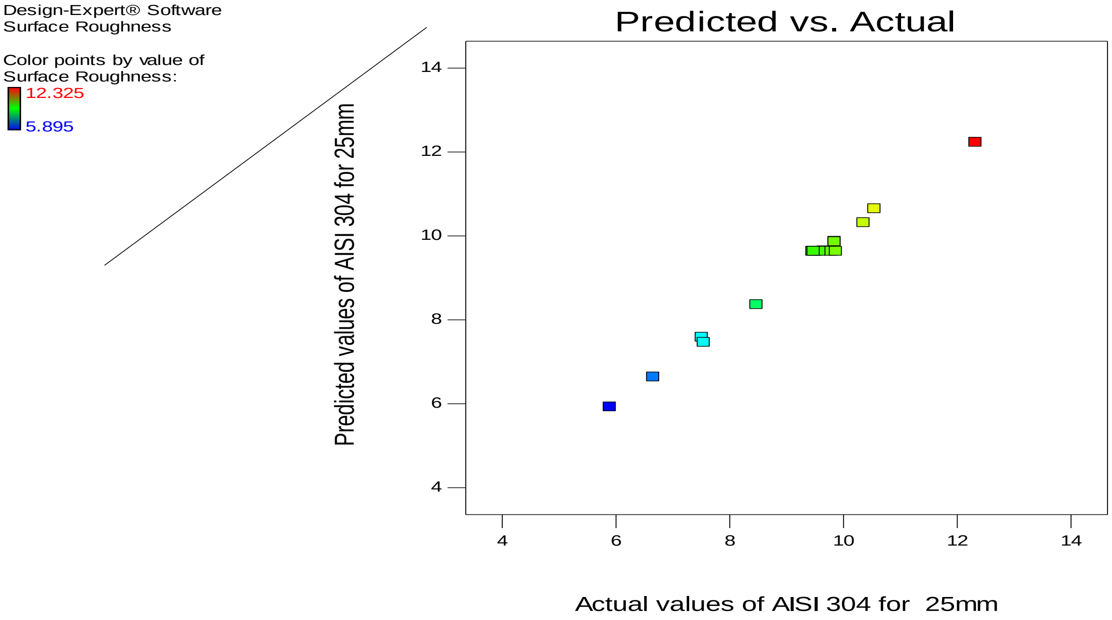

Fig-2: Graph of predicted vs actual surface roughness values of SS 304 for 25 mm

The relationship between the actual and predicted values of experiment of SS 304 for 25 mm is shown in fig-2. It has observed that the developed model is adequate and predicted results are in good agreement with experimental results.

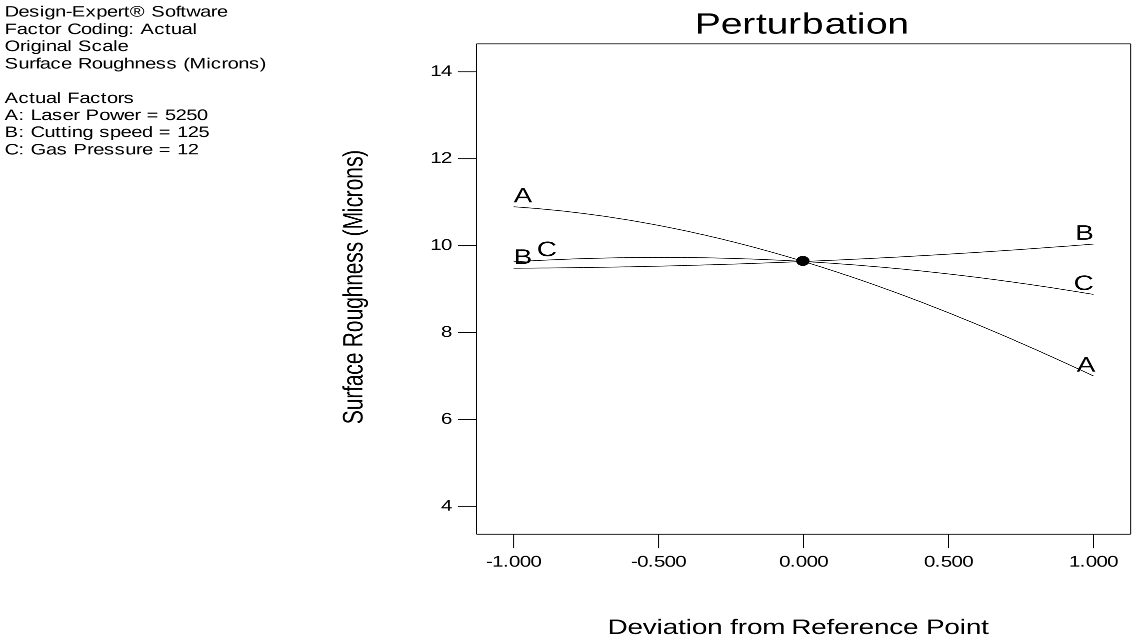

Fig-3: Perturbation plots representing the effect of process parameters on surface roughness

The perturbation plots for surface roughness of SS 304 for 25 mm are shown in fig-3. It shows that laser power increases with decrease in surface roughness. Cutting speed increases with increase in surface roughness and with slight increase in gas pressure surface roughness increases.

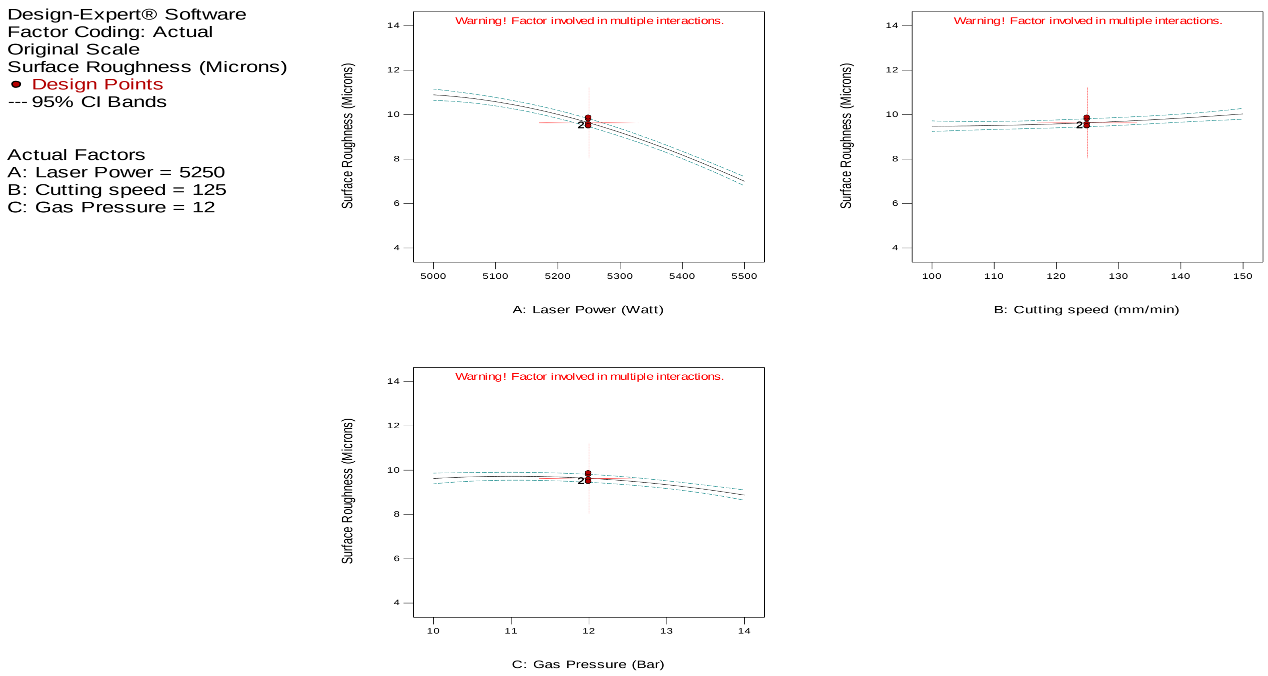

Fig-4: Individual effects of all three parameters on surface roughness

The individual effect of all three parameters, laser power, gas pressure and cutting speed on surface roughness are shown in fig-4. Surface roughness decreases with increase in laser power. With increase in cutting speed there is slight increase in surface roughness value and with increase in gas pressure there is decrease in surface roughness.

3. CONCLUSION

In this paper, the complete analysis of the influence process parameters on the laser cutting process has performedwith Fiber laser cutting machine Bysprint 4020,6KW laser power. After DOE analysis, total 17 run were identified for experiment with sheet metal SS 304 (25 mm thick) as workpiece 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. By using regression analysis method, the optimized value of parameters found as power 5.25 kW, gas pressure 12 bar and cutting speed 125mm/min for the minimum value of surface roughness 9.89µm. 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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