

**Effect of laser cutting parameters on surface roughness of stainless steel 307**

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**Abstract**

Optimal parameters of laser cutting are an important step to improve surface quality of cutting edge in the laser cutting of stainless steel 307. This paper presents a new approach for optimizing the cutting parameters on stainless steel. Based on  $3^3$  full factorial experimental design, cutting experiments were conducted for stainless steel 307 plates using a laser machine (AMADA FONT 3015). The cutting parameters such as, cutting speed, cutting power and gas pressure are optimized for maximizing surface quality. The results indicated that cutting power and cutting speed play an important role in surface quality.

**Keywords**

Laser cutting parameters; Surface roughness; Stainless steel 307

**Introduction**

Laser Beam Machining is a thermal process considering the mechanisms of material removal, in this machine the electrical energy is used to produce high-energy coherent photons [1]. The advantage of laser Machining is with the high flexibility and its ability to cut metal elements with complex geometries at high preciseness, whereas manufacturing a high

cut-edge quality [2]. Producing high-quality cut edges can be done by controlling the laser cutting parameters in a correct manner. There are many parameters for Laser process such as distance of the stand, speed of cutting, diameter of the nozzle, work piece thickness, pressure of the assist gas etc. Many researchers studied the effect of these parameters on widths of the kerf, angle of taper, rate of material removal, heat affected zone (HAZ) and roughness of surface [1, 3-8].

In order to evaluate the laser cutting effect on the surface roughness for a metallic material, stainless steel (SS-307) has been chosen and cutted by laser machine (AMADA FONT 3015) at different parameters. This research is an attempt to find the link between laser cutting parameters and surface roughness, to improve surface quality.

## Experimental

A 2.0 kW AMADA FONT 3015 Laser machine is used for the experiments. Stainless steel grade 307 with a thickness of 4 mm and a length of 8 mm length was used in each experiment; workpieces were cut over a machined length of 10mm. Table 1 shows the chemical composition for the selected material.

Table 1: (SS-307) chemical composition

% from								
C	Mn	Si	P	S	Cr	N	Ni	iron
0.080	2.000	0.750	0.045	0.030	18.000	0.100	8.000	Balance

The conditions of laser cutting are shown in table 2.

Table 2: Conditions of laser cutting

code	Power	Speed	O <sub>2</sub> pressure	code	Power	Speed	O <sub>2</sub> pressure	code	Power	Speed	O <sub>2</sub> pressure
A1	1200	2	4	A10	1000	2	4	A19	1000	5	3
A2	1500	2	3	A11	1000	3	3	A20	1200	2	5
A3	1500	5	5	A12	1500	5	3	A21	1200	3	4
A4	1200	5	3	A13	1000	5	5	A22	1200	2	3
A5	1500	3	3	A14	1200	3	5	A23	1000	5	4
A6	1200	3	3	A15	1500	5	4	A24	1000	3	5
A7	1200	3	4	A16	1000	3	4	A25	1500	2	5
A8	1000	2	4	A17	1200	5	3	A26	1500	3	5
A9	1000	2	3	A18	1200	5	5	A27	1500	2	4

Surface roughness was measured using portable tester (Mitutoyo, Model: 201 stylus profile meter) to find the roughness profile ((Ra, Rq, Rp and Rv). Digital imaging of the laser

cut-edges was done using a Leica microscope and a Canon EOS 1100D digital camera. Statistical method (ANOVA) was used at the end of experiments to find out what factors have a significant effect on surface roughness.

### ANOVA analysis for Surface roughness

A new mathematical model was designed using DESIGN EXPERT software to analyze the results, the full factorial design was selected and analysis of variance (ANOVA) was utilized to evaluate the results. Table 3 shows obtained surface roughness. Table 3 shows the selected factors operated for this study within working levels. Three factors and three levels were used in this experiment. 12 running processes were performed from the equation of full factorial design:

$$\text{Full Factorial Equation} = 2^k \quad (1)$$

where k denotes the number of factors, i.e. 3: Power (W), Speed (mm/min), and O<sub>2</sub> pressure, being examined in this experiment and three levels at the experiment were employed. Table 3 shows the selected factors operated for this study.

Table 3. The selected factors operated for this study

Factors	Levels		
Power (w)	1000	1200	1500
Cutting speed (m/min)	2	3	5
O <sub>2</sub> pressure	3	4	5

## Results and Discussion

### *Microstructures*

Figure 1 shows the cutting surface for each condition. The micrographs of cutting edges revealed that cutting conditions affected on surface of cutting edge. Laser cutting left striations parallel to cutting direction. These striations were visible at high cutting speeds and high power. When the gas pressure was high, the cut edges formed a melted surface and became less stable instead of controlled striation formations. The figure revealed that there is no correlation between the size of striations and the parameters of cutting, and that striation size depends on the thermal history during laser cutting. Marcelo [9] has predicted the distribution of the temperature at the cutting edge. Duley et al. [10] and Yang [11] have founded that there is no correlation between the size of striations and cutting parameters.

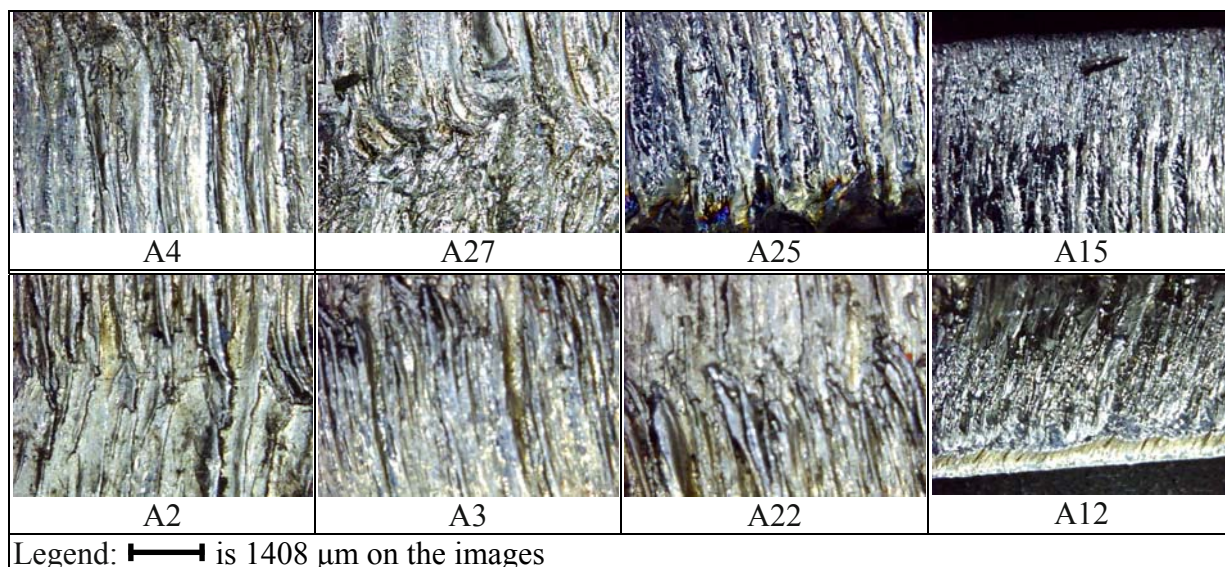


Figure 1. Cutting surface for some samples at different conditions

Using high power leads to deeper striations. The figures reveal also, that the amount of laser power was the most significant factor in striations formation, and fine striations have appeared at high power and speed but at low gas pressure. This may be due to the gas pressure effect on the hydrodynamic behavior of molten metal which affected the molten metal expel from the cutting front and on striations formation [13]. Straight cut edges were found at low cutting speed and at low power.

### *Surface roughness properties*

Figure 2 shows striations take a periodic series when the cutting process was made at low cutting speed and high power.

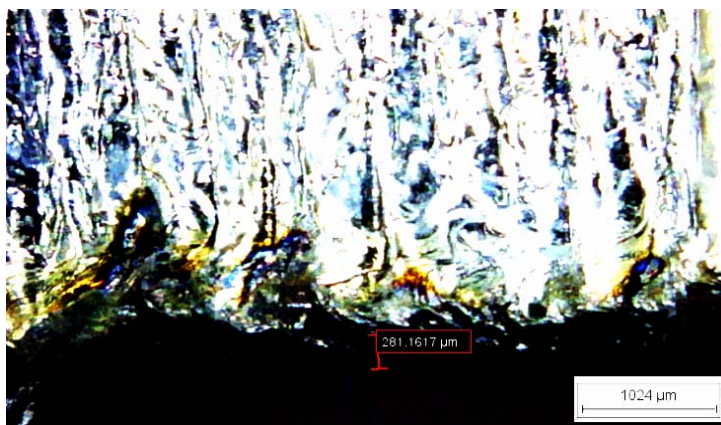


Figure 2. Striations generated using a power of 1500 W and gas pressure of 4 bar with traverse cutting speeds of a 5 m/min and 3 m/min

At high power and cutting speed, the figure 2 reveals inconsistent striations.

Figure 3 shows the roughness properties for cutting in different conditions, the least defined striations were produced at high power and speed and at low gas pressure. Increasing gas pressure leads to non-uniform striations (higher Rv and Rp). The optimum striation in the cutting-edge was found when using low power, speed, and gas pressure also, when using high power and speed, and low gas pressure. Using the right balance between traverse cutting speed and power and using a low gas pressure led to a uniform surface.

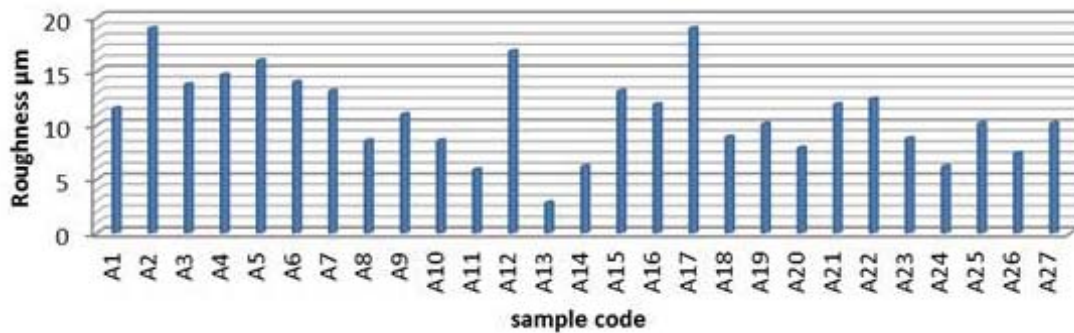


Figure 3. Roughness properties for the cutting surface (Ra) at different conditions

### ANOVA analysis

The analysis of ANOVA is utilized to specify the Laser machining parameters, by using DESIGN EXPERT software version 9. Table 4 and 5 show the design data and design model used in the ANOVA analysis respectively.

Table 4. The design data used in ANOVA analysis

Run	Factor A	Factor B	Factor C	Response	Run	Factor A	Factor B	Factor C	Response
	Power	Speed	O <sub>2</sub> pressure	Roughness		Power	Speed	O <sub>2</sub> pressure	Roughness
1	A level 2	B level 1	C level 2	11.56	15	A level 3	B level 3	C level 2	13.16
2	A level 3	B level 1	C level 1	19	16	A level 1	B level 2	C level 2	11.92
3	A level 3	B level 3	C level 3	13.78	17	A level 2	B level 3	C level 1	19
4	A level 2	B level 3	C level 2	14.67	18	A level 2	B level 3	C level 3	8.91
5	A level 3	B level 2	C level 1	16	19	A level 1	B level 3	C level 1	10.11
6	A level 2	B level 2	C level 1	14	20	A level 2	B level 1	C level 3	7.89
7	A level 3	B level 2	C level 2	13.16	21	A level 2	B level 2	C level 2	11.92
8	A level 1	B level 1	C level 2	8.55	22	A level 2	B level 1	C level 1	12.43
9	A level 1	B level 1	C level 1	11	23	A level 1	B level 3	C level 2	8.76
10	A level 1	B level 1	C level 3	8.55	24	A level 1	B level 2	C level 3	6.16
11	A level 1	B level 2	C level 1	5.87	25	A level 3	B level 1	C level 3	10.15
12	A level 3	B level 3	C level 1	16.86	26	A level 3	B level 2	C level 3	7.4
13	A level 1	B level 3	C level 3	2.79	27	A level 3	B level 1	C level 2	10.15
14	A level 2	B level 2	C level 3	6.16					

Based on ANOVA analysis of surface roughness in Table 5, it can be seen that the model is significant with probability, Prob>F value between 0.0001 to 0.0499 less than 0.05.

It shows that Factors 1 and 2 are significant, while factor 3 is not significant.

Table 5. ANOVA analysis of surface roughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	293.352311	6	48.89205	7.880378	0.0002
A-Power	124.494289	2	62.24714	10.03294	0.0010
B-Speed	13.3406	2	6.6703	1.075113	0.3602
C-O <sub>2</sub> pressure	155.517422	2	77.75871	12.53308	0.0003
Residual	124.085556	20	6.204278		
Total	417.437867	26			

Figure 4 displays the observed values compared with the predicted values calculated from the model.

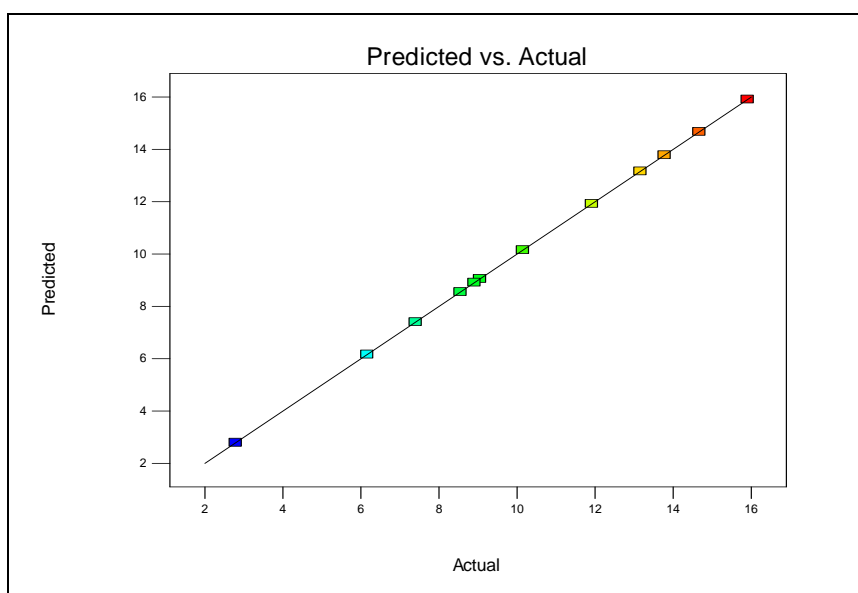


Figure 4. Observed values compared with the predicted values

In figure 4 it can be seen that the regression model fairly well fits with the observed values (error less than 2.7%).

The response ranges from 2.79  $\mu\text{m}$  to 15.91  $\mu\text{m}$  and the ratio of maximum to minimum is 5.70  $\mu\text{m}$ . After eliminating the non-significant terms (B is not significant in Table 5), the final response equation for Surface Roughness is given as:

$$\text{Roughness} = 10.20 - 2.01 \cdot A - 2.31 \cdot C \quad (2)$$

Equations in terms of all coded factors as follows:

$$\begin{aligned} \text{Roughness} = & 10.0375 - 3.2575 \cdot A - 0.9975 \cdot B + 0.7175 \cdot C + 0.0625 \cdot AB \\ & - 0.095 \cdot AC + 0.9375 \cdot BC + 0.25 \cdot C^2 + 1.5 \cdot ABC + 1.8775 \cdot AC^2 - 1.965 \cdot BC^2 \end{aligned} \quad (3)$$

where A: Power; B: Speed and C: O<sub>2</sub> Pressure.

Equation 2 and 3 are multiple regression models based on data collected during the course of the experiment configuration given in Table 3. The obtained equations allow doing estimates. Figure 5 shows the estimated response in 3D surface the Surface Roughness with Speed and O<sub>2</sub> pressure with different levels of the Power.

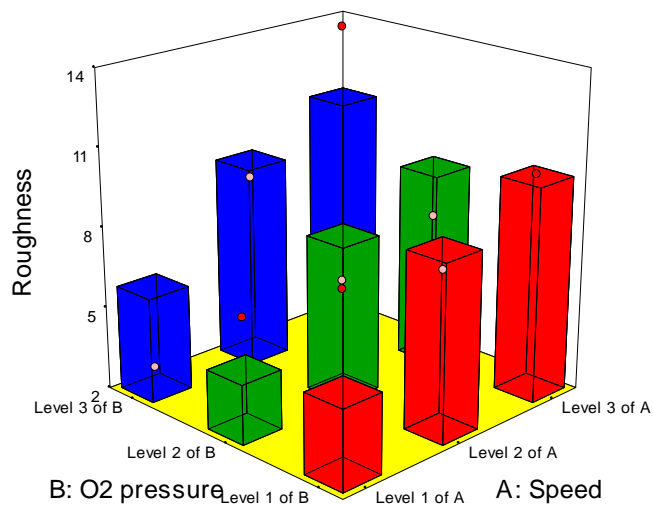
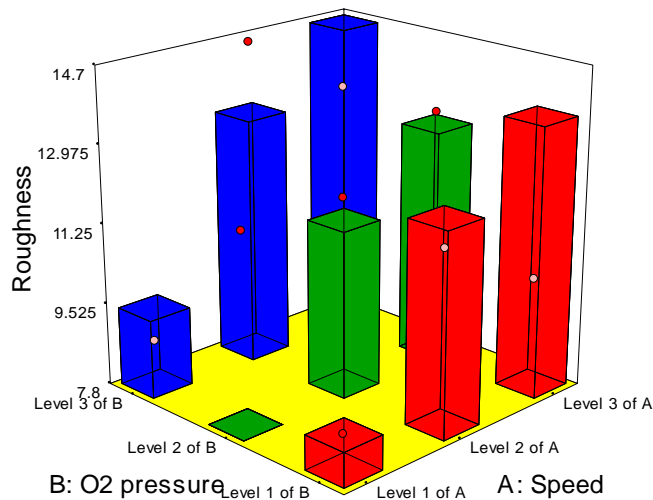
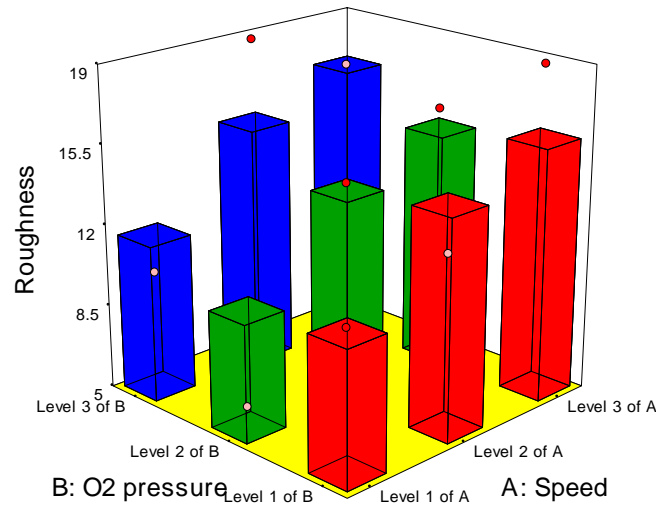


Figure 5. Estimated response of Roughness in 3D surface

The surface roughness tends to increase considerably with the decrease of power and speed [12], [14]. It is clear from the figure that the higher surface roughness can be obtained using 1000 w, 5 bar and 5 mm/min. This is due to lower power and speed exhibits higher distortion on the surface, which leads to higher surface roughness.

In general, it is evident that the surface roughness decreases with an increase in cutting speed (Figure 5). A decrease in laser power, generally increases surface roughness, however the effect of laser power should be considered through interaction with cutting speed and assist gas pressure. Similarly, an increase in gas pressure increases surface roughness. The effects of cutting speed and assist gas pressure were more pronounced than the effect of laser power on surface roughness characteristics.

### **Conclusions**

The present work studies the surface quality after cutting S.S 307 in different conditions (cutting speed, gas pressure and laser power) also it predicts the values of surface roughness with a mathematical model. The conducted experiments give the following conclusions:

- ÷ That higher surface roughness can be obtained using 1000 w and 5 mm\min. This is due to lower power and higher speed exhibits higher distortion on the surface, which leads to higher surface roughness.
- ÷ Gas pressure had less effect of surface roughness. This might be due to small variation in its level.
- ÷ The variation in % errors in the values of roughness was estimated around 2.7 %, so the mathematical model is valid and can be used in machine response's prediction.

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