EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 19, No. 2, April 2022, pp. 63 - 71 ISSN 2090 - 5882
(Received February 19. 2022, Accepted in final form March 21. 2022) jest.journals.ekb.eg

SURFACE ROUGHNESS STUDY OF LASER CUT SURFACE

Mona Younis

Mechanical Engineering Department, Higher Technological Institute, Next to Small Industries Complex, Industrial Area 2, 10th of Ramadan City 11111, Egypt.

ABSTRACT
In the field of surface geometry characterization, the growth of tribology studies has created a lot of new impediments. Progress in measurement techniques and procedures has resulted in a several data on surface morphology, as well as a requirement to comprehend the key factors in surface characterization and apply them to friction and wear mechanisms for better predictive tribosystem design. Choosing the best laser cutting settings for stainless steel 307 is an important step in enhancing the surface quality of the cutting edge. The purpose of this research is to present a unique way for enhancing stainless steel cutting conditions. Based on 33 complete factorial trial designs, laser cutting processes for stainless steel 307 plates were performed. For better surface quality, cutting considerations such as speed of cutting, cutting power, and gas pressure are calibrated. The findings revealed that surface quality is influenced by cutting power and cutting speed.

KEYWORDS
Surface roughness, laser cut surface.

INTRODUCTION
In laser cutting machining, electrical energy is employed to create high-energy coherent photons, [1]. Laser Beam Machining is a thermal technique that considers the principles of material removal. The versatility of laser machining, as well as its ability to cut metal parts with complicated geometries with high precision while producing a high-quality cutting edge, [2], are its main advantages. Controlling the laser cutting settings adequately allows to produce high-quality cut edges. There are several factors for the Laser process, including stand distance, cutting speed, nozzle diameter, workpiece thickness, assist gas pressure, and so on. Many studies investigated the impact of these factors on kerf widths, taper angle, material removal rate, heat affected zone (HAZ), and surface roughness, [1, 3-6]. Also, many researchers have investigated the surface roughness as a predictive tribosystem, [7 - 10].

Stainless steel (SS-307) was chosen and cut by laser machine at varied settings to analyze the laser cutting influence on the surface roughness for a metallic material. This study aims to discover the relationship between laser cutting settings and surface roughness in order to enhance surface quality.

EXPERIMENTAL

The study is carried out using a 2.0 kW AMADA FONT 3015 Laser equipment. Each experiment employed stainless steel grade 307 with a thickness of 4 mm and a length of 8 mm; workpieces were cut across a machining length of 10mm. Table 1 shows the chemical composition for the selected material.

Table 1: (SS-307) chemical composition, %

C	Mn	Si	P	S	Cr	N	Ni	iron
0.08	2	0.75	0.045	0.03	18	0.1	8	Balance

Work study is based on choosing working condition, each one had a code to simplify characterization. Table 2 showed the codes with working conditions.

Table 2: Codding and cutting Conditions of laser cutting

Code	Power	Speed	O2 pressure	Code	Power	Speed	O2 pressure	Code	Power	Speed	O2 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

A Leica microscope and a Canon EOS 1100D digital camera were used to create the cut-edges. To determine which factors have a substantial impact on surface roughness, statistical analysis (ANOVA) was applied.

2.1 ANOVA analysis for Surface roughness

To examine the results, a new mathematical model was created using DESIGN EXPERT software, the complete factorial design was chosen, and analysis of variance (ANOVA) was used to evaluate the results. The surface roughness obtained is shown in figure 3. Table 3 illustrates the parameters that were used in this investigation at various working levels. In this experiment, three components and three levels were employed. From the entire factorial design equation, 12 running procedures were carried out:

Full Factorial Equation = 2k (1)

where k specifies the number of parameters being investigated in this experiment, which are: Power (W), Speed (mm/min), and O2 pressure, and three levels were used in the experiment. Table 3 displays the parameters that were used in this investigation.

Table 3. The operated selected factors

Factors	Levels		
Power (w)	1000	1200	1500
Cutting speed (m/min)	2	3	5
O2 pressure	3	4	5

RESULTS AND DISCUSSION

Microstructures

The cutting surface for each circumstance is shown in Figure 1. Cutting circumstances influence the surface of the cutting edge, according to micrographs of cutting edges. Striations parallel to the cutting direction were left by laser cutting. At high cutting speeds and force, these striations were discernible. Instead of regulated striation patterns, the cut edges developed a melted surface and were less stable when the gas pressure was high. The graphic shows that there is no relationship between striation size and cutting settings, and that striation size is determined by the temperature history during laser cutting. Marcelo [11] estimated the temperature distribution at the cutting edge. There is no association between the size of Striations and cutting parameters, according to Duley et al. [12] and Yang, [13].

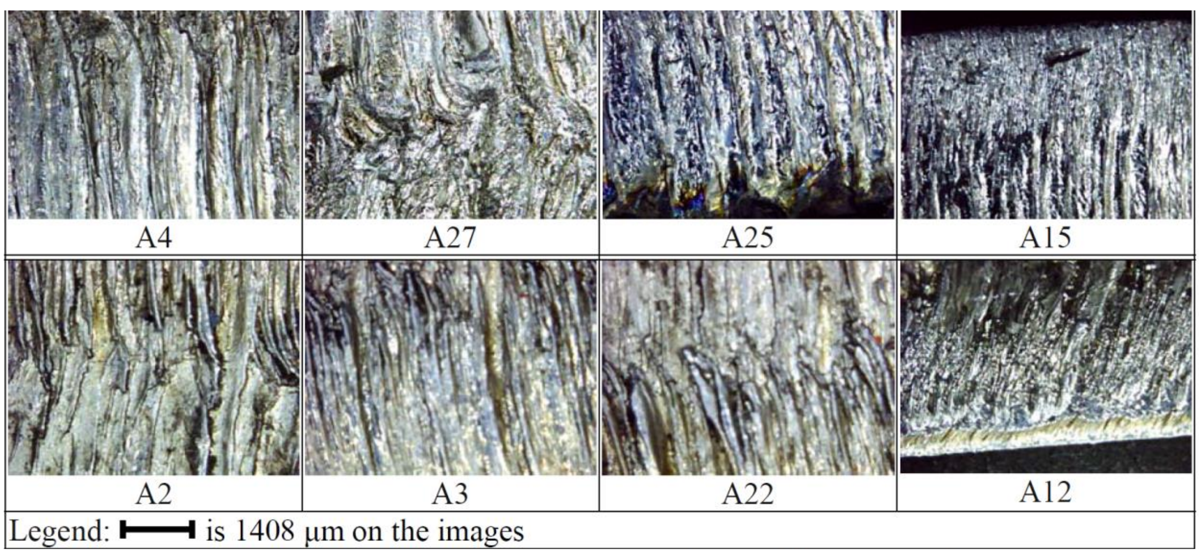

Fig. 1 Selected cutted surface samples.

The most important aspect in the creation of striations was power, and fine striations formed at high power and speed but low gas pressure. This might be attributed to the effect of gas pressure on molten metal's hydrodynamic behavior, which influenced molten metal expulsion from the cutting front and striation development, [14]. At low cutting speed and force, straight cut edges were discovered.

Surface roughness properties

When cutting at low cutting speed and high power, striations follow a periodic sequence, as seen in Fig. 2.

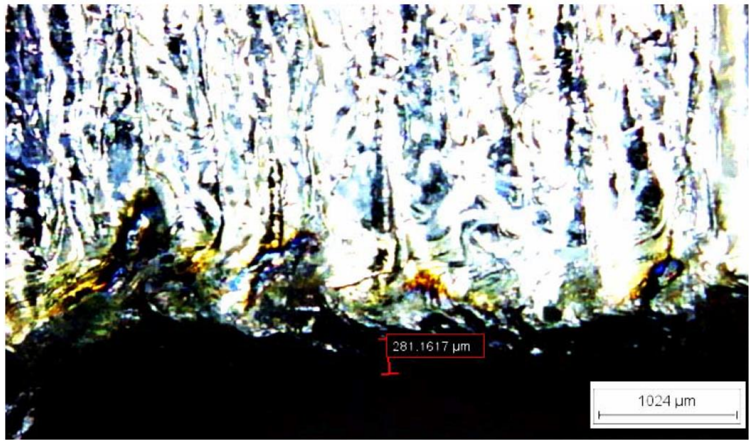

Fig. 2 Striations generated using a power of 1500 W and gas pressure of 4 bar with traverse cutting speeds of a 5 m/min and 3 m/min.

Figure 2 shows uneven striations at high power and cutting speed. The least defined striations were created at high power and speed and low gas pressure, as seen in Figure 3. As the gas pressure rises, the striations become less regular (higher Rv and Rp). When employing low power, speed, and gas pressure, as well as high power and speed and low gas pressure, the cutting-edge striation was determined to be optimal. A homogeneous surface was achieved by striking the correct balance between traverse cutting speed and power and employing a low gas pressure.

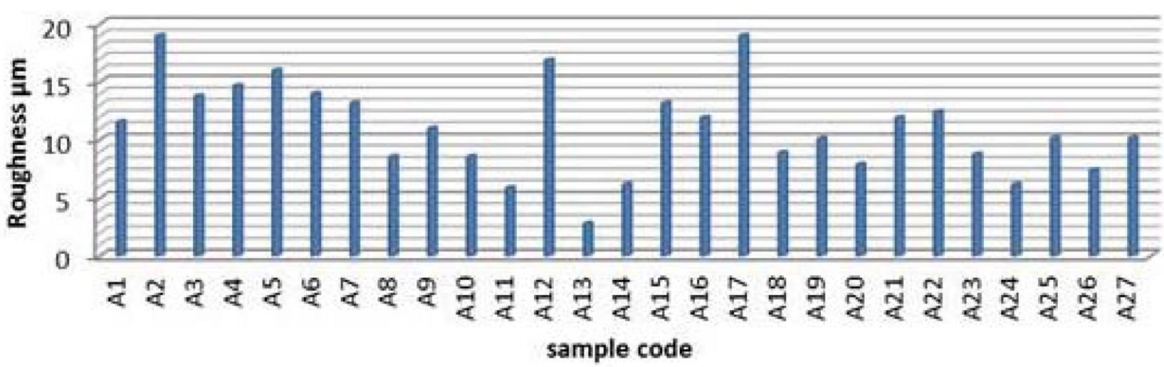

Fig. 3 Roughness Observations At several cutting conditions

ANOVA analysis

Using DESIGN EXPERT software version 9, the ANOVA analysis is used to define the Laser machining settings. The design data and design model utilized in the ANOVA analysis are shown in Tables 4 and 5, respectively. Table 4 shows the ANOVA used data.

Table 4. The design data used in ANOVA analysis

Run	Factor A Power	Factor B Speed	Factor C O_2 pressure	Response Roughness	Run	Factor A Power	Factor B Speed	Factor C O_2 pressure	Response 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					

The model is significant with probability, Prob>F value between 0.0001 and 0.0499 less than 0.05, according to ANOVA analysis of surface roughness in Table 5. It demonstrates that factors 1 and 2 are relevant, but factor 3 is not.

Table 5: analyzed Surface roughness using ANOVA.

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	0.001
B-Speed	13.3406	2	6.6703	1.075113	0.3602
C-O_2 pressure	155.517422	2	77.75871	12.53308	0.0003
Residual	124.085556	20	6.204278		
Total	417.437867	26			

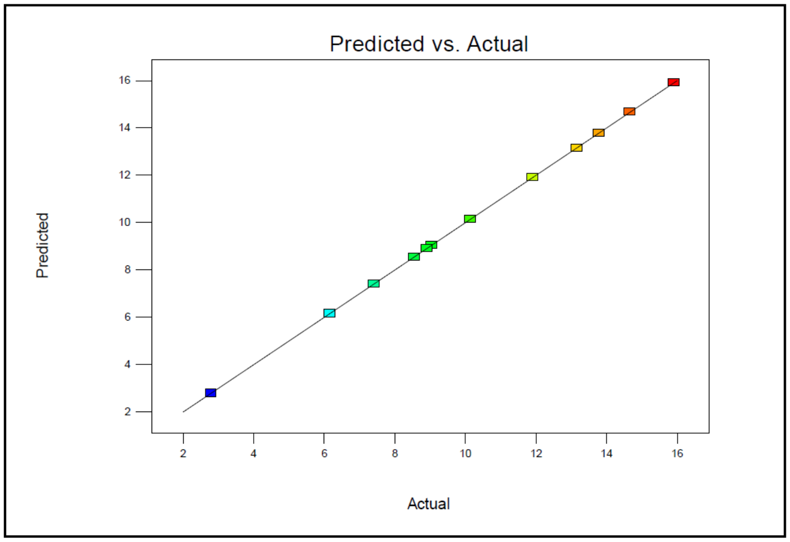

Fig. 4 Predicted values compared with observed values.

Figure 4 shows that the regression model matches the observed data rather well (error less than 2.7%). The response spans 2.79 µm to 15.91 µm, with a maximum-to-minimum ratio of 5.70 µm. After removing the non-significant elements (in Table 5, B is not significant), the final Surface Roughness response equation is as follows:

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

Equations in terms of all coded factors as follows:

$$\text{Roughness} = 10.0375 - 3.2575 \cdot A - 0.9975 \cdot B + 0.7175 \cdot C + 0.0625 \cdot AB - 0.095 \cdot AC + 0.9375 \cdot BC + 0.25 \cdot C2 + 1.5 \cdot ABC + 1.8775 \cdot AC2 - 1.965 \cdot BC2 \quad (3)$$

Where,
A: Power; B: Speed and, C: O2 Pressure.

Equations 2 and 3 are multiple regression models based on data acquired during the experiment setup in Table 3. Estimates can be made using the equations obtained. Figure 5 depicts the estimated response of the Surface Roughness in a 3D surface as a function of speed and oxygen pressure at various levels of power.

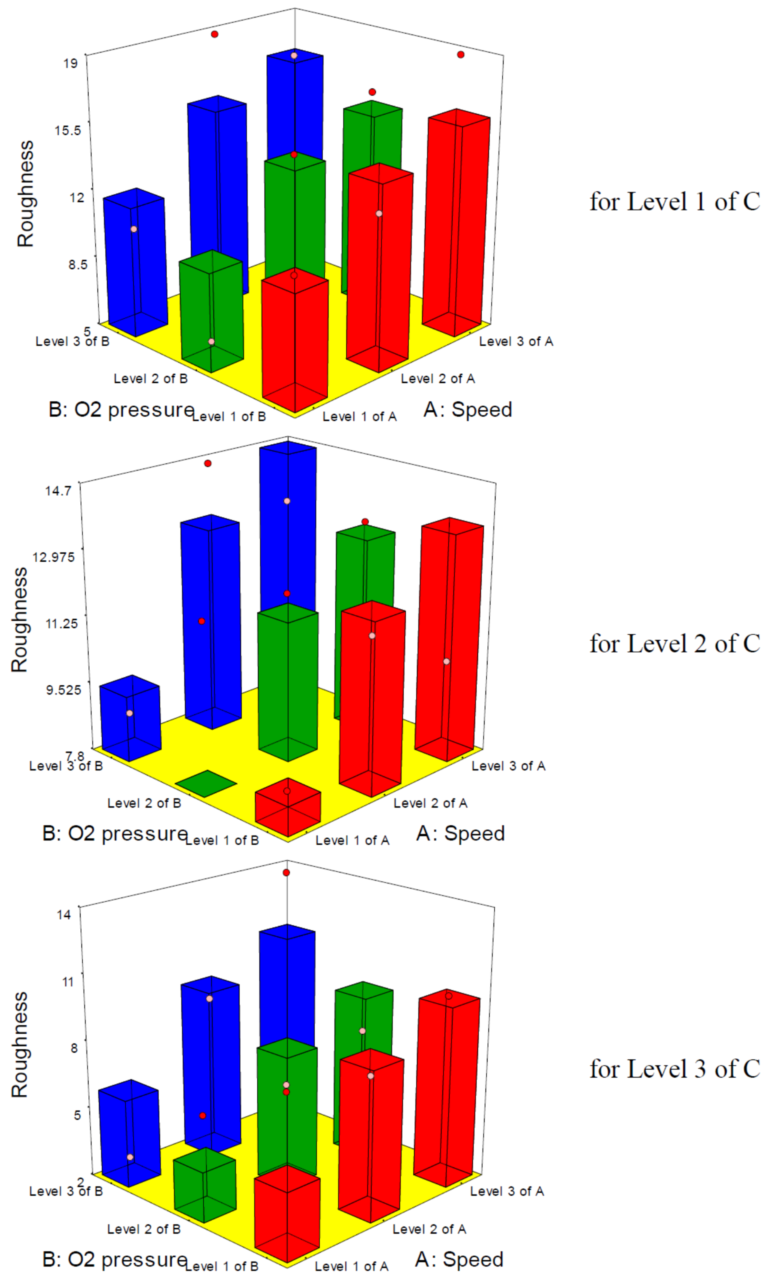

Fig. 5 Estimated roughness in 3D surface.

Surface roughness tends to rise significantly as power and speed are reduced. The greater surface roughness may be achieved with 1000 w, 5 bar, and 5 mm/min, as shown in the image. This is because decreased power and speed cause more surface distortion, resulting in increased surface roughness.

In general, as cutting speed increases, the surface roughness reduces (Fig. 5). Surface roughness is often increased as laser power is reduced; however, the impact of laser power should be evaluated in conjunction with cutting speed and assist gas pressure, [15] Similarly, as gas pressure rises, surface roughness rises. The impacts of cutting speed and assist gas

pressure on surface roughness parameters were more obvious than the influence of laser power.

CONCLUSIONS

The current study investigates the surface quality of S.S. 307 after cutting it under various situations (cutting speed, gas pressure, and laser power), as well as predicting surface roughness values using a mathematical model. It can be concluded that with 1000 w and 5 mm/min, a greater surface roughness may be achieved. This is because lesser power and faster speed cause more surface distortion, resulting in more surface roughness. Surface roughness was less affected by gas pressure. This might be due to minor changes in its level. The range in percent errors in roughness values was calculated to be about 2.7 percent, indicating that the mathematical model is valid and may be utilized to forecast machine response.

REFERENCES

1. Riveiro, A., Abalde, T., Pou, P., Soto, R., del Val, J., Comesaña, R., Badaoui, A., Boutinguiza, M., Pou, J., "Influence of laser texturing on the wettability of PTFE", (2020) Applied Surface Science, 515, art. no. 145984.

2. Schulz W., et all, "Heat conduction losses in laser cutting of metals", Journal of Physics D: Applied Physics, (2009), 26.

3. Antonio Riveiro, et all, "Laser Cutting: A Review on the Influence of Assist Gas", Materials journal, (2019), 12, p. 157.

4. Kovalev, O.B.; Yudin, P.V.; Zaitsev, A.V., "Formation of a vortex flow at the laser cutting of sheet metal with low pressure of assisting gas", J. Phys. D Appl. Phys. (2008), 41, 155112.

5. Rajaram N., et, all, "CO2 laser cut quality of 4130 steel", International Journal of Machine Tools & Manufacture 43 (2003) pp. 351–358.

6. Madic M., et, all, "Surface roughness optimization in CO_2 laser cutting by using Taguchi method", UPB Sci Bull, Ser, (2013), 75, p. 97-106.

7. S. Sekulić "Correlation Between Some Roughness Parameters of the Machined Surface in Finish Turning", Tribology in Industry, Vol. 23, No. 1&2, pp. 6-8, (2001).

8. P.Podsiadlo, G.W.Stachowiak, "Directional Multiscale Analysis and Optimization for Surface Textures", Tribology Letters, Vol. 49, pp. 179-191, (2013).

9. Radovanovic M., "Working Quality by Laser Cutting Machines", Proc. of the 7th Intern. Conf. on Tribology, Budapest, Hungary, pp. 255-258, (2000).

10. I. Etsion, "State of the Art in Laser Surface Texturing", ASME J. Tribology, Vol. 127, pp. 248-253, (2005).

11. Ribeiro dos Santos M., et, all, "Analyses of Effects of Cutting Parameters on Cutting Edge Temperature Using Inverse Heat Conduction Technique", Mathematical Problems in Engineering (2014), p. 11-16.

12. Mohamed Sobih, P. L. CrouseLin, "Laser cutting of variable thickness materials - Understanding the problem", 25th International congress on applications of lasers and electro-optics ICALEO06 At: Scottsdale, AZ, USA, Jan (2006).

13. Nam-Seok Oh, Wan-Sik Woo, Choon-Man Lee, "A study on the machining characteristics and energy efficiency of Ti-6Al-4V in laser-assisted trochoidal milling", International Journal of Precision Engineering and Manufacturing-Green Technology volume 5, pp. 37–45 (2018).

14. Kruusing A., Handbook of Liquids-Assisted Laser Processing, Elsevier Science, 2010.
15. V.Senthilkumar1, N.Periyasamy2, A.Manigandan, "Parametric Investigation of Process Parameters for Laser Cutting Process", International Journal of Innovative Research in Science, Engineering and Technology, pp 2773-2779.2015