J. Adv. Manuf. Eng. 1(1) (2020) 23-28

JOURNAL OF ADVANCES IN
MANUFACTURING ENGINEERING

Analyzing Optimum Process Parameters in Laser Cutting of EN10025-2 Steel Plate

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Abstract

In this study, optimum process parameters were analyzed for minimum surface roughness and radius error in laser cutting of EN10025-2 (S235JR) cold rolled scoured steel plate. The experiments were designed according to Taguchi method. Feed rate, laser power, frequency and focus were selected as process parameters in laser cutting operations. Based on the analyzing results, the optimum process parameter combinations for minimizing the surface roughness and the radius error were obtained.

Keywords: *Laser Cutting, Surface Roughness, Radius Error, Steel Plate, Optimum Parameters*.

1. Introduction

Laser cutting operations have been used in many industrial areas and many research works have been performed in literature. Belic [1] investigated the laser power in CO_2 laser cutting operation and established an equation based on material thickness, cutting speed and cut width. Yilbas [2] examined the effects of cutting parameters on kerf size variations in CO_2 laser cutting of thick sheet metals. According to the researcher's work, gas pressure and laser power intensity was found as significant factors on the percentage of kerf width variation. As increasing the gas pressure and the laser power resulted an increment in thermal erosion around the cut section. Eltawahni [3] studied the optimization of process parameters in high power CO_2 laser cutting of advanced materials. The most significant factor affecting the operating cost was found as cutting speed followed by assist gas pressure and laser power. Furthermore, the influence of all parameters was established at their different levels for all thicknesses and materials. The upper kerf width was inversely proportional to the cutting speed and the focal point position and directly proportional to the other factors. In general, the lower kerf was characterized similarly, however, in this case, the lower kerf width was directly proportional to the focal position. The surface roughness increased with increasing the cutting speed and decreased as increasing the other process parameters. The heat affected zone decreased as the gas pressure and the cutting speed increased and increased as the laser power and the focal position increased. In addition it was found that the nozzle diameter had no significant effect on the surface roughness. Hashemzadeh [4] presented a study about key characteristics of fiber laser cutting and found that the surface roughness for the oxygen laser cut edge was less than that for the nitrogen cut edge. During oxygen laser cutting, the striation patterns were much smoother than those observed in the nitrogen laser cutting. Ürgüplü and Köksal [5] studied the effects of laser cutting process parameters on the quality of metallic components. Based on the study, it was found that each process parameter was needed to be arranged according to the purpose of manufacturing importance as surface roughness, cut edge quality, processing time. Chen et al. [6] investigated the relationship between temperature at cut front edge and kerf quality in fiber laser cutting of Al-Cu alloy. The experimental results showed that there was a close relationship between kerf quality and the temperature at cut front edge. An optimal range of the temperature at cut front edge for accepted kerf quality was found approximately 1800~1950°C. Yilbas et al. [7] presented an investigation on kerf width size analysis and life cycle assessment of cutting process during laser cutting of various materials. According to the results, an increment in laser output power or a reduction in laser cutting speed caused an increment the percentage of kerf width size. Kotadiya et al. [8] performed a parametric analysis of process parameters during laser cutting process on AISI 304 stainless steel. Based on the results of analyzes, laser power was found as the most significant parameter. Joshi et al. [9] studied optimized the process parameters during laser cutting of Ni-based superalloy thin sheet by using response surface methodology. The researchers found that both linear and regression analyses were significant to develop the models. Sharma and Yadava [10] performed an experimental analysis on Nd-YAG laser cutting of sheet materials. Based on the experimental results, it was found that the important input process parameters were laser parameters (laser power, wavelength, mode of operation), sheet material (type, thickness) and process parameters (duration or pulse width, pulse frequency, cutting speed, current, travel direction, assist gas type and pressure, focal plane position, pulse energy,). Sharifi and Akbari [11] presented the effects of process parameters on cutting region temperature and cut edge quality in laser cutting of Al6061-T6 alloy. According to the results, there was a clear dependency between laser power and simultaneous selection of optimum cutting speed to achieve the desired results. It was suggested to select maximum cutting speed while considering the laser power limitation to reach the desired temperature to perform cutting. Oh et al. [12] investigated the cut quality in fiber laser cutting of carbon fiber reinforced polymer (CFRP). During laser irradiation, the pressure inside the kerf increased substantially and formed a fused-cut surface. Thus, the carbon fiber at the kerf edge could undergo a phase change to liquid. Moreover, as the number of passes increased, carbon fibers became fused together, and this phenomena of fusing prevented carbon fibers from delamination and pull-out.

In this experimental study, laser cutting experiments were carried out on EN10025-2 (S235JR) cold rolled scoured steel plate. The experiments were designed based on Taguchi method and the effects of process parameters on the surface roughness and the radius error were analyzed. Thus, it was aimed to obtain optimum cutting parameter combinations for this material, which is widely used in laser cutting applications.

2. Experimental Procedure

In the laser cutting operations, EN10025-2 (S235JR) cold rolled scoured steel plate was selected as workpiece material due to widely used in the construction of buildings and bridges, vehicle structures, and shipbuilding. Its chemical composition and mechanical properties are seen in Table 1 and Table 2, respectively.

Table 1. The chemical composition of EN10025-2 (S235JR) cold rolled scoured steel plate

C (%)	**Si (%)**	**Mn (%)**	**P (%)**	**S (%)**	**Ni (%)**	**Cr (%)**	**Mo (%)**	**V (%)**	**Cu (%)**	**Al (%)**
0.08	0.02	0.21	0.025	0.029	0.08	0.1	0.015	0.003	0.23	0.028

Table 2. The mechanical properties of EN10025-2 (S235JR) cold rolled scoured steel plate

Tensile Strength (N/mm^2)	**Yield Point (N/mm^2)**	**Elongation (%)**
408	311	32

EN10025-2 (S235JR) cold rolled scoured steel plate was cut by laser beam into square shape which had 2 edges with 2.5 mm of edge radius and 2 edges with 90° angle as shown in Figure 1. The thickness of the steel plate was 2 mm thick.

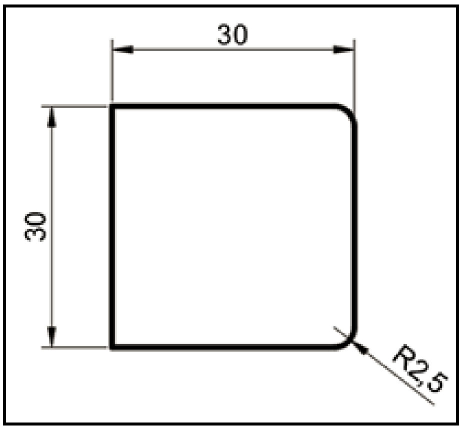

Figure 1. Dimensions and geometry of the samples to be cut

Based on literature, feed rate, laser power, frequency and focus were selected as process parameters in laser cutting of EN10025-2 steel plate as given in Table 3. Additionally, there were some constant parameters which were the nozzle (conical and 2 mm of diameter), Nitrogen (N_2) gas and gas pressure (15 bar).

Table 3. Process parameters in laser cutting of EN10025-2 steel plate

Feed Rate (mm/min)	Laser Power (W)	Frequency (Hz)	Focus
4000	2000	3000	-0.5
5000	3000	4000	-0.8
6000	4000	5000	-1.0

In the experiments, Taguchi method was used and the experimental studies were designed as seen in Table 4 and the laser cutting operations were performed by Durma HD-F 3015 fiber laser machine as seen in Figure 2. In Taguchi's analysis, "Smaller is better" option was selected.

Table 4. The experimental design

Exp. Nu.	Feed Rate (mm/min)	Laser Power (W)	Frequency (Hz)	Focus
1	4000	2000	3000	-1.0
2	4000	3000	4000	-0.8
3	4000	4000	5000	-0.5
4	5000	2000	4000	-0.5
5	5000	3000	5000	-1.0
6	5000	4000	3000	-0.8
7	6000	2000	5000	-0.8
8	6000	3000	3000	-0.5
9	6000	4000	4000	-1.0

Figure 2. Laser cutting process

After laser cutting operations, surface rougness of the samples were measured by utilizing Mituyoto Surftest SJ-210 device. On each samples, 6 (six) surface roughness measurements were performed and arithmetic means were calculated. The edge radii were measured by utilizing Mshot MD30 microscope and then absolute radius errors were determined.

3. Results and Discussions

Based on Taguchi's analysis, the response table of the S/N ratios are given in Table 5 for both surface roughness and radius error. According to the analysis results, the optimum process parameters for surface roughness were determined as feed rate of 5000 mm/min, laser power of 3000 W, frequency of 4000 Hz and focus of -0.8. And the optimum process parameters for radius error were determined as feed rate of 5000 mm/min, laser power of 4000 W, frequency of 4000 Hz and focus of -0.8. These results are also seen in Figure 3 and Figure 4. Based on the results, the optimum results were obtained at the highest laser power due to the fact that thermal efficiency decreased with increasing reducing laser power [2]. Thus the minimum surface roughness and radius error were obtained.

The highest delta values in Table 5 refer to the most effective process parameters on the surface roughness and radius errors. The most effective parameters were determined as feed rate and laser power for surface roughness and radius error, respectively. Additionally, the least effective parameters were found as frequency and focus for surface roughness and radius error, respectively.

Table 5. Response table for S/N ratios

	Level	**Feed rate (mm/min)**	**Laser power (W)**	**Frequency (Hz)**	**Focus**
Surface Roughness	1	-8.960	-9.905	-8.982	-9.122
	2	-7.855	-8.192	-8.637	-8.438
	3	-9.779	-8.497	-8.975	-9.034
	Delta	1.924	1.713	0.345	0.684
Radius Error	1	-4.6596	9.2965	4.8365	3.0442
	2	10.6850	-8.3772	8.8150	7.3360
	3	4.9777	10.0839	-2.6483	0.6230
	Delta	15.3447	18.4611	11.4633	6.7130

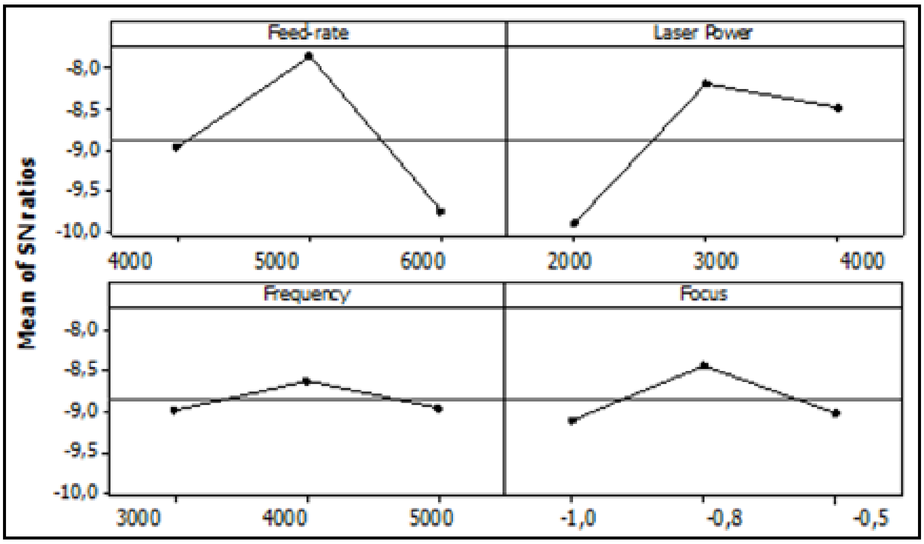

Figure 3. S/N graphs for surface roughness

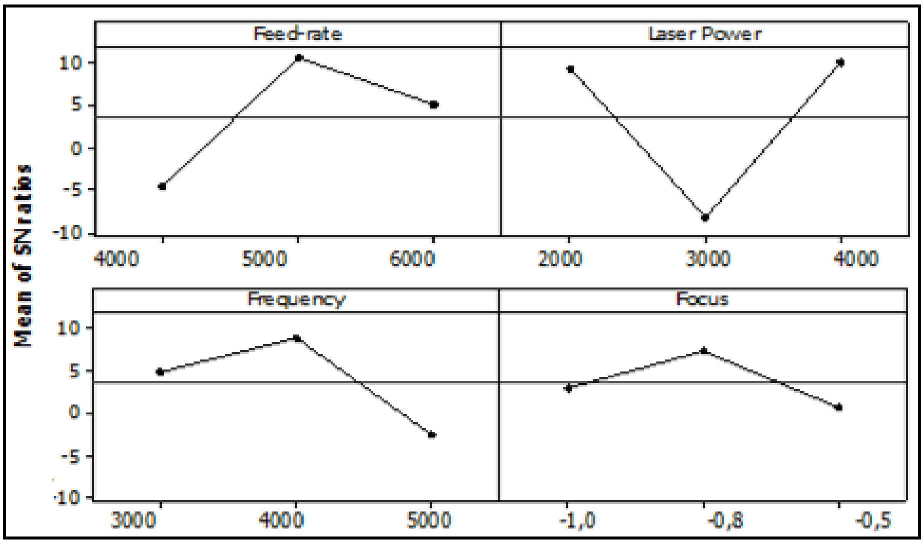

Figure 4. S/N graphs for radius error

The determined optimum process parameters are not included in the design of experiment. Therefore, confirmation experiments were performed for both outputs. The optimum process parameters for the surface roughness caused to 2.031 which corresponded to the minimum value. In addition, the optimum process parameters for the radius error caused to 0.08% with the edge radius of 2.502 mm as seen in Figure 5 which also corresponded to the minimum value.

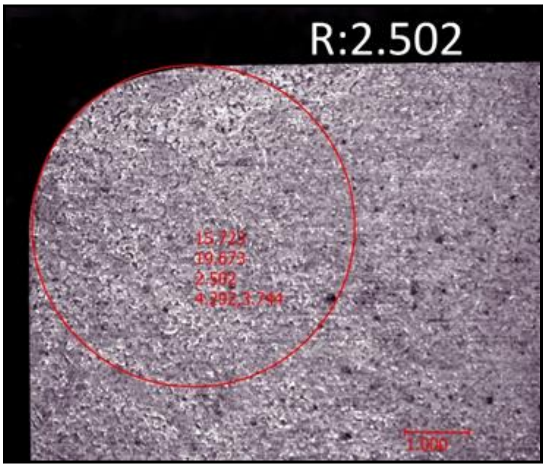

Figure 5. The results of confirmation experiment for edge radius error

4. Conclusion

In this study, the effects of process parameters on the surface roughness and the edge radius errors were investigated and optimum process parameters were determined during laser cutting of EN10025-2 (S235JR) cold rolled scoured steel plate. Feed rate, laser power, frequency and focus were selected as process parameters with 3 (three) different values. In the experimental design, Taguchi method was used. Based on the analysis results, the most and the least effective parameters on the surface roughness were found as feed rate and frequency, respectively whereas those were laser power and focus, respectively, for radius error. The optimum parameter combination was found as feed rate of 5000 mm/min, laser power of 3000 W, frequency of 4000 Hz and focus of -0.8 for the surface roughness. And the optimum parameter combination was determined as feed rate of 5000 mm/min, laser power of 4000 W, frequency of 4000 Hz and focus of -0.8 for the edge radius error. These results were confirmed by performing confirmation experiments.

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