Serbian Tribology
Society

SERBIATRIB '19

16th International Conference on
Tribology

Faculty of Engineering
University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

ANALYSIS AND OPTIMIZATION OF SURFACE ROUGHNESS IN CO_2 LASER CUTTING OF P265GH STEEL

Miloš MADIĆ, Predrag JANKOVIĆ, Miroslav RADOVANOVIĆ, Dušan PETKOVIĆ
Faculty of Mechanical Engineering, Niš, Serbia
*Corresponding author: madic@masfak.ni.ac.rs

Abstract: *This paper is focused on the analysis and optimization of surface roughness obtained in CO_2 laser cutting of 4mm thick P265GH steel plate using oxygen as assist gas. For the purpose of experimental investigation central composite face-centered factorial design with 3 factors was realized. Assist gas pressure, cutting speed and nozzle diameter were considered as input controllable parameters and were systematically varied at 3 levels during the experimentation. Upon realization of experimental trials and measurements of surface roughness, second order non-linear mathematical model for the prediction of surface roughness was developed. Analysis of the developed model revealed the existence of significant parameter interaction effects. It has been observed that the effect of a given parameter on the surface roughness is varying and dependent on the settings of the other parameters. For each nozzle diameter a combination of assist gas pressure and cutting speed which yields minimal surface roughness was determined with the use of contour plots.*

Keywords: *CO_2 laser cutting, surface roughness, central composite design, mathematical model, P265GH steel*

1. INTRODUCTION

Laser cutting is one of the most widely used non-traditional contour cutting technologies in modern industry. The cutting process is achieved by concentrating high power and energy densities by focusing the laser beam on the workpiece material surface into a very small spot. Subsequently, the material being irradiated by the laser beam heats, melts and even evaporates in a fraction of a second. The removal of this molten and evaporated material is achieved by using the coaxial stream of assist gas, which type and pressure depend on the applied laser cutting method as well as the workpiece type and its thickness. Despite the simplicity of the process, multiple parameters affect the result in terms of cost, productivity, geometrical quality and surface quality. For a given material, some of them contribute to the melting, while others contribute to the removal of this molten material [1].

During the past years researchers, practitioners and scientists apply and combine different experimental methods, analytical and empirical approaches as well as mathematical and computational techniques and methods in order to analyze, model and control the cutting process and/or to obtain new insights about the laser cutting process. As the laser cutting process itself is a very complex process, often described as multi input multi output process, different laser cutting performances are being investigated. Related to the geometrical quality of cut, kerf width (top and bottom), kerf taper angle, perpendicularity deviation and dross adherence are widely investigated. Surface roughness, striation frequency, boundary layer separation point, drag line separation and erosion are often used as quality indicators of surface pattern. Size of the heat affected zone, micro-hardness, material removal rate, costs, cutting time are also some of the most important performance characteristics of the cutting process.

Great practical importance of surface roughness and its complex nature motivated the present research aimed at modeling and optimization of surface roughness in CO_2 laser cutting of a pressure vessel steel P265GH. To this aim, central composite face-centered factorial design with 3 parameters, such as assist gas pressure, cutting speed and nozzle diameter, was realized and the experimentally obtained data were used for surface roughness analysis, modeling and optimization.

2. EXPERIMENTAL SETUP AND DETAILS

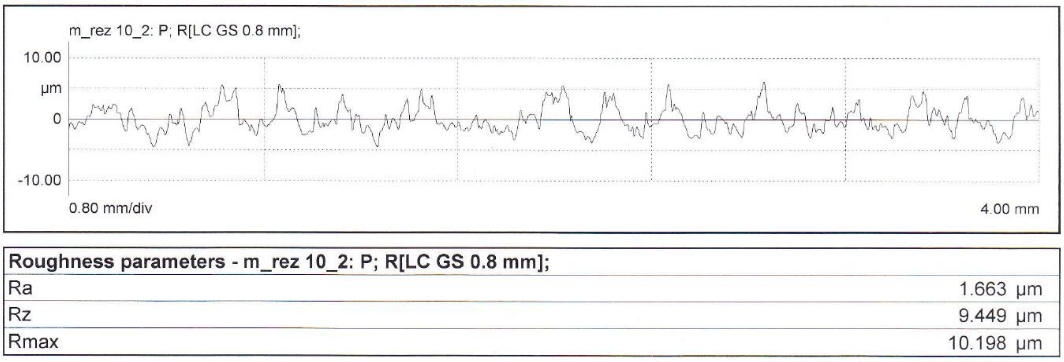
The workpiece material used in the study was a 4 mm thick pressure vessel steel P265GH. This steel is carbon non-alloy steel designed for high temperature applications. Because of a good weldability it is widely used for manufacturing pressure vessels, piping elements, boilers, heat exchangers and similar components. From a plate the specimens with dimensions of 50 × 90 mm were cut using oxygen, Oxycut 3.5. In experimentation the following conditions were constant: CW operating mode, Gaussian distribution beam mode (TEM_{00}), laser power 1.3 kW, lens focal length of 127 mm, focal point position of 0 mm and standoff distance of 1 mm. On the other hand, three laser cutting parameters such as oxygen pressure (p), cutting speed (v) and nozzle diameter (d_n), were varied in accordance with the central composite face-centered factorial design. This type of central composite designs requires only 3 levels of each parameter during experimentation. The parameter levels used in the experiment are given in Table 1.

Table 1. Laser cutting parameter levels

Level	p (bar)	v (m/min)	d_n (mm)
-1	0.7	2.6	1.25
0	1.1	2.9	1.5
+1	1.5	3.2	2

In experiment, 8 trials in factorial points, 6 trials in axial (star) points and 3 trials in central point were conducted. In order to avoid bias, the experimental trials were performed at random. All trials were conducted in manufacturing environment using the Prima industry CO_2 laser cutting machine.

Surface roughness of cut edge was selected as the process response as its values are essential for characterization of the cut surface. It was assessed in terms of the average roughness (R_a). The measurements were made using digital, stylus type measuring instrument MahrSurf-XR1. The averaged value of three measurements taken along the cut at approximately in the middle of the workpiece thickness was recorded for each specimen. The surface roughness profile obtained in trial 10 (p=1.5 bar, v=2.9 m/min, d_n=1.5 mm) is given in Figure 1.



Roughness parameters - m_rez 10_2: P; R[LC GS 0.8 mm];	
Ra	1.663 µm
Rz	9.449 µm
Rmax	10.198 µm

Figure 1. Surface roughness profile (left) and measured surface roughness

3. RESULTS AND DISCUSSION

Based on experimentally measured values of surface roughness in all experimental trials the mathematical model relating the laser cutting parameters and surface roughness (R_a) was developed in the form of the second order polynomial equation:

$$\begin{aligned} R_a &= 1.53 - 0.11p + 0.15v - \\ & 0.41d_n + 0.34p^2 + 0.27v^2 + \\ & 0.002d_n^2 + 0.13pv + 0.29pd_n - 0.43vd_n \end{aligned} \quad . \quad (1)$$

The coefficient of determination (R^2) value of 0.88 and mean average percentage error of about 10.2 % indicated that the model explained 88 % of the variability in surface roughness values and that the model has acceptable degree of accuracy. For the purpose of the analysis of the effects of laser cutting parameters on the surface roughness, 3 interaction graphs were developed (Figure 2).

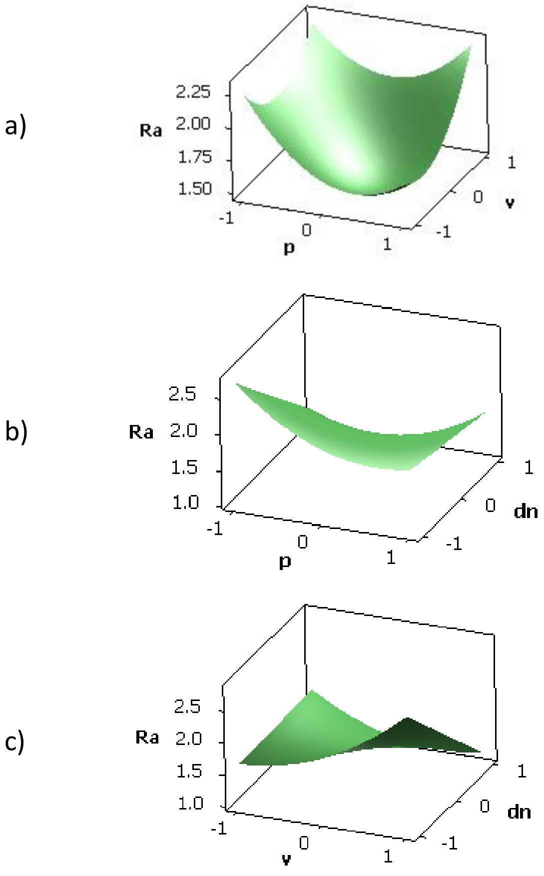


Figure 2. Interaction effects of the laser cutting parameters on the surface roughness

As could be observed from Figure 2a, for a given nozzle diameter, there exists an optimal combination of oxygen pressure and cutting speed which yields minimal surface roughness. For the selected intervals of change, for both parameters, positive and negative correlation between these parameters and surface roughness alter. From Figure 2b it could be observed that large nozzle diameters tend to produce smoother cut surfaces. This may be due to reduced jet velocities which prevent the turbulence of the melt or due to insensitivity of larger nozzles to minor misalignment and changes in oxygen supply pressure [2]. Figure 2c reveals that there exists a significant interaction effect between the cutting speed and nozzle diameter. Lower surface roughness values can be obtained in combination of low cutting speed and smaller nozzle diameter or in combination of high cutting speed and larger nozzle diameter. On the other hand, the roughest cut surface is obtained when using the smallest nozzle diameter and the highest cutting speed, which corresponds to the conditions of the least interaction time between the laser beam and workpiece material and low flow rate in the cutting zone which results in lower induced energy from exothermic reaction which, in addition to laser energy, is not sufficient to evacuate the molten metal cleanly and efficiently. Other possible reasons for this observation may be due to changes in kerf width, coupling efficiency and inclination angle of the cutting front due to cutting speed as well as increased oxygen jet velocities and possible turbulences. A nozzle with a small diameter creates difficulties in alignment and localizes the gas, resulting in a rough edge [3]. The interaction effect of these two parameters on the surface roughness is even more complex considering that the nozzle diameter may influence the cutting speed itself and that for a given workpiece material and thickness there exists an optimal nozzle diameter which gives the maximal cutting speed [4]. The change in the effect of the cutting speed on the surface roughness was also reported in the case of CO_2 laser cutting of P256GH steel with thickness of 6 mm [5].

The afore-given discussion indicates a very complex nature of surface roughness formation in CO_2 laser cutting of P256GH steel necessitating the careful selection of process parameters via process optimization. Given that the nozzle diameter is in essence discrete parameter which can have only a finite set of values, optimization of surface roughness with respect to other parameters can be performed using contour plots. The contour plot showing the change of surface roughness with respect to oxygen pressure and cutting speed for the nozzle diameter of 2 mm is given in Figure 3.

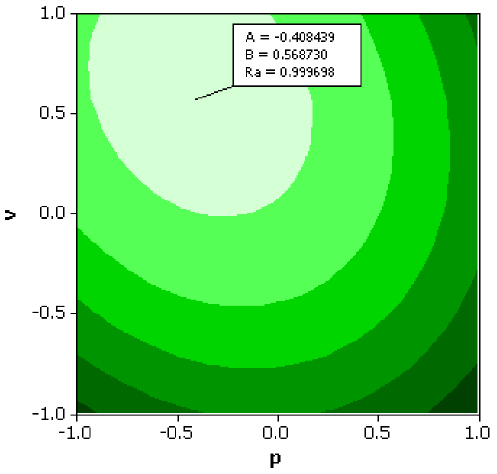


Figure 3. Contour plot of surface roughness

In Figure 3, A and B designate coded values of oxygen pressure and cutting speed. After transforming the coded values into real parameter values it could be observed that oxygen pressure of 0.94 bar and cutting speed of 3.07 m/min yield the minimal surface roughness of 1µm. In the case of using the smallest nozzle diameter (1.25mm), the combination of oxygen pressure of 1.4 bar and cutting speed of 2.61 m/min would yield the minimal surface roughness of 1.42 µm.

4. CONCLUSION

The conclusions drawn from the conducted study can be summarized by the following points:

- For the considered experimental hyper-space there exist significant interactions between laser cutting parameters which ultimately affect surface roughness formation.
- For each nozzle diameter there exists a certain combination of cutting speed and assist gas pressure which yield minimal surface roughness which belong to grade N7.
- The minimal surface roughness of 1µm can be obtained using the nozzle diameter of 2mm. Considering laser cutting costs, however, one should be kept in mind that an increase in the nozzle diameter by a factor of 2, increases the the assist gas flow rate by a factor of 4.

The developed surface roughness model can be used in line with other models as the functional constraint in the formulation of different laser cutting optimization problems.

ACKNOWLEDGEMENT

This work was carried out within the project TR 35034, financially supported by the Ministry of Science and Technological Development of the Republic of Serbia.

REFERENCES

[1] A. Riveiro, F. Quintero, M. Boutinguiza, J.D. Val, R. Comesaña, F. Lusquiños, J. Pou: Laser cutting: a review on the influence of assist gas, Materials, Vol. 12, No. 1, pp. 157, 2019.

[2] J. Powell: *CO_2 Laser Cutting*, Springer-Verlag, London, 1993.

[3] J. Ion: *Laser Processing of Engineering Materials: Principles, Procedure and Industrial Application*, Elsevier, 2005.

[4] W.M. Steen, J.N. Kamalu: Laser cutting, in: M. Bass (Ed.): *Materials Processing: Theory and Practices,* Imperial College of Science and Technology, London, pp.15-111, 1983.

[5] R. Kowalczyk, W. Zebala: Analysis of laser cutting speed influence on the surface quality and shape deviation of steel parts, Proceedings of the SPIE, Vol. 9290, id. 929011 9, 2014.