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INVESTIGATIONS AND OPTIMIZATION OF LASER PROCESS PARAMETERS USING BOX BENHKEN DESIGN APPROACH FOR ADVANCED MATERIALS

Sagarkumar J Aswar[1], Nilesh Diwakar[2], S. D. Kalpande[3]
[1]Ph.D. Research Scholar, RKDFIST, SRK University, Bhopal, India.
[2]Prof., Department of Mechanical Engineering, RKDFIST, SRK University, Bhopal, India.
[3]Prof., Department of Mechanical Engineering, GCOERC, Nashik, India.

Corresponding author: Sagarkumar J. Aswar, sagaraswar123@gmail.com

Abstract:
This paper presents the results of an experimental study conducted to identify the parameters of the laser machining process that yield the best results when working with Hastelloy C276, a nickel-based alloy commonly used in the aerospace, defense, energy, and food processing industries. Laser cutting is a non-contact thermal cutting process that uses a high-power laser beam to melt and vaporize the material. The Box-Behnken design with ANOVA analysis was utilized to determine the impact of laser machining process parameters (laser power, cutting speed, and gas pressure) on Heat-Affected Zone (HAZ) and surface roughness (Ra). Applying specific optimization techniques, a set of approximate optimal parameters was obtained. According to the results, a laser with a power of 2400 watts, gas pressure of 15.66 bar and cutting speed of 2232.58 mm/min yielded machined components with the best possible quality and efficiency, with a surface roughness of 0.78 (μm), HAZ of 0.127 mm. Overall, the Box-Behnken design approach with response surface methodology (RSM) is a powerful tool that can be used to optimize laser machining process parameters for the material Hastelloy C-276 sheet. With this approach, the process parameters can be adjusted to yield the desired performance and quality of the machined parts. Furthermore, the results of this study demonstrate the importance of setting the laser power to the optimal value in order to achieve the best results.

Key words: Heat affected zone (HAZ), Surface roughness (Ra), Laser power, Cutting speed, Gas pressure

1. INTRODUCTION

Hastelloy is a family of nickel-based alloys that contain varying amounts of molybdenum, chromium, and other elements to provide high strength, corrosion resistance, and heat [1]. These properties make Hastelloy ideal for use in harsh environments such as chemical processing, oil and gas production, and aerospace [2]. It has also been a highly attractive material for naval/marine applications [3]. Laser cutting is a precise and efficient cutting method that has gained popularity in recent years due to its ability to cut a wide range of materials with high accuracy and speed [4]. Laser cutting of Hastelloy has unique challenges due to its high melting point, low thermal conductivity, and tendency to form a hard and brittle heat-affected zone (HAZ) during cutting [5]. In this research paper, we will explore the recent developments in laser cutting of Hastelloy and the potential applications of this process in various industries. Compared to traditional cutting methods such as plasma cutting or water jet cutting, laser cutting has several advantages when it comes to cutting Hastelloy [6,7]. As a first advantage, laser cutting does not involve any motorized power or touch with the material being removed [8-10]. Second, laser cutting produces a narrow kerf width and a small HAZ, resulting in minimal material waste and distortion. Third, laser cutting can achieve high cutting speeds and accuracy, making it suitable for mass production and complex geometries [11]. However, laser cutting of Hastelloy has limitations. The high energy input of the laser beam can cause melting, vaporization, and oxidation of the material, leading to surface roughness, cracking, and porosity [12-14]. In addition, the thermal stress induced by the laser beam can cause distortion and residual stress in the material. The quality of laser cutting for Hastelloy depends on various process parameters such as laser power, cutting speed, focal position, assist gas, and nozzle diameter [15]. The laser power determines the amount of energy delivered to the material, affecting the cutting depth, kerf width, and edge roughness [16]. The cutting speed affects the heat input and cooling rate of the material, influencing the microstructure and HAZ width. The focal position determines the focus diameter and shape of the laser beam, affecting the spot size and energy density at the cutting surface. The assist gas, usually nitrogen or oxygen, helps to remove the molten material and protect the cutting zone from oxidation [17-19]. The nozzle diameter affects the gas flow rate and pressure, affecting the gas flow pattern and the shape of the molten pool. To improve Hastelloy C-276's wear resistance [20] used laser surface treatment in an argon atmosphere, where they found the adjusting the laser's specifications to produce a hard, durable layer without annealing in advance is a method to achieve it. Ra and HAZ were measured after being machined from Inconel 718, a nickel-based superior alloys, to determine the impacts of various laser cutting parameters. employing an X-ray and a scanning electron microscope. CO2 laser cutting process factors which enhance Ra, HAZ, kerf width, and material removal rate (MRR) when machining stainless steel were investigated using a preference selection index [21]. Used experimental data and the RSM method to do a statistical analysis While machining sheets of polycarbonate with a laser, the properties "Ra and geometry" are influenced by the process parameters of the laser, which include the laser power, the rate of cutting, and the focal location. In order to get a high frequency cut while employing a Nd:YAG laser with pressurized gas, a multi-objective optimization of the kerf deviation, kerf width, and kerf taper [24]. Parametric studies conducted on laser machining processing parameters such as laser power, cutting speed, and gas pressure discovered that laser power seems to have a significant impact on Ra and top kerf when working with stainless steel (ASTM 304) [25]. Particle swarm optimization, a swarm-based optimization method, was used to optimize the objective function, i.e., the geometrical quality, of a test done on Inconel-718 to use a pulsed Nd: YAG laser beam. [26] is being carried out research in order to examine the quality of laser cutting in relation to the processing parameters of CO2 laser cutting for the aluminum alloy AA5083. These processing parameters include laser power, scanning speed, pulse frequency, and the gas pressure. Joshi et al., [27] carried out a study to use a pulsed Nd-YAG laser and a Box-Behnken design to investigate kerf geometry and metallurgical variation in resource aluminum alloy (Al 6061-T6) with selected settings of lamp current, pulse width, pulse frequency, and cutting speed. Their goal was to determine how these variables affected the kerf geometry and the metallurgical variation. Sharifi et al., [28] conducted experimental research on the CO2 laser cutting of the material Al 6061 T6 alloy in order to investigate the impacts of laser process parameters such as speed, laser power, standoff distance, and sheet thickness on temperature and cutting-edge quality. It was discovered that the power of the laser has a significant impact on the output qualities that were examined. Anghel et al., [29] determine the impact of factors such as laser power, cutting speed, focal location, and gas pressure on efficiency feature of Surface roughness, operational research is conducted utilizing CO2 laser during the profile cutting of gears manufactured of alloy stainless steel 304. Elsheikh et al., [30] had carried out investigative research utilizing RSM in order to determine the impact of cutting variables such as cutting speed, gas pressure, laser beam power, and sheet thickness on cutting quality for said materials poly methyl methacrylate.

Producing complicated profiles using more conventional methods is a challenging task that takes a significant amount of time. In order to achieve the level of accuracy, it is necessary to adjust the laser process parameters to their optimal values. In this article an effort is made by using Box-Benhken design to determine the impact of varying laser process parameters on the size of the heat affected zone (HAZ) and the surface roughness (Ra). In this research paper, the effects of process parameters on the cut quality, heat-affected zone are observed.

2. METHODS AND MATERIALS

In this research, the material chosen was Hastelloy C-276 sheet or plate of the desired thickness and dimensions. Clean the surface of the material to remove any dirt, oil, or debris. Place the material on a flat and stable work surface.

Hastelloy C-276 is made up of 15.5% chromium, 0.6% magnesium, 0.088% carbon, 0.034% silicon, 0.001% Sulphur, and 0.004% phosphorus. In addition, it has 0.004% phosphorus and 0.001% Sulphur. The level of carbon, which has a range of values, is managed so that it is appropriate for almost all the service applications. The results of the Spectro analysis are presented in Table 1, which details the chemical composition of Hastelloy C-276; Table 2 meanwhile, details the mechanical properties of the materials that were utilized in the research [31].

Table 1. Chemical composition of Hastelloy C-276

Element	C	Mn	Si	S	P	Cr	Ni	Mo	Co	W	Fe	V
W%	0.005	0.41	0.02	0.002	0.005	15.83	Bal	16.36	0.05	3.45	6.06	0.17

Table 2. Carbon steel's mechanical characteristics

Material	Tensile strength (MPa)	Yield strength (MPa)	Elongation	Density
Hastelloy C-276	790	355	40%	8.89/cm3

Fig. 1 represents the laser cutting process of Hastelloy C-276 samples. The location of the focal plane in relation with the upper surface Hastelloy C-276 sheet having thickness of 3.7mm, is illustrated in the Fig. 2.

Fig. 1. The laser cutting process of Hastelloy C-276 sheet

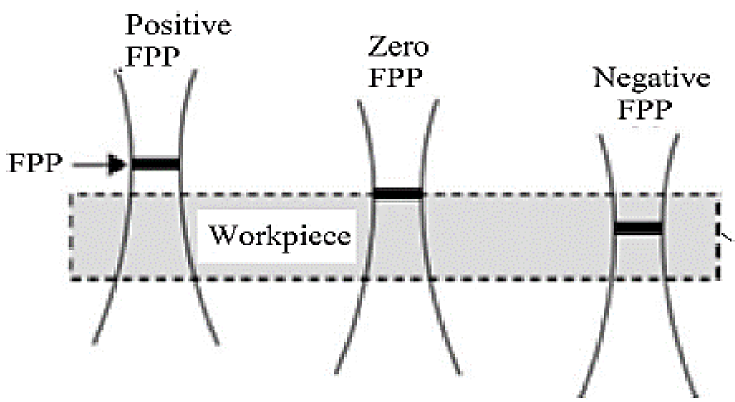

Fig. 2. The location of the focal plane in relation with the upper surface Hastelloy C-276 sheet

Laser system setup: For experimentation on the system a set up the laser cutting machine in a well-ventilated area with appropriate safety measures in place, including safety glasses, gloves, and a face mask is utilized. Before the experimentation it was ensured that the laser beam is properly aligned and focused. By using nitrogen as the assist gas, the cutting experiments are performed in a continuous 4 kW CO2 laser cutting machine. Large number of trials were performed on the set up to determine the cutting parameters based on the thickness and composition of the Hastelloy material. These parameters include the laser power, cutting speed, and focal length of the lens. The parameters will depend on the specific laser cutting system being used and the desired cutting quality. Table 3 shows the input process parameter with their limiting range

Table 3. Input process parameter with limiting range

Input process parameters	Unit	Notation	Min Limit	Max Limit
Laser Power	Watt	LP	2400	3800
Cutting Speed	mm/min	CS	1100	2400
Gas Pressure	Bar	GP	11	17

3. DESIGN OF EXPERIMENTS

Box–Behnken designs, created in 1960 by George E. P. Box and Donald Behnken, are experimental designs for response surface methodology [32]. Each component, or independent variable, has one of three equally spaced values, commonly −1, 0, +1. (The following aim requires three levels.) The design should suit a quadratic model with squared terms, two-factor products, linear terms, and an intercept. The quadratic model's coefficient-to-experimental point ratio should be fair (in fact, their designs kept in the range of 1.5 to 2.6). The estimation variance should rely mostly on the distance from the center (this is achieved exactly for the designs with 4 and 7 components) and not change considerably inside the smallest (hyper) cube containing the experimental points. Rotatability Box-Behnken design outperforms three-level full factorial design, central composite design (CCD), and Doehlert design despite its weak corner coverage of nonlinear design space. Same kind of methodology was adopted by various researcher in the past for different processes and obtained the good results [33-39]. A specific number of factors are placed through all factorial design combinations in each block, while the remaining factors are retained at the center values. In the Box–Behnken design for three factors, three blocks vary two factors through the four potential high and low combinations. Include center points (in which all factors are at their central values). As per the stated design of experimental strategy the cutting parameters have been employed for the cutting and the experiments are performed on the Hastelloy material. During all the trials, the laser beam impact angle was kept at 900. A uniform distance was kept between the square profiles cut (20 mm × 20 mm × 3.7 mm), during each consecutive trial and in a single pass and a key-hole cut was also made in each specimen, for the purpose of measuring the kerf width.

In order to reduce the allowable range of process parameters and to sort out the acceptable upper and lower level of parameters. Under this experiment, complete cutting, the minimum value (surface roughness, Heat affected zone) were the governing aspects considered for determining the working ranges. The list of all parametric settings of rotatable central composite designs, that are running along with their obtained corresponding responses are listed in the Table 4.

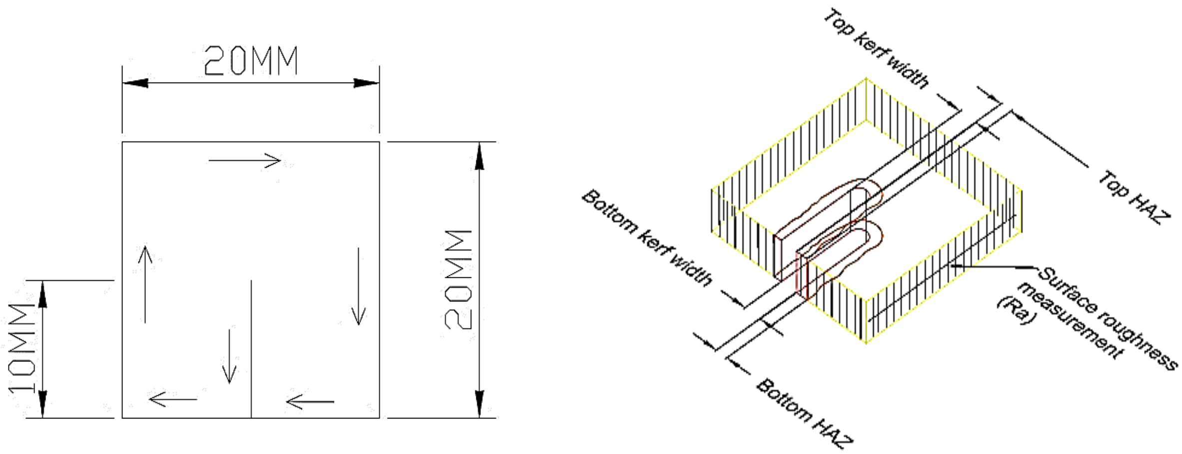

Fig. 3. Geometrical features of the cross-section of the kerf

Table 4. Experimental design matrix with the corresponding results for Hastelloy C276

Sr. No.	Laser power (watt)	Cutting speed (mm/min)	Gas pressure (bar)	HAZ (mm)	Surface roughness (μm)
1	3100	1762.5	14	0.190	0.95
2	3800	1762.5	17	0.196	1.17
3	3100	2400.0	11	0.199	1.02
4	3100	1762.5	14	0.191	0.96
5	3100	2400.0	17	0.188	0.99
6	3800	1762.5	11	0.191	1.16
7	3800	1125.0	14	0.209	1.15
8	2400	1125.0	14	0.153	0.89
9	2400	2400.0	14	0.136	0.77
10	2400	1762.5	17	0.123	0.86
11	3100	1125.0	11	0.214	1.08
12	3800	2400.0	14	0.196	1.10
13	3100	1762.5	14	0.190	0.96
14	2400	1762.5	11	0.148	0.88
15	3100	1125.0	17	0.201	1.09

After the cutting operation is complete, remove the Hastelloy material from the laser cutting machine. Inspect the cut for any rough edges, burrs, or other imperfections. Use appropriate post-processing methods to remove any imperfections and achieve the desired surface finish. Overall, laser cutting of Hastelloy requires careful attention to detail and adherence to safety protocols. By following the experimental strategy outlined above, one can achieve a clean and precise cut with minimal heat-affected zone.

3.1 Analysis of HAZ

Table 5. demonstrates the Box-Benhken design along with the “ANOVA” results for the obtained quadratic model of "HAZ." The "F-value" that was calculated for the model to be 1878.98, which indicates that the model is credible and reliable. This is because the F-value is a measure of the overall variation in the model which is explained by the term and the regressors. In addition to this, the model terms, and square terms for "laser power" (LP), "gas

pressure" (GP), and "cutting speed" (CS), were discovered. Table 5 shows the "F-value" foreach term, such as linear, squared, and interaction. A term with higher "F-value" would have a bigger effect on the model. The "laser power" has a "F-value" of 10623.10, which is higher than other parameters, indicating it has the most impact on "HAZ," followed by the "cutting speed" parameter and the "gas pressure" parameter. The value of "Pred R-Squared," which was found to be 99.61%, is in good agreement with the value of "Adj R-Squared," which was found to be 99.92%. These values are both measures of the model's goodness of fit, with R-squared representing the proportion of the variance in the dependent variable that can be explained by the independent variables. In addition, the P value for each of the parameters was found to be less than 0.05, indicating that the parameters are significantly contributing to the results obtained.

The Box-Benhken design is a powerful tool for finding the most impactful parameters for a given model. By using this design, it is possible to determine which parameters have the most significant effect on the model's outcome and to make decisions based on the results obtained. The F-value, R-squared and P-value are all indicators of the model's reliability and accuracy, which is essential in determining the best parameters for the model. In this case, the higher F-value and R-squared values indicate that the model is credible, and the lower P-value suggests that the parameters are contributing significantly to the results obtained. This provides insight into the parameters that have the most impact on "HAZ," and can be used to make data-driven decisions and optimize the model accordingly.

Table 5. ANOVA analysis of HAZ

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.0107	0.0012	1878.98	0.00
Linear	3	0.0074	0.0025	3889.74	0.00
LP	1	0.0067	0.0067	10623.10	0.00
CS	1	0.0004	0.0004	663.95	0.00
GP	1	0.0002	0.0002	382.11	0.00
Square	3	0.0031	0.0010	1626.14	0.00
LP*LP	1	0.0026	0.0026	4068.38	0.00
CS*CS	1	0.0003	0.0003	535.43	0.00
GP*GP	1	0.0000	0.0000	1.98	0.22
2-Way	3	0.0002	0.0001	121.05	0.00
LP*CS	1	0.0000	0.0000	6.32	0.05
LP*GP	1	0.0002	0.0002	355.26	0.00
CS*GP	1	0.0000	0.0000	1.58	0.26
Error	5	0.0000	0.0000		
Lack-of-Fit	3	0.0000	0.0000	2.50	0.30
Pure Error	2	0.0000	0.0000		
Total	14	0.0107			
S: 0.0007958	R2: 99.97 %		R2(adj): 99.92%	R2(pred): 99.61 %	

Regression equation for HAZ

HAZ = 0.1508+ 0.000322 LP-0.000105CS-0.01518 GP- 0.0 LP*LP+ 0.00 CS*CS+ 0.000065GP*GP + 0.00 LP*CS + 0.000004 LP*GP+ 0.00 CS*GP -------------------- (1)

3.2 Analysis of Surface Roughness

The developed statistical model is tested by ANOVA, the results for the surface roughness are presented in Table 6. From this table the F value of 1251.81 suggests that the model is statistically important. also, since "Prob > F" is less than 0.05, the term containing factor effects such as "Laser Power" (LP), "Gas Pressure" (GP), and "Cutting speed" (mm/min) is important. Moreover, the obtained F value with possible probability i. e. P for all terms is presented in Table 4. Form this table it has been determined that the "F-value" of "laser power" is 9493.64, which is significantly greater than the values of the remaining variables. The "laser power" parameter is known to have the greatest influence on the "Surface roughness" metric, trailed by the "cutting speed" and "gas pressure" indices. Once again, the model's "Pred R-Squared" score of 99.61% demonstrates excellent concordance with the "Adj R-Squared" score of 99.88%.

Table 6. ANOVA analysis of surface roughness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.206548	0.022950	1251.81	0.000
Linear	3	0.187775	0.062592	3414.09	0.000
LP	1	0.174050	0.174050	9493.64	0.000
CS	1	0.013612	0.013612	742.50	0.000
GP	1	0.000112	0.000112	6.14	0.056
Square	3	0.016923	0.005641	307.70	0.000
LP*LP	1	0.000041	0.000041	2.24	0.195
CS*CP	1	0.002156	0.002156	117.62	0.000
GP*GP	1	0.015203	0.015203	829.23	0.000
2-Way	3	0.001850	0.000617	33.64	0.001
LP*CS	1	0.001225	0.001225	66.82	0.000
LP*GP	1	0.000225	0.000225	12.27	0.017
CS*GP	1	0.000400	0.000400	21.82	0.005
Error	5	0.000092	0.000018		
Lack-of-	3	0.000025	0.000008	0.25	0.858
Pure	2	0.000067	0.000033		
Total	14	0.206640			
S: 0.0042817		R2: 99.96%	R2(adj): 99.88%		R2(pred): 99.73%

Regression equation for surface roughness

Ra = 2.192+ 0.000134 LP- 0.000323 CS - 0.20274GP - 0.0 LP*LP+ 0.0 CS*CS+ 0.007130 GP*GP+ 0.00 LP*CS + 0.000004 LP*GP - 0.000005 CS *GP--------------(2)

4 RESULTS AND DISCUSSION

The influence of laser machining process parameters like “laser power”, “cutting speed”, “gas pressure”, on “HAZ” and “surface roughness” is evaluated in detailed. The material is removed away because of the intense focused laser at the cutting zone. The results are discussed with the corresponding output characteristics as follows:

4.1 Heat affected zone (HAZ)

The effect that processes parameters, those used in laser machining, such as “laser power”, “cutting speed”, “gas pressure”, on “HAZ” is shown as the main effects plots for “HAZ” in Fig. 4. Throughout the laser cutting of Hastelloy C-276, it is impossible to prevent seeing "HAZ." As the amount of "laser power" goes up, the performance feature "HAZ" goes up gradually. This occurs since the value of "laser power" grows, its intensity on the workpiece material for machining also increases, which results in a degradation of the side upper face of the cutting zone as illustrated in Fig. 4. To reduce how much "laser power" affects "HAZ," a minimum number is preferable. It is observed from Fig. 5 that as the value of “cutting speed” increases, the performance characteristics “HAZ” decreases. As the value of “cutting speed” increases, it reduces the time for machining and interaction of “laser power” with the workpiece material results in desirable HAZ.

It is observed from the Fig. 6-8 as the “gas pressure” increases; there is a gradual decrease in the performance characteristics “HAZ”. Whenever the value of “gas pressure” increases, the focused of the beam is more confine towards the cut results in reduction of “HAZ”. Further, “gas pressure” gives to the cooling of the workpiece and therefore, greater values of gas pressure contribute towards reduction in the amount of the surrounding “HAZ”. It is concluded that the minimum “HAZ” would occurs at lower values of “laser power” and higher value of “cutting speed”.

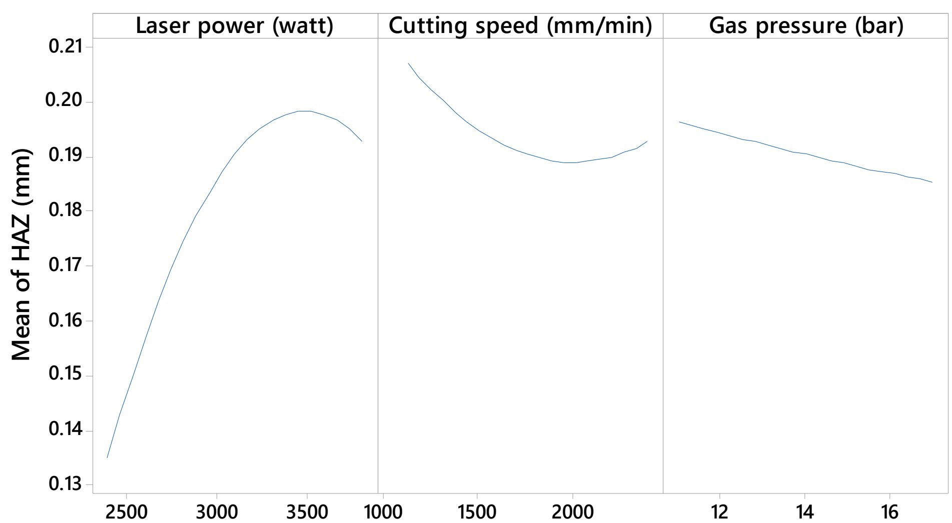

Fig. 4. Main effects plots of HAZ

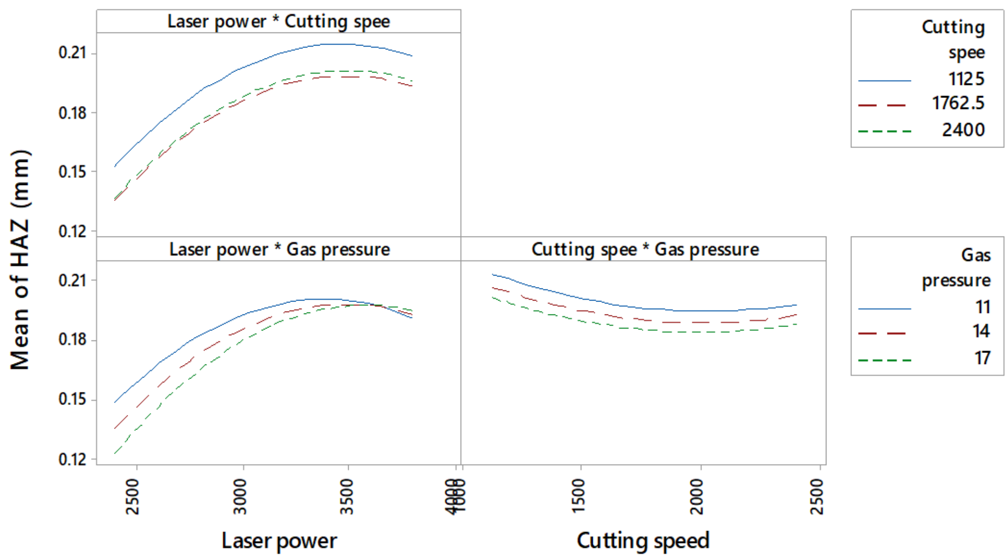

Fig. 5. Interaction plots of HAZ

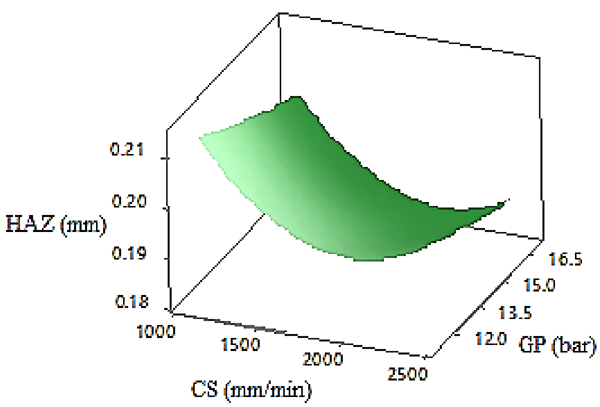

Fig. 6. Surface plot of HAZ vs GP, CS hold values LP

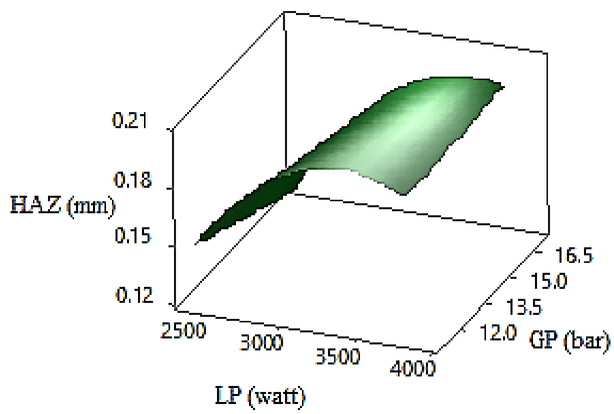

Fig. 7. Surface plot of HAZ vs GP, LP hold values CS

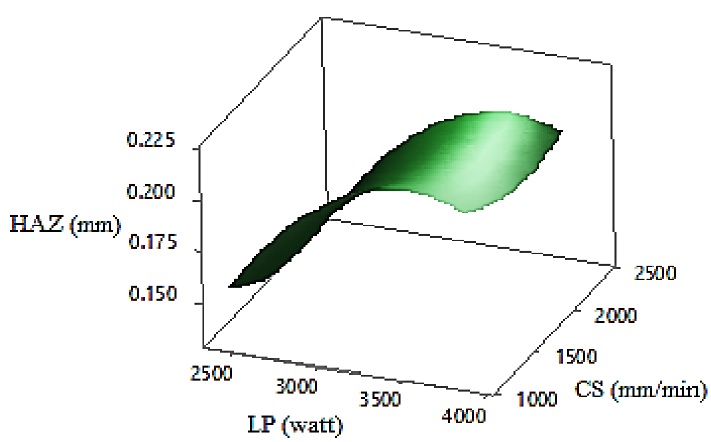

Fig. 8. Surface plot of HAZ vs CS, LP hold values GP

4.2 Surface Roughness (Ra)

The main effect of selected laser machining parameters like "laser power", "cutting speed", "gas pressure" on "Ra" is shown in Fig. 9. As the value of "laser power" increases the performance characteristic "Ra" is degrading rapidly. This occurs because as the value of "laser power" increases, its strength on the workpiece material for machining increases which degrades the side face of the specimen. To reduce the effect "laser power" on "Ra" minimum value is desirable. It is observed from Fig. 10 as the value of "gas pressure" increases; the performance characteristics "Ra" improved gradually. This is because as the value of gas pressure increases it creates thrust at side face along with "laser power" which produces intense energy to cut the specimen smoothly.

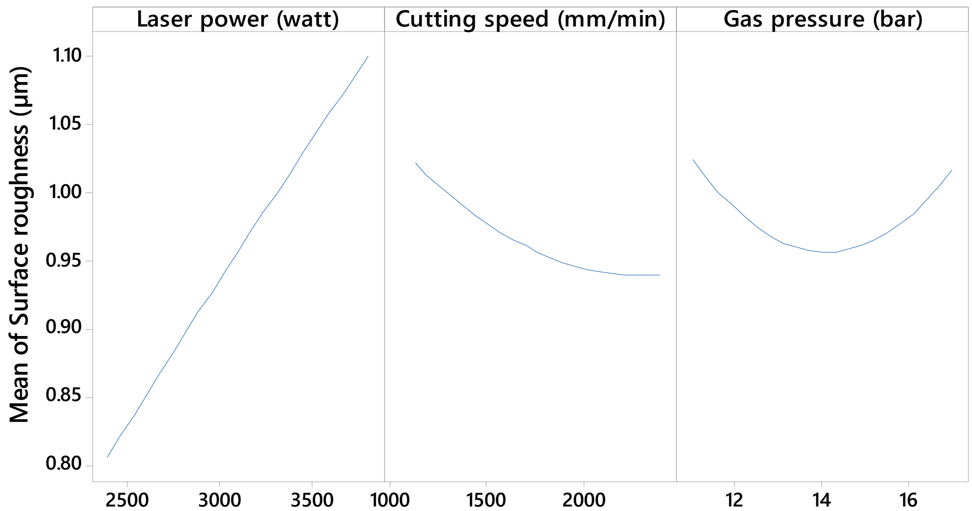

Fig. 9. Main effects plots of Surface roughness

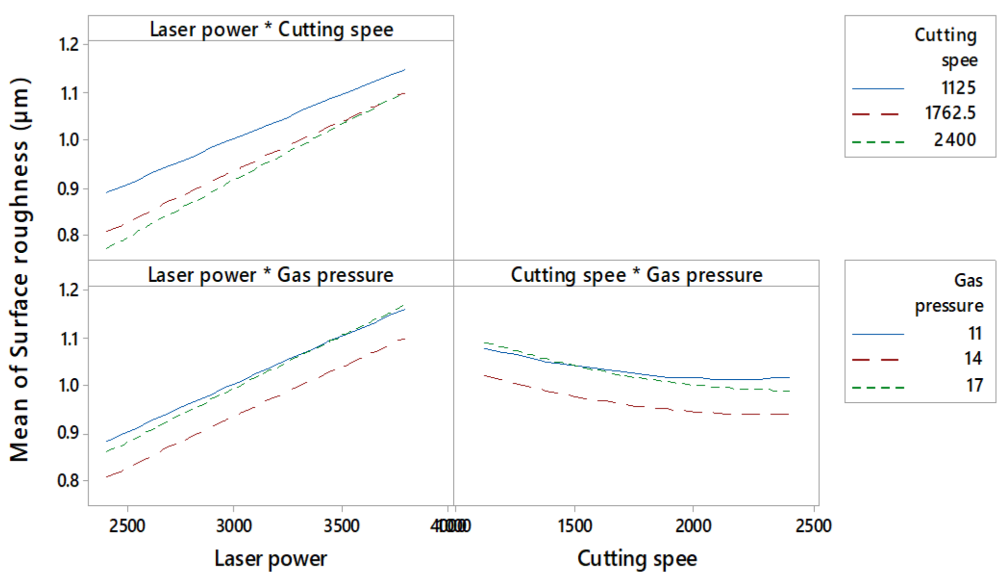

Fig. 10. Interaction plots of Surface roughness

The effect of selected laser machining parameters like “laser power”, “cutting speed”, “gas pressure” on “Ra” is shown in Fig.11-13. As the value of “laser power” increases the performance characteristic “Ra” is degraded rapidly. This occurs because as the value of “laser power” increases, its strength on the workpiece material for machining increases which degrades the side face of the specimen. To reduce the effect “laser power” on “Ra” minimum value is desirable. It is observed from response plots, as the value of “gas pressure” increases; the performance characteristics “Ra” improved gradually (little effect). This is because as the value of gas pressure increases it creates thrust at side face along with “laser power” which produces intense energy to cut the specimen smoothly.

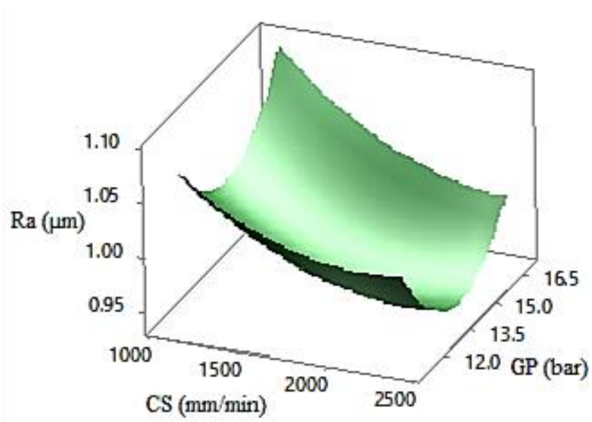

Fig. 11. Surface plot of Ra vs GP, CS hold values LP

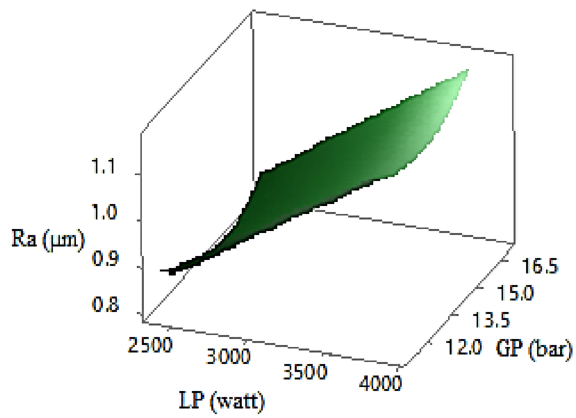

Fig. 12. Surface plot of Ra vs GP, LP hold values CS

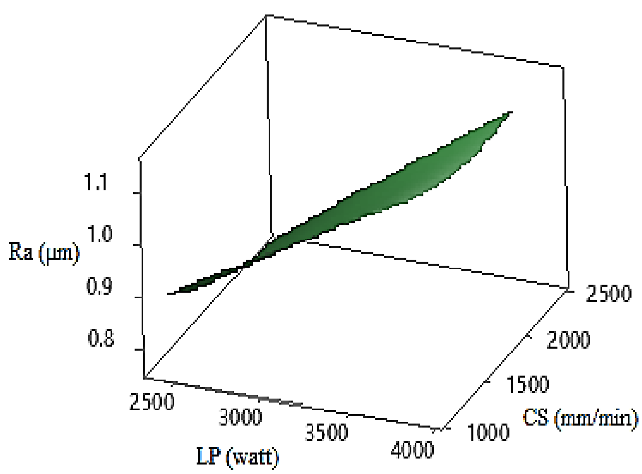

Fig. 13. Surface plot of Ra vs CS, LP hold values GP

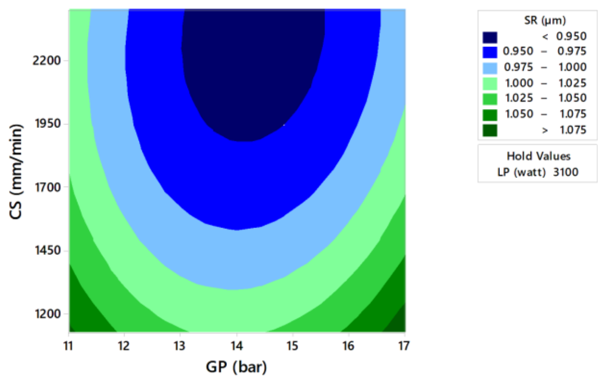

Fig. 14. Contour plot of CS vs GP, hold values LP

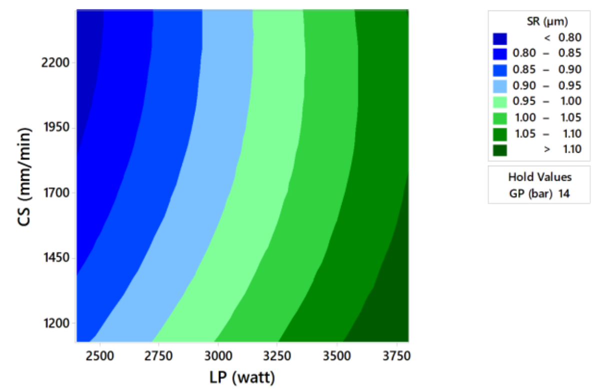

Fig. 15. Contour plot of Ra vs CS, hold values LP

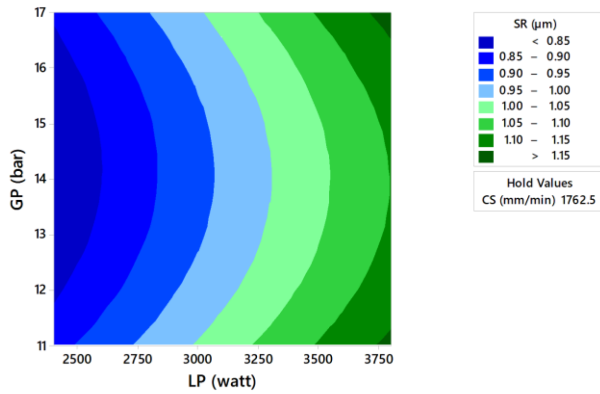

Fig. 16. Contour plot of GP vs LP, hold values CS

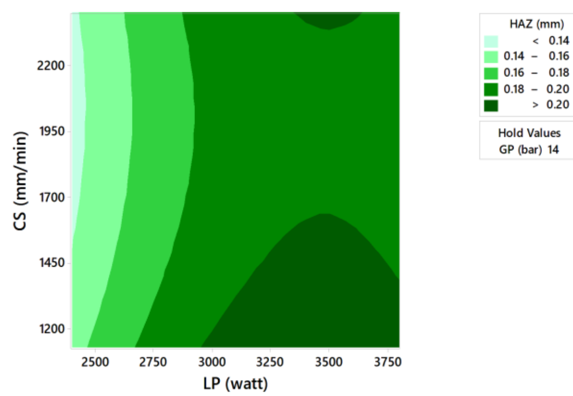

Fig. 17. Contour plot of CS vs LP, hold values GP

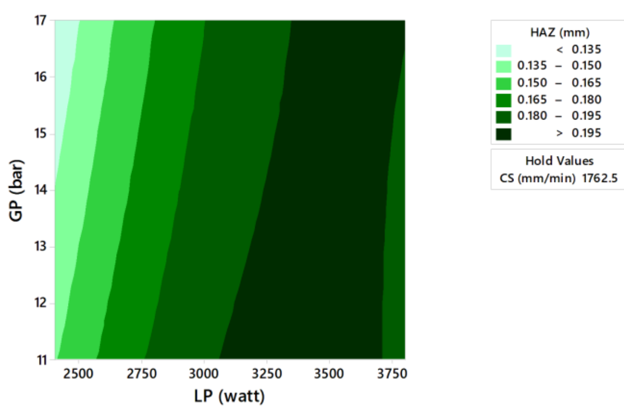

Fig. 18. Contour plot of GP vs LP, hold values CS

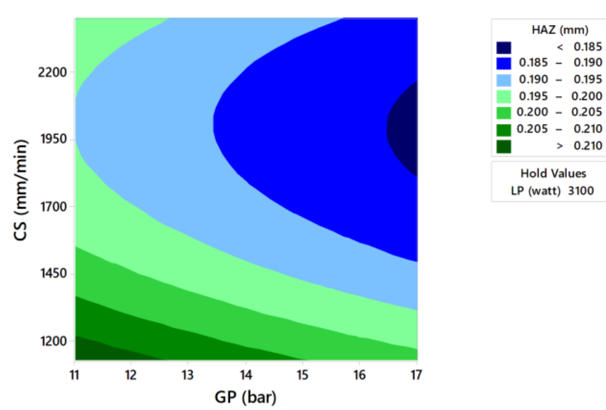

Fig. 19. Contour plot of CS vs GP, hold values LP

4.3 Optimization and confirmation test

The results of using the Box-Behnken design approach with response surface methodology (RSM) to optimize laser machining process parameters for the material Hastelloy C-276 sheet revealed that when using the optimal combination of parameters, including a laser power of 2400 watts, gas pressure of 15.66 bar, and cutting speed of 2232.58 mm/min, yielded an increase in the performance and quality of the machined parts. Specifically, this combination yielded a surface roughness of 0.78 (µm), a heat-affected zone (HAZ) of 0.127 mm. These results demonstrate that this combination of parameters is the optimal choice for achieving the highest performance and quality of the machined parts. Furthermore, the results reveal that the laser power has the greatest influence on the performance and quality of the machined parts, followed by the feed rate and the scanning speed. Therefore, it is important to adjust the laser power to the optimal value in order to achieve the best results.

Overall, the Box-Behnken design approach with response surface methodology (RSM) is a powerful tool that can be used to optimize laser machining process parameters for the material Hastelloy C-276 sheet. With this approach, the process parameters can be adjusted to yield the desired performance and quality of the machined parts. Table 7 shows the predicted and actual results of optimized parameter where obtained result shows good agreement with the predicted results.

Table 7. Predicted and actual results of optimized parameter

Sr. No.	Parameter	Level	Predicted results	Actual results	% error
1	LP (watt)	2400	Ra = 0.78 (µm)	Ra = 0.80 (µm)	2.56
2	GP (bar)	15			
3	CS (mm/min)	2232	HAZ = 0.127 (mm)	HAZ = 0.135 (mm)	6.29

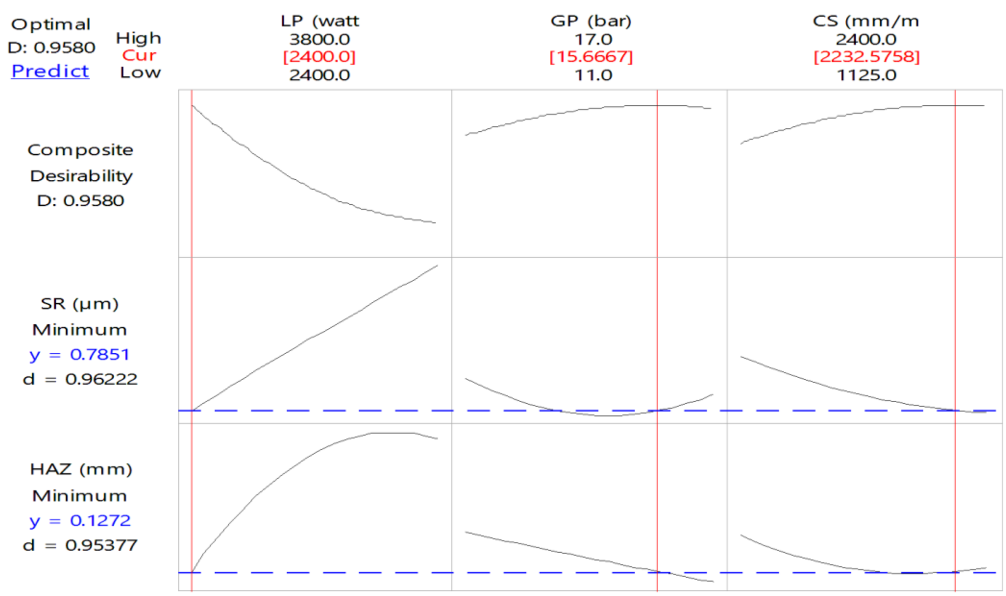

Fig. 20. Optimization plot

5. CONCLUSIONS

In this study, the laser machining process parameters for the material Hastelloy C-276 sheet are improved with the help of Box Benhken design approach with response surface methodology. This approach is used to determine the most optimal values for the parameters. The primary goal of this investigations is to optimize the output characteristics, which include "HAZ" and "Ra" for the selected range of process parameters which include "laser power," "cutting speed," "gas pressure," The major conclusions of this research are that the Box-Behnken design approach with response surface methodology (RSM) is a powerful tool that can be used to optimize laser machining process parameters for the material Hastelloy C-276 sheet in order to achieve the desired performance and quality of the machined parts.

1. "Laser power" is found to be the most significant factor in determining Ra and HAZ.
2. Using the many process factors that are taken into consideration, regression models are created for "HAZ," "Ra," These regression models are optimized in order to acquire the best possible value of the process parameters that are being considered for the laser machining process.
3. Specifically, the optimal combination of parameters yielded an increase in performance and quality of the machined parts with a surface roughness of 0.78 (μm) and HAZ of 0.12 mm.
4. Furthermore, it was determined that the laser power has the greatest influence on the performance and quality of the machined parts, followed by the feed rate and the cutting speed, thus emphasizing the importance of setting the laser power to the optimal value.
5. The research also showed that the optimal combination of parameters for laser machining of Hastelloy C276 included a laser power of 2400 watts, gas pressure of 15.66 bar, and cutting speed of 2232.58 mm/min.
6. This demonstrates that the Box-Behnken design approach with response surface methodology (RSM) can maximize the performance and quality of the machined parts by adjusting the process parameters to the optimal values. Additionally, the results of this study demonstrate the importance of setting the laser power to the optimal value in order to achieve the best results.
7. Additionally, the results of this study demonstrate that the Box-Behnken design approach with response surface methodology (RSM) can be used to optimize laser machining process parameters for the material Hastelloy C-276 sheet in order to achieve the desired performance and quality of the machined parts.

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