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Assessment of Kerf Width During Laser Beam Machining of Inconel 718

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Abstract
The present investigation is planned to evaluate the kerf width during the machining of Inconel 718 using the laser beam technique. Laser beam machining is a non-traditional material removal process used to machine complex and intricate shapes with high accuracy. A laser beam with a diameter of 0.2 mm was focused on the work material for machining. Response surface technique was employed for designing the trials. The power of the laser, the pressure of gas, and the frequency of the pulse were chosen as the machine variables. Post machining, the specimens were kept under scanning electron microscopy to measure the kerf induced during the operation. The kerf ranged between 0.21 mm to 0.39 mm for the present set of trials. From the analysis, it is revealed that laser power imparts major impact over the kerf width, following to it is frequency of the pulse. The kerf was observed to follow an increasing trend with both these parameters. Gas pressure was observed to be an insignificant variable for the performance measure. The value of residual error of 1.17% during model validation indicates that the developed model is accurate.

Keywords- LBM, Inconel 718, Kerf width, SEM.

1. Introduction

The Laser Beam Machining (LBM) is a non-traditional technique of removal of material. It uses the thermal energy generated by concentrating a beam of laser on the workpiece. When it strikes the surface of the work, the energy transforms into heat which melts the material and removes the debris within a short span of time (Stournaras et al., 2009; Singh et al., 2021). A narrow beam of light with intense energy is produced that generates sufficient energy to machine the work.

LBM is a machining procedure where the metal is removed without tool-work contact. This eliminates the mechanical residual stress and also no tool wear is observed. It can cut complex and intricate profiles with high accuracy. LBM emerges as the technique widely used in automobile (Anand et al., 2006), aerospace

(Yeo et al., 1994), electronics (Pfleging et al., 2000; Hirogaki et al., 2001; Huang et al., 2026), medical industries (Alayed et al., 2025). A very narrow heat affected zone is observed post-machining. It is generally a precise material removal technique that is used to cut very hard materials. Kerf width is the width of the machined material through the laser and it has a major role in predicting the precision of technique. **Table 1** summarises the few studies on the assessment of kerf width using LBM.

Table 1. Assessment of kerf width using LBM.

Reference	Material studied	LBM variables	Findings
Mathew et al. (1999)	Carbon Fiber Composite	Power of laser, Repetition rate	The study revealed that power of laser and repetition rate of pulse had great influence over the performance of machine. Results recommended to use minimum values of machine variables to achieve optimum results.
Dubey and Yadava (2008)	Alloy Steel	Pressure of gas, frequency and Speed of cutting	The frequency and speed of cutting majorly influence the kerf width of silicon alloy steel. No physical interpretation of results was discussed. Kerf lied between 0.3367 to 0.4200 mm even for a specimen of 0.5 mm thickness.
Sharma and Kumar (2019)	A653 Galvanized Steel	Pressure of gas, Power of laser and feed rate	In this, kerf width follows an increasing trend with all the variables. Among the selected parameters, power was considered as insignificant through the trials. Kerf lied between 0.241 to 0.489 mm even for a sheet of 0.5 mm thickness.
Parthiban et al. (2018)	Stainless Steel (SS) 304	Power, Speed and pressure of gas	They showed that keeping high value of speed and power leads to minimum kerf. Only the range of parameters are discussed. Kerf lied between 0.4027 to 0.4339 mm even for a sheet of 2.5 mm thickness.
Shinde and Kubade (2017)	SS 304	Power of laser and Rate of feed	The power and rate of feed were the crucial factors for kerf width. They recommended to set lower value of electrical parameters for optimizing the kerf produced.
Khed and Kamble (2015)	Aluminium Alloy	Power, Cut speed, Gas pressure	The range of laser power was between 1-1.4 kW. The kerf width of Aluminium Alloy is influenced by power and speed and they suggested to set low pressure (12 bar) and speed for achieving lower kerf.
Pawar et al. (2014)	American Iron and Steel Institute (AISI) 321	Frequency, Power and Cut speed	They suggested the use of lower level of speed (2500 mm/min) and power (2.4 kW) for achieving minimum kerf width. It was also found that the pressure of gas and the frequency of pulse had negligible influence on the kerf width.
Hema et al. (2020)	Copper	Power, Cut speed, Pressure of gas	The power of laser (3 kW) and the speed (1 m/min) have crucial impact on the performance of the machine while pressure of gas seems to be insignificant. Only quantitative contribution is discussed.
Stournaras et al. (2009)	Aluminium Alloy	Power of laser, Speed of cut	Both the variables are crucial factors for kerf width and a lower value of electrical parameters will yield optimal kerf. Limited number of trials were conducted to assess the results.
Rajesh et al. (2019), Umeshkumar and Chavan (2021)	SS 304	Laser power, Cutting speed	The influence of power and cut speed is highest among the selected LBM factors. Lower values of these parameters were recommended by the researchers so as to achieve lower kerf width.
Eaysin et al. (2025)	AISI P20	Power, Speed of cut, Pressure of gas	The minimum kerf width is generated at higher level of speed and pressure and medium level of laser power. The kerf width ranged between 0.60-0.92 mm.
Ji et al. (2024)	Titanium Alloy	Frequency, Power of laser and feed rate	The power and feed frequency were crucial variables for kerf width whereas frequency was found to be insignificant. Kerf width is observed to increase with increasing level of machine variables. Kerf width ranged between 0.468-2.1019 mm.
Sharma et al. (2022)	Aluminium Alloy	Frequency, Power of laser	The frequency is major dominating variable for kerf width and moderate values of LBM parameters must be set to achieve minimum kerf.
Singh et al. (2021)	Hybrid Polymeric Composites	Power, Cut speed and Pressure of gas	Elevated value of pressure and speed of cut must be chosen so as to achieve lower kerf width. No physical interpretation has been discussed by the researchers.
Sharma et al. (2010)	Nickel Based Super alloy	Cut speed, Pressure of gas, Pulse width and frequency	The result suggested that the kerf width for thin sheet of nickel-based supper alloy was optimum when the cut was straight rather than curved. The kerf width lied between 0.3630 to 0.6040 mm.
Shrivastava and Pandey (2018)	Inconel 718	Stand-off distance and Power	The results depict that least kerf width is achieved with lower level of power and medium level of stand-off distance. 0.74 - 0.81 mm was the range of kerf for a sheet thickness of 1.4 mm of Inconel 718.

Table 1 continued…

Roy et al. (2017)	Inconel 625 super alloy	Lamp current, Pulse frequency, Duty cycle	From the results it was elucidated that frequency and speed of cut are insignificant for kerf width while laser power and lamp current were sensitive. No physical interpretation of variables with kerf were discussed. The kerf width lied between 0.076 to 0.23 while machining 0.9 mm sheet of Inconel 625.
Madhav and Reddy (2025)	Haste Alloy	Power, Cut speed, Stand-off distance, Pressure of gas	It is found that all the machine variables follow increasing trend except cut speed. Moreover, they concluded that the developed model based on RSM can estimate the performance of the machine.
Alayed et al. (2025)	Glass	Scanning rate, Pulse duration, Wavelength	The study concluded that the scanning rate balances the finish. Lower pulse time yields improved precision and minimum HAZ. Higher pulse time yields thermal stresses.

From the previous literature it is found that majority of work on width of kerf is performed to optimize the parameters of laser beam machine. No practical feasibility of the trend has been explained by the researchers. Very less literatures were found that analyse the kerf width of Inconel 718. No physical interpretation of variables with performance measure were discussed. In few researches, only the range of performance measure and quantitative contribution are discussed. The impact of parameters towards the kerf width were not assessed. Some studies were found to have a limited number of trials to assess the kerf width. Machine variables such as power, frequency, speed of cut, gas pressure, feed rate, etc. were selected by the investigators to evaluate the performance of the machine. This assessment is accomplished to elucidate the influence and physical interpret the performance of laser beam machine and to find best possible set of machine variables for minimizing the kerf width. Although existing studies illustrates the kerf characteristics of material, but this research is conducted to assess the impact of laser variables on a thicker sheet of nickel-based alloy. This study will consider practical machining conditions so as to enhance the translational relevance of the optimized results.

2. Material and Methodology

The trials were performed on Jarc 1530 fibre metal laser cutting machine manufactured by Jarc Teknology as shown in the **Figure 1**. It is a fibre type laser and operates at a wavelength of 1064 nm with continuous wave mode. For the present assessment, the diameter of the beam at focus was kept as 0.1 mm, the focal length was set as 100 mm and the stand-off distance was 0.5 mm for all the trials. Inconel 718, a nickel-based alloy, with a 5 mm thickness has been selected as the work-material for assessment. The cutting speed for 5 mm thick Inconel 718 sheet was kept as 1 m/min. It finds its applicability in aerospace and turbine industries. **Figure 2** illustrates the machine setup for trials. **Figure 3** demonstrates the machined specimens for kerf width measurement.

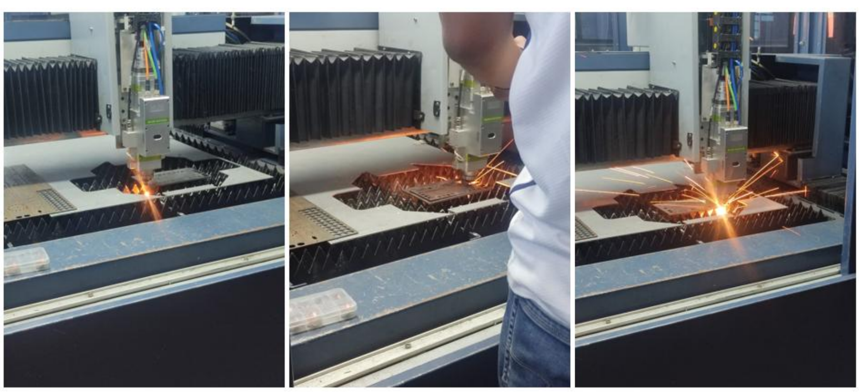

Figure 1. Machining of Inconel 718 on LBM.

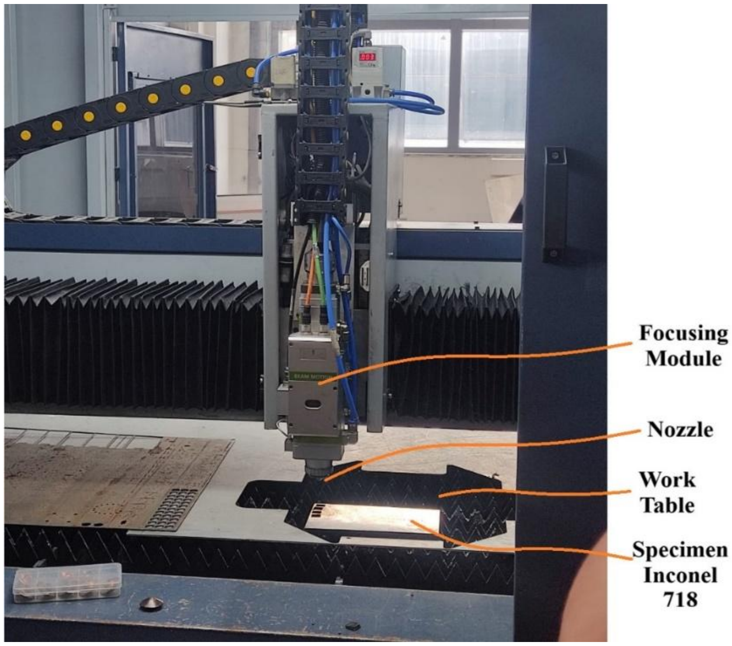

Figure 2. Machine setup for trials.

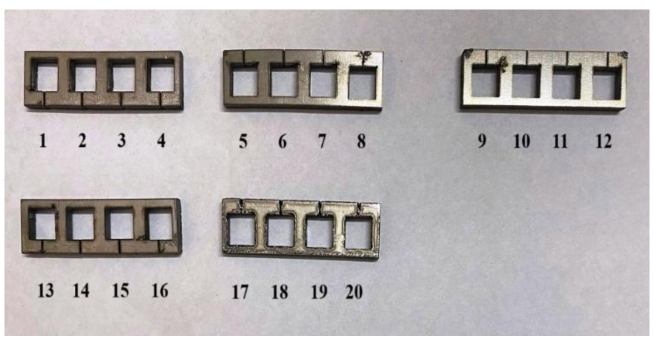

Figure 3. Machined specimens for kerf width measurement.

Inconel 718 possess high melting temperature and has low thermal conductivity. Laser power, frequency of pulse and pressure were chosen as the primary machine variables as they directly dominate the heat input, energy modulation and melt expulsion dynamics during laser machining process. Kerf formation is predominantly governed by these variables. Other variables like cutting speed, stand-off distance, etc were kept constant to isolate the influence of thermal and gas-assisted mechanism on the kerf. **Table 2** depicts the range of various LBM variables selected for the present assessment along with their units. Initial trials were performed so as to analyze the range of machine variables. Below 2 bar gas pressure, intensity of laser seems to be less effective hence the minimum range of it is kept as 2 bar. Moreover, the upper limit was set as 6 bar based on past literatures (Dubey and Yadava, 2008; Khed and Kamble, 2015; Parthiban et al., 2018; Sharma and Kumar, 2019; Hema et al., 2020). Similarly, below 1 kW laser power, the rate of removal of material was not significant. Based on past research, the upper limit of power of laser is set as 1.5 kW (Mathew et al., 1999; Dubey and Yadava, 2008; Stournaras et al., 2009; Shinde and

Kubade, 2017; Parthiban et al., 2018; Rajesh et al., 2019; Eaysin et al., 2025). Furthermore, the pulse frequency was ranged between 20-50 Hz in most of the literatures (Dubey and Yadava, 2008; Pawar et al., 2014; Sharma et al., 2022; Ji et al., 2024).

Table 2. Range of LBM variables.

Parameter	Unit	Range
Laser Power	kW	1, 1.25, 1.5
Gas Pressure	Bar	2, 4, 6
Pulse Frequency	Hz	20, 35, 50
Cutting Speed	m/min	1 (constant)
Stand-off Distance	mm	0.5 (constant)

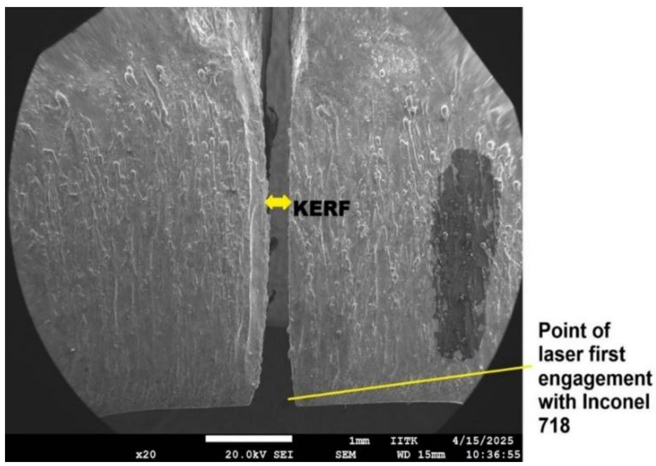

Figure 4. Illustration of kerf and the point of laser first engagement with the workpiece.

Field emission – scanning electron microscopy (FE-SEM) was performed on JEOL JSM 7100F SEM machine. **Figure 4** depicts a sample of image taken through microscope for the measurement of kerf. Linear measurements were made to estimate the extent of kerf width induced post machining. The trails were designed by response surface methodology. A second order model was established with central composite design (CCD) and a total of twenty trials were planned using the chosen variables. CCD was selected due to its suitability in developing second order models with estimation for both linear and quadratic effects, including axial points which permits effective curvature detection. Box Behnken does not include axial points and is less sensitive to curvatures.

3. Result and Discussion

Kerf width plays an important character in analyzing the precision of laser beam machine. A wide kerf may result in loss of design and thus effecting the tolerance of the part. For achieving precision, a minimum kerf is desired for intricate parts. It generally relies upon the material properties, its thinness, machine variables and geometry of product. The following **Table 3** represents the kerf width obtained while performing the trials designed by RSM.

Out of twenty samples, **Figure 5** demonstrates four micrographs of sample 1, 2, 9 and 13 undertaken to illustrate the estimation of kerf width for the corresponding sample. The values of the performance measure were quantified in millimetre. The kerf ranged between 0.21 mm to 0.39 mm for the present set of trials. In earlier researches which were carried on Inconel or nickel-based alloys, the minimum kerf width ranged above 0.3630 mm (Sharma et al., 2010; Shrivastava and Pandey, 2018) for 1.4 mm thick specimen. Hence, the present set of trails proves to yield minimum kerf width with 5 mm sheet thickness as compared to the earlier research.

Table 3. Kerf width corresponding to each trial.

Trial No.	Laser power (kW)	Gas pressure (bar)	Pulse frequency (Hz)	Kerf width mm
1	1	2	20	0.21
2	1.5	2	20	0.29
3	1	6	20	0.25
4	1.5	6	20	0.33
5	1	2	50	0.28
6	1.5	2	50	0.34
7	1	6	50	0.26
8	1.5	6	50	0.39
9	1	4	35	0.23
10	1.5	4	35	0.34
11	1.25	2	35	0.28
12	1.25	6	35	0.27
13	1.25	4	20	0.27
14	1.25	4	50	0.31
15	1.25	4	35	0.23
16	1.25	4	35	0.22
17	1.25	4	35	0.23
18	1.25	4	35	0.24
19	1.25	4	35	0.22
20	1.25	4	35	0.23

Figure 6 illustrates the SEM observation of sample 2 depicting wider kerf and recast layer deposition due to increased melt pool at higher laser power. Consequently, after procuring the kerf width values, the data was analysed. While conducting the sequential model and lack of fit assessments, portrayed in **Tables 4** and **5**, the assessment recommended that the trials comply with quadratic equation modelling.

Subsequently, variance analysis was accomplished in the further investigation of kerf width and is depicted in **Table 6**. F-Value for the model is 7.46 which indicates model's significancy it has a 0.21% chance of occurrence because of noise. The probability values of Power (A) and Pulse Frequency (C) are significant.

Probability value of gas pressure (B) is 0.2261 which elucidates the insignificancy of the model term. The F-value of lack of fit of 20.21 suggest its significancy and it has a 0.25% chance of occurrence because of noise. In addition to this, fit statistics were taken under consideration. The Adequate precision assess the ratio of signal and noise. A value of 9.642 for this model depicts its adequacy and could be utilized for navigating the design space. Here, the developed quadratic model represents strong explanatory capability with 0.8704 R^2 value and a statistically significant regression ($p = 0.0021$). The coefficient of variance of 9.05% indicates good experimental reliability. A relatively low predicted R^2 may be attributed to the inherent stochastic nature of machining of Inconel 718 which involves complex melt pool instability, plasma shielding effect and rapid thermal gradients. **Table 7** illustrates the fit statistics.

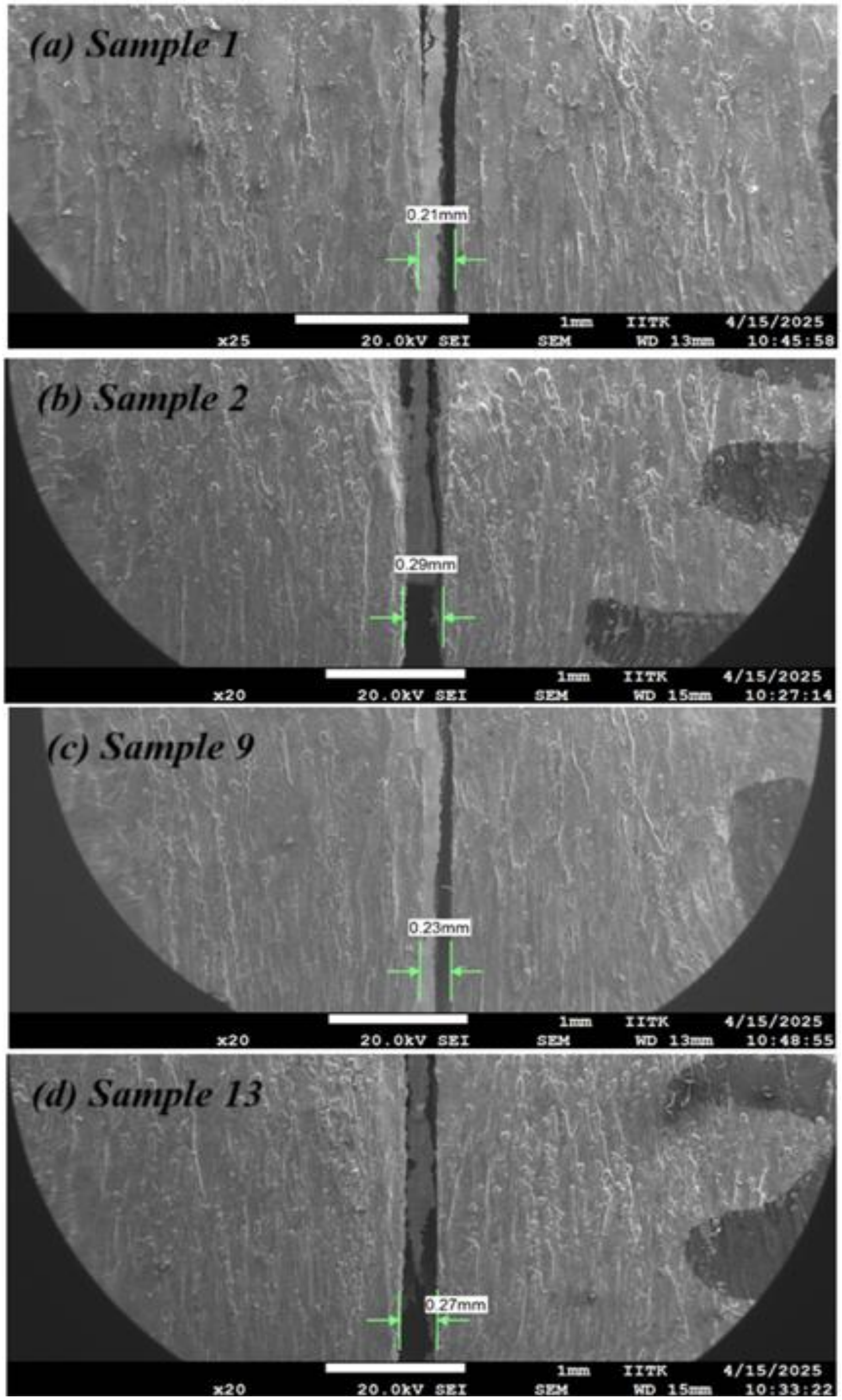

Figure 5. SEM micrographs depicting kerf width estimation for (a) Specimen 1; (b) Specimen 2; (c) Specimen 9; (d) Specimen 13.

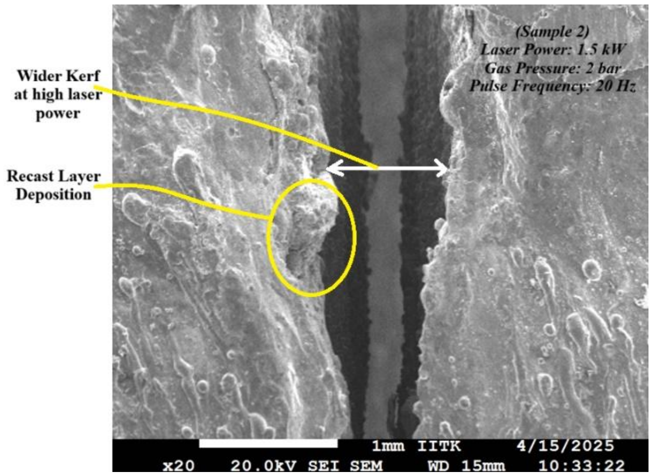

Figure 6. SEM micrographs depicting wider kerf and recast deposition at higher laser power.

Table 4. Sequential model assessment for kerf width.

Model term	Sum of squares	DOF	Mean square	F-value	prob-value	
Mean vs. Total	1.47	1	1.47			
Linear vs. Mean	0.0275	3	0.0092	7.73	0.0021	
Two-FI vs. Linear	0.001	3	0.0003	0.2513	0.859	
Quadratic vs. Two-FI	**0.0119**	**3**	**0.004**	**6.59**	**0.0098**	**Recommended**
Cubic vs. Quadratic	0.0014	4	0.0004	0.4555	0.7668	Aliased
Regression Error	0.0046	6	0.0008			
Total	1.52	20	0.0758			

Table 5. Lack of fit for kerf assessment.

Model term	Sum of squares	DOF	Mean square	F-value	prob-value	
Linear	0.0186	11	0.0017	29.91	0.0008	
2-FI	0.0176	8	0.0022	38.84	0.0004	
Quadratic	**0.0057**	**5**	**0.0011**	**20.21**	**0.0025**	**Recommended**
Cubic	0.0043	1	0.0043	76.36	0.0003	Aliased
Pure Error	0.0003	5	0.0001			

Table 6. Variance analysis for kerf width.

Model term	Sum of squares	DOF	Mean square	F-value	prob-value	
Model	0.0404	9	0.0045	7.46	0.0021	Recommended
Laser Power (A)	0.0212	1	0.0212	35.2	0.0001	
Gas Pressure (B)	0.001	1	0.001	1.66	0.2261	
Pulse Frequency (C)	0.0053	1	0.0053	8.8	0.0141	
A-B	0.0006	1	0.0006	1.02	0.3366	
A-C	0.0001	1	0.0001	0.1872	0.6745	
B-C	0.0003	1	0.0003	0.5199	0.4874	
A^2	0.0012	1	0.0012	1.91	0.1966	
B^2	0.0003	1	0.0003	0.5001	0.4956	
C^2	0.0018	1	0.0018	2.96	0.1158	
Residual	0.006	10	0.0006			
Lack of Fit	0.0057	5	0.0011	20.21	0.0025	Recommended
Pure Error	0.0003	5	0.0001			
Cor Total	0.0464	19				

Table 7. Fit statistics for kerf width.

Standard deviation	0.0245	**R^2**	0.8704
Mean	0.271	**Adjusted R^2**	0.7538
Coefficient of variance %	9.05	**Predicted R^2**	0.1621
		Adequate precision	9.6424

An equation with actual factors which could be utilized for predicting the response provided with every level of machine variables was derived from the design expert software through analysis and is illustrated as Equation (1). The machine variables must be specified in actual units.

$$\text{Kerf Width (mm)} = 0.733003 - 0.739182 \times \text{LP} - 0.030492 \times \text{GP} - 0.006803 \times \text{PF} + 0.0175 \times \text{LP} \times \text{GP} + 0.001 \times \text{LP} \times \text{PF} - 0.000208 \times \text{GP} \times \text{PF} + 0.327273 \times \text{LP}^2 + 0.002614 \times \text{GP}^2 + 0.000113 \times \text{PF}^2 \quad (1)$$

Table 8. Coefficient in terms of coded variables for kerf width.

Variable	Coefficient approximation	DOF	Standard error	95% CI low	95% CI high	V I F
Intercept	0.2428	1	0.0084	0.224	0.2616	
Laser Power (A)	0.046	1	0.0078	0.0287	0.0633	1
Gas Pressure (B)	0.01	1	0.0078	-0.0073	0.0273	1
Pulse Frequency (C)	0.023	1	0.0078	0.0057	0.0403	1
A-B	0.0087	1	0.0087	-0.0106	0.0281	1
A-C	0.0037	1	0.0087	-0.0156	0.0231	1
B-C	-0.0063	1	0.0087	-0.0256	0.0131	1
A^2	0.0205	1	0.0148	-0.0125	0.0534	1.82
B^2	0.0105	1	0.0148	-0.0225	0.0434	1.82
C^2	0.0255	1	0.0148	-0.0075	0.0584	1.82

The coefficient approximation depicts the probable variation in response with a variation in variable value keeping rest of the variable constant. The overall average response of all trials is the intercept. Variance Inflation Factor (VIF) has a value of 1 when the variable is orthogonal. Whereas, multi-collinearity is depicted by a value higher than 1. Moreover, larger VIF represents severe correlations of variable. Generally, VIFs less than 10 are tolerable. **Table 8** depicts that VIF for linear and interaction terms is 1 but the quadratic terms have as VIF value of 1.82.

The **Figure 7** depicts the analytical plots for kerf width. In **Figure 7(a)**, normal plot is demonstrated which shows that the data points are linear for normality which is desirable. Most of the points are lying near to the probability line. Hence the assessed quadratic model is valid and accurate. Furthermore, **Figure 7(b)** illustrates the predicted vs actual plot for kerf width. The data points are dispersed around the diagonal and the linear graph indicates that the experimental assessments of kerf width with minimal deviation are in accord with the forecast values. This also approves the accuracy and validity of the model developed. Earlier research also portrays linear relations for minimum deviation of kerf width for model validation (Khed and Kambale, 2015; Ji et al., 2024; Eaysin et al., 2025).

In addition to this, response surface graphs were plotted for the quadratic model as shown in figure 8. It is observed that gas pressure is nearly ineffective for kerf width while the laser power has direct impact on it as demonstrated in **Figure 8(a)**. As the level of power is increased, the kerf also increases and reduces the accuracy of the process. A similar trend was observed by previous researchers (Pawar et al., 2014; Shinde and Kubade, 2017; Rajesh et al., 2019; Sharma and Kumar, 2019). The laser power is directly influenced by the intensity of energy produced. More the power, more will be its intensity and hence kerf will increase.

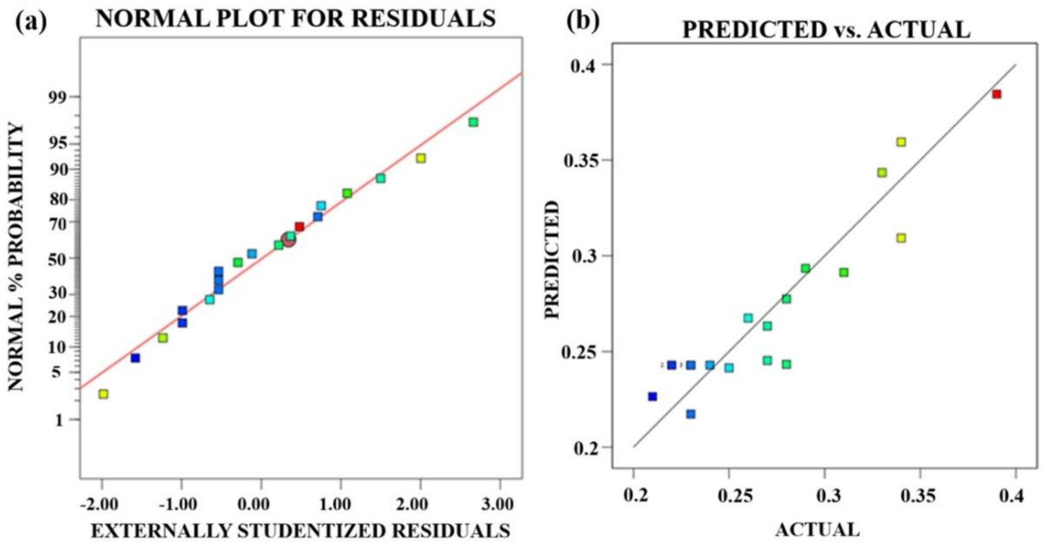

Figure 7. Analytical plots for kerf width (a) Normal plot for residual and (b) Predicted vs actual plot.

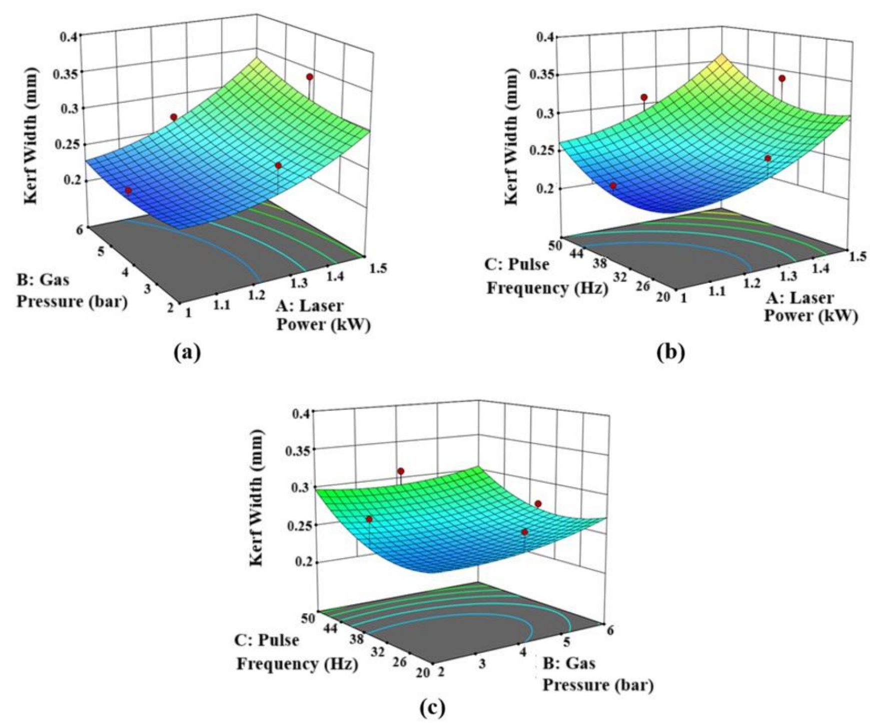

Figure 8. Response surface graphs for kerf width with (a) Power and pressure of gas; (b) Power and frequency; (c) Pressure of gas and frequency.

Moreover, **Figure 8(b)** and **(c)** elucidates that the kerf primarily declines by a rise in frequency but again tend to increase with further increase in the value of frequency. A similar trend was also observed in previous literature (Dubey and Yadava, 2008; Roy et al., 2017; Sharma et al., 2022). As suggested by variance analysis, laser power and frequency are significant model terms for kerf while gas pressure is inconsequential variable. The insignificancy of gas pressure complies with earlier studies (Dubey and Yadava, 2008; Pawar et al., 2014; Parthiban et al., 2018; Hema et al., 2020). The curve graphs depict the existence of quadratic model terms.

Higher laser power causes excessive melting which increases the lateral melting of Inconel 718. This results in wider kerf formation. The pulse frequency governs the heat accumulation rate. Here, a higher frequency yields thermal build-up due to limited cooling time that causes lateral melting whereas lower frequency delivers better dimensional control because of lower melt spreading. Gas pressure plays a secondary role but it stabilizes the kerf by increasing the removed material expulsion. With low gas pressure, the removed material accumulates and creates kerf irregularity while a higher level of gas pressure clears the machining gap and creates a narrow and more stable kerf. Laser power primarily drives the kerf widening while the frequency amplifies the thermal accumulation influence.

4. Validation of the Model

To validate the present quadratic model, model validation using point prediction was undergone as illustrated in **Table 9**. The predicted value is drawn through the analysis performed while a validation trial is performed on the centre points. Upon comparing the predicted and validated value, a residual error is estimated. For the model, the residual error is 1.17% for the kerf width which shows that the obtained model is accurate. This low residual error illustrates that the present assessment shows better results than the earlier literatures (Parthiban et al., 2018; Sharma and Kumar, 2019).

Table 9. Validation of the quadratic model.

S. No.	Input Parameters	Kerf Width (mm)		Residual Error %
		Predicted	Validated	
1.	Laser Power = 1.25 kW; Gas Pressure = 4 bar; Pulse Frequency = 35 Hz	0.242818	0.24	1.17%

5. Conclusion

The assessment conducted on kerf width during LBM of Inconel 718 using power of laser, pressure of gas and pulse frequency as machine variables have following conclusion.

- Kerf width plays an important character in analyzing the precision of laser beam machine. A wide kerf may result in loss of design and thus effecting the tolerance of the part. For achieving precision, a minimum kerf is desired for intricate parts. It generally depends upon the material properties, its thickness, machine variables and geometry of product.
- Upon conducting the Sequential Model and Lack of fit tests the assessment recommended that the trials comply with quadratic equation modelling. F-Value for the model is 7.46 which indicates model's significancy it has a 0.21% chance of occurrence because of noise. The probability values of Laser Power (0.0001) and Pulse Frequency (0.0141) are significant. Probability value of gas pressure (0.2261) elucidates the insignificancy of the model term.
- The F-value of lack of fit of 20.21 suggest its significancy and it has a 0.25% chance of occurrence

because of noise. In addition to this, fit statistics were taken under consideration. The Adeq. precision assess the ratio of signal and noise. A value of 9.642 for this model depicts its adequacy and could be utilized for navigating the design space.
- The normal plot shows that the data points are linear for normality which is desirable. Most of the points are lying near to the probability line. Hence the assessed quadratic model is valid and accurate. Furthermore, the predicted vs actual plot for kerf width. The data points are dispersed around the diagonal and the linear graph indicates that the experimental assessments of kerf width with minimal deviation are in accord with the forecast values. This also approves the accuracy and validity of the model developed.
- The response surface graphs showed that gas pressure is nearly ineffective for kerf width as cited by previous researcher while the laser power has direct impact on it. As the level of power is increased, the kerf also increases and reduces the accuracy of the process. The laser power is directly influenced by the intensity of energy produced. More the power, more will be its intensity and hence kerf will increase. The kerf width initially declines with a rise in frequency but again tend to increase with further increase in the value of frequency. As suggested by variance analysis, laser power and frequency are significant model terms for kerf while gas pressure is inconsequential variable. The curve graphs depict the existence of quadratic model terms.
- Higher laser power causes excessive melting which increases the lateral melting of Inconel 718. This results in wider kerf formation. The pulse frequency governs the heat accumulation rate. Here, a higher frequency yields thermal build-up due to limited cooling time that causes lateral melting whereas lower frequency delivers better dimensional control because of lower melt spreading.
- For the model, the residual error is 1.17% for the kerf width which shows that the obtained model is accurate.

Conflicts of Interest

The authors confirm that there is no conflict of interest to declare for this publication.

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AI Disclosure

The author(s) declare that no assistance is taken from generative AI to write this article.

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