

Optimization of Laser Cutting Parameter on AISI 321

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ABSTRACT: Laser cutting used in many industrial cutting applications. AISI 321 (Stainless Steel) is material having excellent corrosion resistance and better hardness. Quality of a surface is also utmost importance in laser cutting. The aim of the paper is to study and find the best cutting parameters for AISI 321 of 10mm thickness of minimum surface roughness corresponding with minimum striation, maximum hardness. Input parameters are cutting speed, gas pressure, pulse frequency and nozzle gap in laser cutting. The work is based on industrial implementation knowledge to arrive at optimal cutting conditions using RSM (Response Surface Methodology) to meet specified process performance.

KEYWORDS: Laser Cutting, AISI 321 (Stainless Steel), Surface Roughness, Hardness, RSM.

I. INTRODUCTION

Metal cutting is one of the non-convective machining material removing processes in the manufacturing processes. Metal cutting is the removal of metal from a work piece to get finished product with required size, surface roughness and hardness. Cutting quality is determined by changes in material properties and cut surface properties which reduce the cost of post processing treatment and machining. RSM is significantly implemented for prediction and optimization of cutting parameters of laser.

II. LITERATURE REVIEW

As material thickness increases, cutting speed decreases was concluded by Nagaraja et al. [1]. In [2], author observed cutting speed and thickness of plate have high contribution on surface roughness. In [3] their work proposed that surface roughness decreases with increasing of the cutting speed for continuous wavelength, dross is there even lower cutting for high power. [4] Proposed that when the heat input was increased when the cutting speed was high, the dross-free cutting was achieved. In [5] Author found that due to excessive heat distribution hardness changes from cut zone towards center. [6] Hayat A. Eltawahni Observe the dross formed during inert gas assist cutting is usually more difficult to remove than the more brittle oxide dross formed when oxygen is used as an assist gas. B Tirumala Rao, A K Nath in [7] predicted that cut thick sheets, the focal point of the beam should be inside the workpiece to obtain good cut quality in thick plates more than 10mm the operating pressure should be less than 2 bar. In [8] concludes about Elimination of Striation that can be achieved with intermediate range of cutting speed, while beside this range striation is observed by optimizing gas pressure, it stabilizes hydrodynamic behaviour of molten metal which is easily expelled the molten metal from the cutting front and reduce the striation. In [9] Amount of absorption is dependent on wavelength of light. Striation formation depends on pulse frequency. It is found that AISI 321 is not much studied for laser cutting considering surface roughness, Hardness, and dross which is difficult to machine due to low thermal conductivity. P.J. Pawar and G.B. Rayate in [10] has done multi-optimization of laser parameter for determining kerf width, taper angle and surface roughness.

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III. EXPERIMENTAL SETUP

Amada LCG 3015 CO₂ LASER cutting machine of 4KW at 1.5 Bar gas pressure, N₂ gas 4.0 nozzle diameter, 85% duty cycle having continuous wave type mode and specifications shown in table 1 was used for cutting of AISI321 10 mm thickness, plate having dimensions 130mm*285 mm as shown in figure.1 with straight profile cut beside each side perpendicular to grain direction.



Figure. 1 Amada LCG 3015

Technical Data	LCG 3015
Maximum Thickness	10mm
Repeatability	± 0.0002
Auxiliary Gas	Nitrogen
Working Range	
x axis, mm	3073.4mm
y axis, mm	1549.4mm
z axis, mm	99.82mm
Power Requirements	200/220V ±10% 50/60Hz

Table. 1 Specifications of Amada LCG 3015

Chemical composition of AISI321 material is shown in table 2 which shows addition of the titanium to increase its corrosive properties. As long term exposure to temperature decreases corrosive properties. Physical properties of AISI321 are shown in table 3.

Content	C	Mn	Si	S	P	Cr	Ni	Ti
%	0.10	1.75	0.70	0.02	0.02	18.50	1.60	0.55

Table. 2 chemical composition

Common form	Tensile strength MPa (min.)	Yield strength (0.2% offset) MPa (min.)	Elongation % in 50mm (min.)	Hardness
Sheet	515	205	40	93 HRB

Table. 3 Physical Properties

The surface roughness was measured with Mitutoyo stylus instrument (S1210). Hardness was measured with Rockwell hardness tester scale B before cutting at the surface of plate which was 93HRB. After cut were made hardness was measured at the linear regions along cutting direction on three cut zones as shown in figure 2(b). The experiment was conducted by varying parameter value and two levels as given in table 4.

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Parameters	Level 1	Level 2
Cutting Speed (mm/m)	800	900
Frequency (Fz)	700	900
Nozzle gap (mm)	0.7	0.3

Table.4 Parameter and Levels

The parameters value is varied according to L_8 by using MINITAB 15 software as given in table 5. Based on parametric value experiment is carried corresponding to surface roughness and hardness.

IV. EXPERIMENTAL RESULTS

The results of measurements of surface roughness and cut surface hardness of cut faces workpiece are evaluated after laser cutting as given in table 5. Where BSL is boundary separation layer.

Experiment No	Cutting speed	Frequency	Nozzle gap	Surface roughness(RA)		Hardness(HRB)		
				Upper cut surface	Lower cut striation	Cut surface	BSL	Striations
1	800	700	0.3	2.292	7.7275	87	90	92
2	900	700	0.3	1.482	10.0715	91	72	72
3	800	900	0.3	1.992	6.2175	92	86	84
4	900	900	0.3	1.8405	12.574	92	76	63
5	800	700	0.7	1.647	14.3785	74	52	80
6	900	700	0.7	1.3485	7.956	74	70	73
7	800	900	0.7	1.514	4.7525	82	91	82
8	900	900	0.7	2.2645	13.743	71	63	80

Table.5 Results

The after the cutting is carried out surface is differentiated as upper cut surface, Boundary separation layer (BSL), striation are shown in figure 2. where measurement are taken.



Figure 2 (a) maximum striation 2. (b) Cut of Optimum cutting parameter

A) ANOVA Analysis:

MINITAB 15 was used for analysing the measured responses. For all quadratic model for all responses should have maximum predicted and adjusted R^2 value. The resulting ANOVA (tables 6 to 10) quadratic model outlines the analysis of variance for each response and gives significant model term. The values near to 100% shows reasonable agreement and indicates adequate model. From table 6, table 8, and table 10 R^2 value are 97.90%, 98.88%, 99.17%, respectively which indicates the model used for the analysis is appropriate. From table 7 and table 9 R^2 value are 81.98% and 72.18% respectively which shows that defect in model are not significant.

The results of ANOVA for responses has statistical significance of the quadratic model for the response are given in following tables

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Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	0.887401	0.887401	0.1479	7.76	0.268
Linear	3	0.207596	0.207596	0.069199	3.63	0.364
Interaction	3	0.679805	0.679805	0.226602	11.89	0.209
Residual Error	1	0.019061	0.019061	0.019061		
Total	7	0.906462				
R-Sq = 97.90%		R-Sq(pred) = 0.00%		R-Sq(adj) = 85.28%		

Table 6 ANOVA cut surface Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	73.9195	73.9195	12.3199	0.76	0.705
Linear	3	19.1319	19.1319	6.3773	0.39	0.791
Interaction	3	54.7876	54.7876	18.2625	1.12	0.585
Residual Error	1	16.2464	16.2464	16.2464		
Total	7	90.1659				
R-Sq = 81.98%		R-Sq(pred) = 0.00%		R-Sq(adj) = 0.00%		

Table 7 ANOVA Striation Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	542.75	542.75	90.458	14.77	0.197
Linear	3	486.375	486.375	162.125	26.47	0.142
Interaction	3	56.375	56.375	18.792	3.07	0.392
Residual Error	1	6.125	6.125	6.125		
Total	7	548.875				
R-Sq = 98.88%		R-Sq(pred) = 28.58%		R-Sq(adj) = 92.19%		

Table 8 ANOVA for Cut Section Hardness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	945.5	945.5	157.583	0.43	0.821
Linear	3	596.5	596.5	198.833	0.55	0.731
Interaction	3	349	349	116.333	0.32	0.825
Residual Error	1	364.5	364.5	364.5		
Total	7	1310				
R-Sq = 72.18%		R-Sq(pred) = 0.00%		R-Sq(adj) = 0.00%		

Table 9 ANOVA for Hardness of Boundary separation layer

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Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	537	537	89.5	19.89	0.170
Linear	3	322.5	322.5	107.5	23.89	0.149
Interaction	3	214.5	214.5	71.5	15.89	0.182
Residual Error	1	4.5	4.5	4.5		
Total	7	541.5				
R-Sq = 99.17% R-Sq(pred) = 46.81% R-Sq(adj) = 94.18%						

Table 10. ANOVA for hardness at striation

Response surface modelling:

The mathematical model in form of polynomial was developed from ANOVA obtained using experimental matrix with help of RSM in MINITAB 15.

The response equation roughness at striations, hardness at cut zone, hardness at are given below

Ra at upper cut = $40.6469 - 0.0442581C.S - 0.0374966F - 19.1612NG + 4.26875CS*FZ + 0.0176687CS*NG$

Ra at lower cut surface (striation) = $275.830 - 0.32201*C.S - 0.4012*F + 91.9650*NG + 0.0004856*C.S*F - 0.0766562*C.S*NG - 0.0301969*F*NG$

Hardness at the cut zone = $-231.375 + 0.37625*C.S + 0.335625*F + 126.250*NG - 3.7500*C.S*F - 0.187500*C.S*NG - 0.00625000*F*NG$

Hardness at boundary separation layer (BSL) = $-3310625 + 0.552500*C.S + 0.747500*F - 3810250*NG - 905000*C.S*F + 0.225000*C.S*NG + 0.200000*F*NG$

Hardness at striation = $494.250 - 0.405000*C.S - 0.176250*F$

$+ 467.550*NG + 0.000100000*C.S*F + 0.400000*C.S*NG + 0.162500*F*NG$

Where C.S, F, NG, are cutting speed, frequency, nozzle gap.

Effect of parameters:

The effect of various parameter were studied by plotting the matrix plot as shown in below figure 3

Effect of cutting speed, frequency and nozzle gap on surface roughness (Ra) and hardness (Ha):

As cutting speed and nozzle gap increases, Ra (cut Surface) decreases and as frequency increases Ra (cut Surface) increases.

As cutting speed increases Ra (striations) increases rapidly also it slightly decreases with frequency and it slightly increases with increase with increase in nozzle gap.

As cutting speed increases Ha (cut Surface) decreases slightly, it increases with increasing frequency and it rapidly decrease with increase in nozzle gap.

As cutting speed and nozzle gap increases Ha (BSL) decrease and its increases with increasing frequency.

As cutting speed increases Ha (striations) decreases with it, it remains constant with frequency and also increases minutely with nozzle gap.

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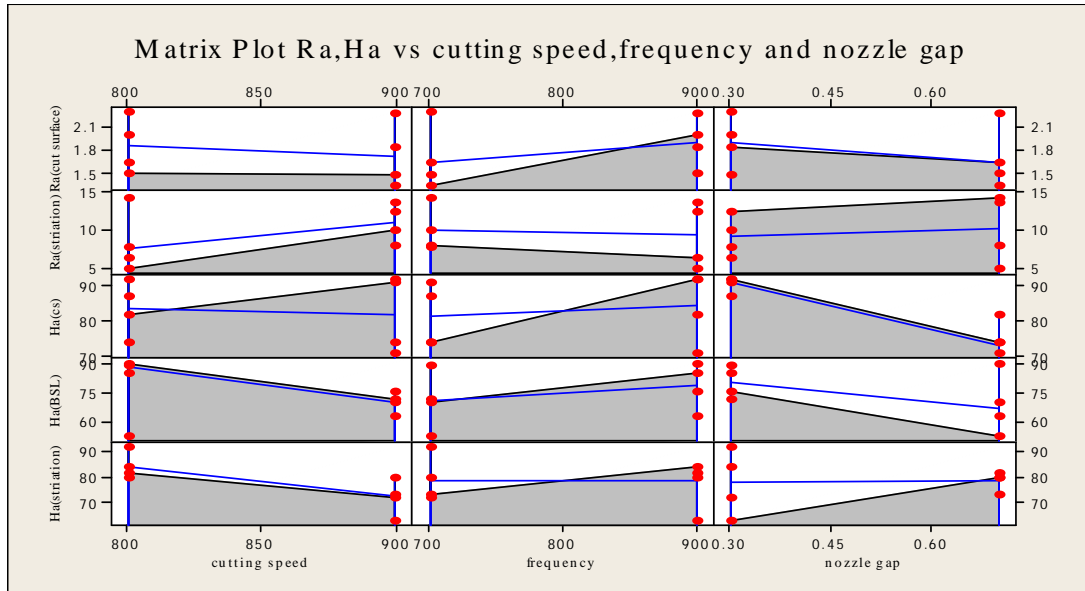


Figure 3 Matrix plot of Ra, Ha vs cutting speed, frequency and nozzle gap

B) Response Optimization

For finding suitable response point of factor which is best point for this experiment Response Optimizer function, by implementing the small the better for surface roughness and higher the better for Hardness. The highest Hardness value indicates that the trial combination could be near to the ideal value is used to find suitable value of the factors are as follows:

The values in red shows the optimal parametric the graph below shows each factor in each column affect the response. D indicates the composite desirability and d is the individual desirability.

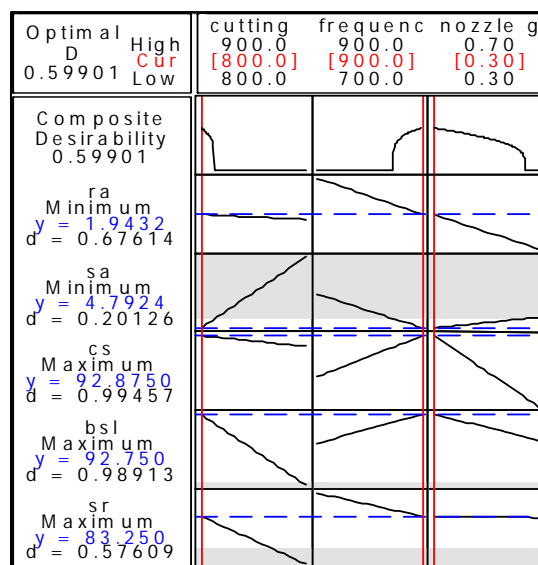


Figure.4. Response optimization

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V .CONCLUSION

1. Optimum parameter obtained to meet the requirement for cutting of 10 mm thickness AISI321 are cutting speed at 800mm/m frequency about 900 Hz and nozzle gap is 0.3 mm. Fine cutting was obtained as shown in figure 2(b).where as rough cutting surface obtained which is undesirable shown in figure 2(a)
2. Cutting speed, Nozzle gap, frequency has major effect on surface roughness.
3. Hardness of material is affected mainly by cutting speed and frequency in laser cutting.
4. Nozzle gap and cutting speed affects the hardness at the lower cut striation portion.

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BIOGRAHY



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