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Analysis of Surface roughness and Kerf tapper in CO2 laser cutting of SS304

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ABSTRACT

This article presents the effect of cutting speed on Kerf Taper and surface roughness in laser cutting of SS304. Experimental plan design by using the Taguchi method .Test samples were cut with varying cutting speed, Power and Pressure while other process parameters like Plate thickness and Beam diameter etc. remained constant. Surface roughness of each test sample was measured in several places along cut depth. Measure kerf taper by using Travelling microscope. Results were analyzed, discussed and conclusions regarding the effect of cutting Speed, Power and Pressure on surface roughness and Kerf Tapper by using the Taguchi Method.

Keywords: **Co_2 laser, Stainless steel 304, Surface roughness (Ra), Kerf Tapper (kf).**

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I. INTRODUCTION

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation which describes the theory of laser operation. One of the applications of laser is laser machining. The cost of cutting hard-to-machine materials by conventional mechanical machining processes is high due to the low material removal rate and short tool life, and some materials are not possible to cut by the conventional machining process at all. Laser beam machining is the machining processes involving a laser beam as a heat source. [1]

Present day, laser cutting is widely used in industrial applications, being one of the most significant and rapidly developing modern material cutting methods alongside abrasive water-jet cutting. This is due to its numerous advantages, such as high cutting precision, possibility to cut complex shapes, low kerf width, lack of presence of mechanical cutting forces, lack of tool wear, perpendicular, sharp cut edges and narrow heat-affected zone in cut material [2, 3,4]. Laser cutting can be used to cut a variety of different materials like mild steel, alloy steels, nickel alloys, aluminum and even very hard materials difficult to machine otherwise, such as CBN (cubic boron nitride) [4, 5, 6, 7]

However, choosing the optimum laser for an application may not be case of simply selecting the highest beam quality at the required power level. When the application requires a very fine cut with good edge quality a combination of good beam quality and a small spot size is required. [8] The wider kerf width produced using a larger spot size increases the volume of ejected material and also would generate cuts of good quality but at much reduced assist gas consumption. Processing parameters include the characteristics of the laser cutting process that can be modified to improve the quality of the cutting process and achieve the required results of cutting.[9] The parameters of the laser cutting process can be classified into four major categories: specified parameters of laser cutting, input parameters of laser cutting, operating parameters of laser cutting and output parameters of laser cutting.[9] The specified parameters of laser cutting are: gas type, gas purity, gas pressure, the diameter and shape of the nozzle. Gas pressure and the shape of the nozzle have an effect on the roughness of the cut. The consumption of cutting gas depends on gas pressure and diameter of the nozzle. Cutting by low pressure gas requires the pressure of up to 5 bars, whereas in cutting by high pressure gas, the pressure can reach 20 bars. Operating parameters of laser cutting with which the quality of cutting can be optimized are: focus position, laser power, gas pressure, feed rate and the distance between the nozzle and the cutting surface. Original cutting parameters are optimized to ensure maximum reliability of the process. Each laser is supplied with a set of cutting parameters. Cutting parameters are given for the materials of specific type and thickness. For materials for which the laser manufacturer did not provide the recommended values, new cutting parameters could be set.[9,10,11,12]

Cutting parameters are scalar values which have a direct effect on the process of cutting. In order to properly modify the cutting parameters it is important to know how the part has been programmed and which cutting technology is used. The cutting of new material must be preceded by experimental cutting. If any problems concerning the quality of cutting should arise in the experimental phase, they can be fixed by adjusting the original cutting parameters. The optimization of cutting parameters can be derived from the existing samples, and their recommended

II. LITERATUREREVIEW

Hitashi ozaki et (2012) Experiment was conducted on CO2 laser cutting machine & working material as a SS-304 and analyze the effect of input parameter such laser type, power, focal length of lens, piercing time, cutting speed cut length on output parameters like kerf taper and heat affected zone. From the experience it was concluded that increase in laser power lead to increase the critical cutting speed. When the heat input was increased the kerf width & remove area of kerf was also increased. When the laser power was decreased or cutting speed was increased the rate of pressure rise in the chamber during cutting process decreased. The laser power was increased also heat affected zone increase. Speed was increased there HAZ decreases.[13] **S. Saravanakumar et (2015)** has investigate the effect of input parameter like laser power, laser cutting speed, Laser gas pressure on kerf width heat affected zone. Experiment was conducted on Co2 laser cutting machine and working material was SS304. After experiment it was concluded that quality of cut as critical issue in laser cutting process. Decrease laser power & feed then decreases the heat affected zone. [14] **A.M. sifullah et (2016)**In this investigation they will use the CO2 laser cutting machine & working material is SS-304. Has investigate the effect of input parameters on cutting speed, laser power on heat affected zone, stress concentration. It was concluded that thermal analysis show that width of heat affected zone increases with increase in laser power & heat affected zone decrease with increase in feed.[15]**Krzysztof Jarsoz et (2016)** In this investigation they will use the CO2 laser cutting machine & working material is SS-304 and analyze effect of laser power, gas pressure, nozzle diameter, nozzle standoff, focal length on output parameters like kerf width and heat affected zone, surface roughness. From this experiment it was concluded that decreasing cutting speed to increase heat affected zone and kerf width. Increasingcutting speed produced good surface cut. [16]**Umang V Patel et (2014)** In this paper they was use co2 cutting machine and working material SS304. From experiment it was concluded that in the machining process the power is most affected parameter on surface roughness.[17] **Rasmi Rajan Behera et(2014)** In this investigation they will use the CO2 laser cutting machine & working material is SS-304. They will selected input parameters are laser pulse energy , water layer thickness, scanning speed ,scanning pass number and output parameters are kerf width ,kerf depth and surface roughness from this experiment it was concluded that water layer thickness increases kerf width , kerf depth and surface roughness decreases . Scanning speed increases kerf depth and surface roughness decreases. [18]**Dhaval P. Patel et (2012)** In this investigation they will use the CO2 laser cutting machine & working material is SS-304. For experiment, selected input parameters are material thickness,gas pressure, laser power, cutting speed and output parameter is kerf width.From thisexperiment it was concluded that power and cutting speed increases kerf width goes on decreases. [19]

III. EXPERIMENTAL SETUP

3.1 Selection of machine

The experiments were conducted on CNC laser cutting machine Trulaser 3030(L20), Trumpf at Kakade Engineering Company.This machine used a 10.6 µm wavelength CO2 laser with a nominal power output of 2900W at pulsed mode. Focal length of lens used was 127 mm, nozzle diameter (1.0 mm), stand-off distance (4 mm), and material thickness (5 mm) were kept constant throughout the experimentation. A 5 mm thick Stainless steel-304 was used as workpiece material. Technical Specification of laser cutting machine is given in Table 1

3.2 Selection of Material

Table No 1

1.	Maker	TRUMPF
2.	Type	Trulaser 3030(L20)
3.	Laser rated output (W)	2100
4.	Laser maximum output (W)	2400
5.	Pulse peak power (W)	2900 (Note 1)
6.	Pulse Frequency	0-35267Hz
7.	Pulse duty	0-100%
8.	Laser wavelength	12.6 µm
9.	Beam mode	Low order mode
10.	Beam diameter at exit (mm)	≤25
11.	Polarization	45˚ linear
12.	Net weight	12000kg
13.	Laser gas	CO2
14.	Input power supply	AC 220V+10%, -15% 60Hz
15.	Power supply capacity	33 kg
16.	X – Axis Travel	3000 mm
17.	Y – Axis Travel	1500 mm
18.	Z-Axis Travel	115mm

SS- 304 has selected as workpiece material due to lower carbon which minimize carbide precipitation. SS-304 has used in high-temperature applications and widely utilized material for sheet metal operation for various industrial and household applications like screws, machinery parts, car headers, and fabrication of electronics components. The chemical composition of the SS-304 is provided in Table 2

Table 2 Chemical composition of the SS-304

Element	C	Si	Mn	P	S	Cr	Ni
% Composition	0.08 %	0.75 %	2.00 %	0.045 %	0.03 %	18-20 %	8-10.5 %

3.3 Selection of Response Parameters

To perform experiment input parameters are Gas pressure, Power, Cutting Speed .The values of the parameters that have varied during the execution of experiments are shown in Table 3.

Cutting speed (Vc) It is a travel of a point on the cutting edge relative to the surface of cut in unit time in the process accomplishing the primary cutting motion. It is expressed in mm/min.

Gas Pressure (P) Pressure is the expression of force exerted on a surface per unit area. Symbol of pressure is P and unit is Kg/cm2.

Power (po) The rate which electric energy transfer (Kw)

Table 3 Laser cutting variables and their levels

Sr. No.	Factors	Levels		
		Low level (1)	Medium level (2)	High level (3)
1.	Gas Pressure (N/mm^2)	14	15	17
2.	Power (W)	3000	3000	2800
3	Cutting Speed (mm/min)	1200	1300	1470

3.4 Response Parameters

Surface Roughness (Ra)

It is component of surface texture. It is qualified by vertical deviation of real surface from its ideal form. Unit is micrometer.

Kerf taper (Kf)

Kerf taper is special and undesirable geometrical feature inherent to laser beam machine. It is angle which ranges from 0.1 to 2 ^{0} in normal condition and measured in degree.

3.5 Design of experiment

Design of experiment based on Taguchi method: In this investigation experiment are carried out by varying three control factors Cutting speed, gas pressure and input power on laser cutting machine.Full factorial design of experiments would require a large no. of runs; Hence Taguchi based design of experiment method was implemented. Taguchi method Orthogonal Array provides a set of well-balanced experiments, and Taguchi's signal-to-noise. (S/N) ratios, which are logarithmic functions of the desired output, serve as objective functions for optimization. It helps to learn the whole parameter space with a minimum experimental runs. Taguchi replaces the full factorial experiments with a lean, less expensive, faster partial factorial experiment. The reason for the choice of the array are listed in following

- The array gives minimum number of experiment to be performed with factor level chosen as per the experiment.
- It does not have any mixed level.
- It considers necessary effect.

Experimental plan selected by using MINITAB 17 Software. For three parameter and three level L9 orthogonal array is available. The array depicted by L_9 (3^3) form Taguchi's standard orthogonal array, has been chosen.L9 orthogonal array shown in following table.

Table 4 Experimental Plan Taguchi L9 Orthogonal Array

Exp. No.	Power W)	Cutting Speed (mm/min	Gas Pressure (N/mm2))
1	2800	1200	14
2	2800	1320	15
3	2800	1470	17
4	2900	1200	15
5	2900	1320	17
6	2900	1470	14
7	3000	1200	17
8	3000	1320	14
9	3000	1470	15

3.6 Experimental Result

A series of experiments were performed under the experimental plan to analyze the influence of the process parameters upon processed surface roughness and kerf tapper and to obtain a complex relationship to show roughness variation according to these parameters. The combination of factors was chosen as per orthogonal array. Eachexperiment was repeated randomly and twice under identical environments conditions.

After performing experiment as per L_9orthogonal array, the response variables or output are surface roughness and kerf tapper tabulated in Table 5

Table 5 Experimental results

Exp. No.	Power (W)	Cutting Speed (mm/min)	Gas Pressure (N/mm2)	Kerf Taper (°)	Surface roughness (μ)
1	2800	1200	14	4.59	3.335
2	2800	1320	15	1.15	2.855
3	2800	1470	17	1.33	3.940
4	2900	1200	15	7.14	3.545
5	2900	1320	17	3.585	1.457
6	2900	1470	14	9.14	5.176
7	3000	1200	17	2.435	2.562
8	3000	1320	14	2.57	3.906
9	3000	1470	15	8.99	6.231

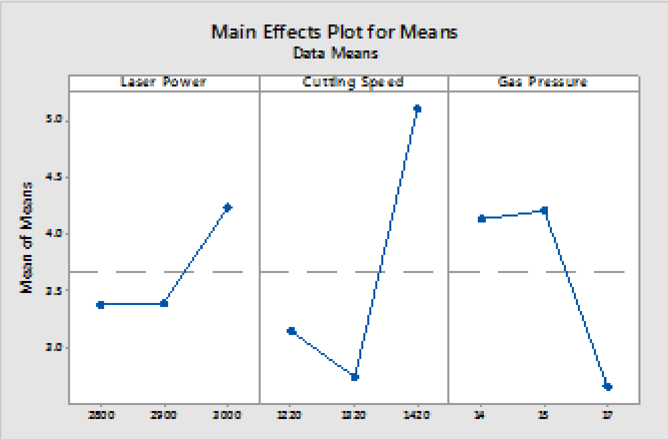

Figure 1 Main effect plot for Ra

Basic main effect plot are drawn in Figure 1 where relationship between surface roughness versus Laser power, Cutting speed and Gas pressure respectively is shown. As power increases surface roughness remain same From2800W to 2900W after that surface roughness goes on increases as power increases. For cutting speed surface roughness goes on decreases from 1200 mm/min to 1320 mm/min of cutting speed after that surface roughness goes on increases as cutting speed goes on increases. For gas pressure surface roughness goes on increases up-to 15 N/mm^2 and then goes on decreases as gas pressure goes on increases.

Basic Main effect plot for kerf tapper are drawn in Figure 2 where relationship between Kerf Tapper versus Laser power, cutting speed and Gas pressure respectively is shown. As power increases kerf tapper goes on increases up-to 2900W after that Kerf Tappergoes on decreases. For cutting speed Kerf Tapperfirstly goes on decreases up-to cutting speed 1220 mm/min then kfgoes increases as cutting speed increases. For gas pressure Kerf Tapper goes on increases up-to 15 N/mm^2 and then goes on decreases as gas pressure increases.

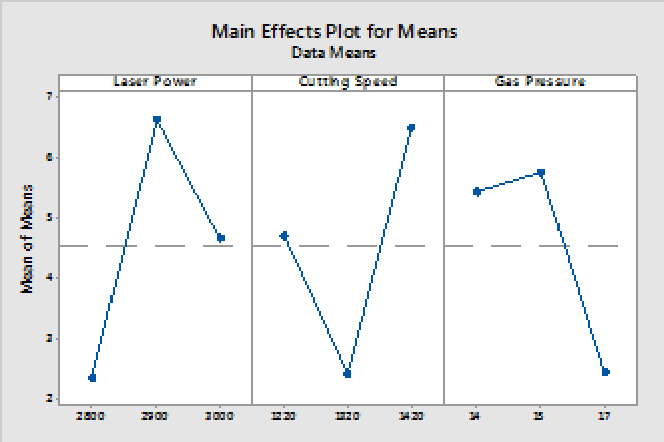

Figure 2 Main effect plot for Kf

4. Analyses of Experimental Data

Basic statistical techniques of S/N ratio is used for predicting the significant and sub significant parameters for each of performance characteristics

Response Table 6 for Signal to Noise Ratios for Ra

Level	Power	Cutting Speed	Gas Pressure
1	-10.495	-9.875	-12.192
2	-9.514	-8.072	-11.999
3	-11.966	-14.027	-7.784
Delta	2.452	5.955	4.409
Rank	3	1	2

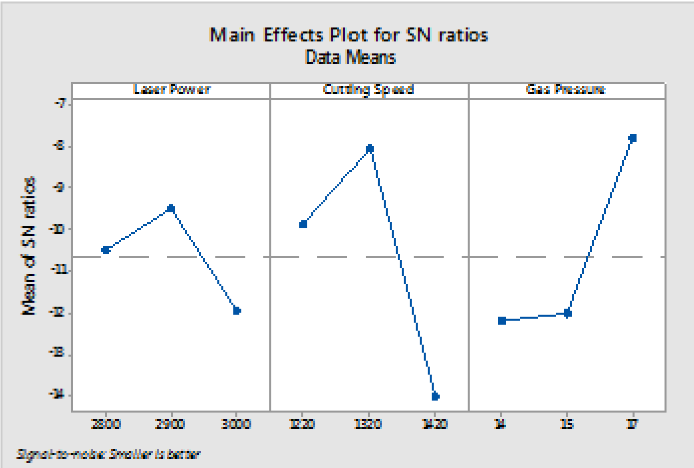

Figure 3 Main effect plot for S/N ratio (Ra)

Response table for signal to noise of surface roughness is shown in Table 5 and for Surface roughness, calculation of signal to noise follows "Smaller to better" model The main S/N for surface roughness is shown in Figure 3 as main effect plot. It shows the main effect on surface roughness which is primarily due to cutting speed. The Laser power and Gas pressure found to be insignificant from main effect plot. The greater is the S/N ratio; larger is variance of the surface roughness around the desired values. Optimal result could be found out from the main effect plot by selecting the highest levels of S/N ratio values. Therefore, based on the S/N analysis, the optimal process parameters for surface roughness are as follows: Laser Power at level 2(2900W), cutting speed at level 2(1320 m/min) and Gas Pressure at level 3 (17N/mm^2).

Response Table7.for Signal to Noise Ratios for Kf

Level	Power	Cutting Speed	Gas Pressure
1	-5.642	-12.680	-13.551
2	-15.794	-6.834	-12.454
3	-11.668	-13.590	-7.099
Delta	10.152	6.756	6.452
Rank	1	2	3

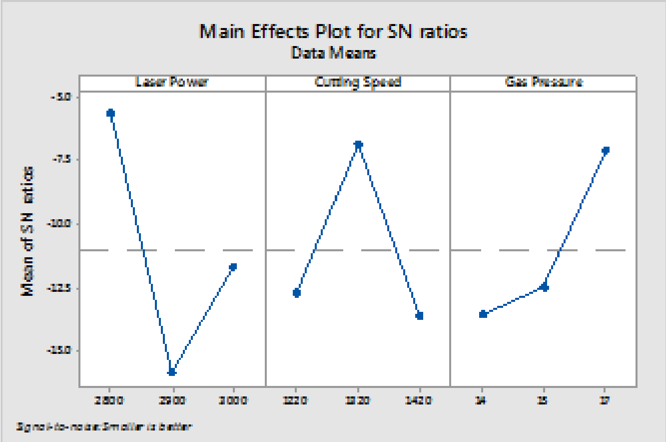

Figure 4 Main effect plot for S/N ratio (Kf)

Response table for signal to noise of Kerf Tapper is shown in Table 7 and for Kerf Tapper, calculation of signal to noise follows "Smaller to better" model

The main S/N for Kerf Tapper is shown in Figure 3 as main effect plot. It shows the main effect on Kerf Tapper which is primarily due to Laser Power. The Cutting Speed and Gas pressure found to be insignificant from main effect plot. The greater is the S/N ratio; larger is variance of the Kerf Tapper around the desired values. Optimal result could be found out from the main effect plot by selecting the highest levels of S/N ratio values. Therefore, based on the S/N analysis, the optimal process parameters for Kerf Tapper are as follows: Laser Power at level 1 (2800W), cutting speed at level 2(1320 m/min) and Gas Pressure at level 3 (17N/mm^2).

IV. CONCLUSION

Basically, surface roughness, kerf tapper are strongly correlated with cutting parameter such as cutting speed, laser power and Gas pressure. Hence, optimization of process parameter based on the parameter design of the Taguchi method is adopted. The optimal level of process parameter is the level with highest signal-to-noise ratio according to Taguchi orthogonal array design. Similarly. From experimental study it was concluded that for surface roughness most significant factor is cutting speed followed by Gas pressure and Power. For kerf tapper most significant parameter is Laser power followed by Cutting speed and Gas pressure.

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