Experimental investigation of kerf width in CO_2 Laser Cutting using RSM

Manchala sadasivan Raviteja[1], A.Bhargav[2]

[1]*Assistant professor, Production Engineering and Engineering design, Mechanical Engineering Department, Dhruva Institute of Engineering & Technology (India)*

[2]*Assistant Professor, Production Engineering, Mechanical Engineering Department, Mits engg. College, Madanapally (India)*

ABSTRACT

Laser machining process is one of the subtractive manufacturing processes. The LBM is a thermal separation process. The laser machining could be used for processing variety of materials especially thermally and electrically conducting or non-conducting and also low reflectivity, which other unconventional machining process were not able to machine them by WEDM, USM, EDM, ECM, PAM...etc.,

AISI-304L (Austenitic Stainless Steel) is one of the engineering metals it has a high melting point and high toughness metal. So, further Laser processing of this AISI-304L material is the best suitable metal. The cutting parameters are highly affects the output responses like Kerf width, edge quality, HAZ and hole taperness...etc., were the characteristics used to analyze the quality of job. In this research 2.0 mm AISI-304L is cut with CO_2 laser. Laser power, cutting speed, gas pressure and focal distance are to be variable parameters for this research. The main aim of this research is to narrate these conditions to formation of Kerf width as minimum as possible. By using the optimization tool like RSM to minimizing the Kerf width.

Keywords: CO_2 Laser, AISI-304L, Optimization, and RSM.

I. INTRODUCTION

Laser cutting is one of the most consistent advanced manufacturing technologies for industrial productions and has experienced a numerous changes since its starting in the 1970s. Laser cutting is an unpredictable process which is characterized by various parameters and these parameters will decide the efficiency of the entire process in terms of productivity, cut quality and cost. Maximizing the productivity and cut quality along with minimization of the cost are the main particulars of manufacturers [1]. The practical and theoretical background will support in the systematically selection, laser process

parameters are generally chosen based on the handbook values. The optimal cutting parameters are set for achieving a desired goal. Improper selection of cutting parameters causes high manufacturing costs, low product quality and high waste and on the other hand, the suitable selection of these parameters results in enhancement of the end product quality [2]. Consequently, it has the more significance to precisely evaluate the relationship between laser cutting parameters and cutting performance through mathematical model and subsequently determinate the optimal or near-optimal cutting parameters through the use of optimization method.

II. LASER PRINCIPAL

A laser beam is produced in a glass tube with a mirror at both the ends. The laser gas is passed into the glass and spread by a turbine. The laser gas is a combination of carbon dioxide, nitrogen and helium. This combination of laser gas is usually known as a CO_2 laser. There are a few other lasing gas combinations available and in use, but only for high powered industrial lasers, the CO_2 mixture is the most commonly used. An external power source, such as the electrical power (DC power) or radio frequency (RF generator) that excite the atoms in the laser gas which release the excited atoms in the laser gas mixture. When the atoms of the laser get excite, the stimulated gas atoms give off a photon of 17 lights. This photon excites other atoms and gives more photons. This is in the form a chain reaction [3].

The photons produced moves between the two mirrors in the glass tube until a portion escapes through it partially reflective mirror. The laser beam is focussed onto the workpiece to be cut by matching the focal length of the laser beam to the depth of the cut result in high productivity and the best cut quality [4].

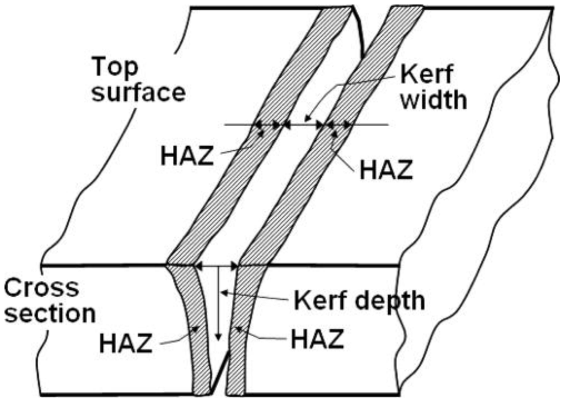

Fig. 2.1 Principle of Laser cutting

III. EXPERIMENTATION ON AUSTENITIC STAINLESS STEEL 304L

The stainless steels are widely used in engineering materials. However, steels are not easy to cut by oxy-fuel method due to higher melting points and low viscosity of the formed oxides. It can be cut by the laser cutting process high accurately [5].

Table 3.1: Composition of AISI 304L

Elements	304L % of weight
Chromium	18.0 min – 20.0 max
Nickel	8.0 min – 12.0 max
Carbon	0.030
Manganese	2.00
Phosphorus	0.045
Sulphur	0.030
Silicon	0.75
Nitrogen	0.10
Iron	Bal

Austenitic stainless steels exhibit superior corrosion resistance, oxidation resistance, and good tensile and creep properties. These steels have greater thermal expansion and heat capacity, with lower thermal conductivity than other stainless. Austenitic stainless steel is chosen as the material for investigation as it finds widespread applications in petroleum refining, various manufacturing industries, mining, power generation-nuclear, pulp and paper industries, chemical and petrochemical processing-pressure vessels, heat exchangers, piping systems, flanges, fittings, valves and pumps and medical industries and in high temperature applications. The literature survey indicates that no research work has been carried out on the material proposed.

This project will use AISI 304L as material that needs to cut. Austenitic stainless steel is a one of the types of Stainless Steel.

Table3.2: Experimental Conditions

Factors	Units	Levels		
		-1	0	1
Power	KW	1.6	1.8	2.0
Cutting Speed	mm/sec	4000	4250	4500
Gas Pres.	Bar	2.0	2.5	3.0
Focal Dist.	mm	0.4	0.55	0.7

For the above table the input values are coded by using MINITAB 14 and the coded values are displayed in below table 3.3

Table 3.3: Coded values of input values

Power KW	Cutting Speed mm/sec	Gas Pres. bar	Focal Dist. mm
1.6	4000	2.0	0.4
1.6	4000	2.5	0.55
1.6	4000	3.0	0.7
1.6	4250	2.0	0.55
1.6	4250	2.5	0.7
1.6	4250	3.0	0.4
1.6	4500	2.0	0.7
1.6	4500	2.5	0.4
1.6	4500	3.0	0.55
1.8	4000	2.0	0.55
1.8	4000	2.5	0.7
1.8	4000	3.0	0.4
1.8	4250	2.0	0.7
1.8	4250	2.5	0.4
1.8	4250	3.0	0.55
1.8	4500	2.0	0.4
1.8	4500	2.5	0.55
1.81	4500	3.0	0.7
2.0	4000	2.0	0.7
2.0	4000	2.5	0.4
2.0	4000	3.0	0.55
2.0	4250	2.0	0.4

International Journal of Advanced Technology in Engineering and Science
Vol. No.5, Issue No. 07, July 2017
www.ijates.com
ijates
ISSN 2348 - 7550

2.0	4250	2.5	0.55
2.0	4250	3.0	0.7
2.0	4500	2.0	0.55
2.0	4500	2.5	0.7
2.0	4500	3.0	0.4

IV. RECORDING THE RESPONSES

In the wake of leading the tests according to the outline grid, for measuring the yield reactions i.e. cut edge qualities, for example, Kerf width, HAZ, Surface roughness and burr height. The genuine cut example is indicated in Figure 4.2. At that point the Kerf width was measured utilizing Optical microscope as demonstrated as a part of Figure 4.1. For every reaction the readings were measured at three separate segments of the cut [6]. The study is centred to explore the impacts of methodology variables on the structures of the every cut. A normal of three estimations taken at three better places and the yield reactions are recorded for every situated. The yield reactions recorded are indicated in the Table 4.1.

It is a microscope with the light source at base and it has a condenser on the top which is pointing downwards while the objective is under the stage indicating upwards. It has the inverted optical microscope is generally focussed by adjusting and moving the objective lens along a vertical axis and horizontal axis to bring it nearer to the specimen. The focus mechanism normally adjusted by dual concentric knob for coarse and fine modification. It is has a camera at the top to take the images of the workpiece

Fig. 4.1 Inverted Optical microscope

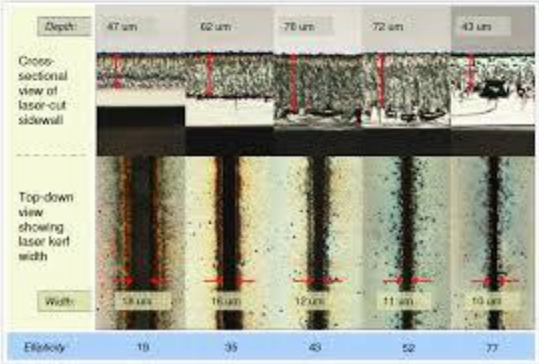

Fig. 4.2 Response of Kerf width

Table 4.1: Measured Kerf width using Microscope

Run Order	Input Variables				Output Variable
	Power KW	Cutting Speed mm/sec	Gas Pres. bar	Focal Dist. mm	Kerf width
1	1.6	4000	2.0	0.4	381.51
2	1.6	4000	2.5	0.55	375.57
3	1.6	4000	3.0	0.7	376.57
4	1.6	4250	2.0	0.55	373.62
5	1.6	4250	2.5	0.7	371.02
6	1.6	4250	3.0	0.4	383.05
7	1.6	4500	2.0	0.7	367.03
8	1.6	4500	2.5	0.4	381.42
9	1.6	4500	3.0	0.55	378.81
10	1.8	4000	2.0	0.55	375.58
11	1.8	4000	2.5	0.7	367.79
12	1.8	4000	3.0	0.4	377.7
13	1.8	4250	2.0	0.7	366.48
14	1.8	4250	2.5	0.4	378.61
15	1.8	4250	3.0	0.55	377.61
16	1.8	4500	2.0	0.4	379.07
17	1.8	4500	2.5	0.55	377.17
18	1.81	4500	3.0	0.7	379.07
19	2.0	4000	2.0	0.7	367.78
20	2.0	4000	2.5	0.4	377.72
21	2.0	4000	3.0	0.55	373.71
22	2.0	4250	2.0	0.4	381.28
23	2.0	4250	2.5	0.55	374.38
24	2.0	4250	3.0	0.7	373.69
25	2.0	4500	2.0	0.55	375.23
26	2.0	4500	2.5	0.7	375.34
27	2.0	4500	3.0	0.4	367.73

V. OPTIMIZATION

5.1 Modelling and Optimization Tools in Laser Cutting: A Brief Review

To enhance the quality with least manufacturing costs, timing, higher productivity and process safety, setting the process parameters essentially in the best possible way. These days most of the industries are utilizing completely automated and computer-controlled machines to accomplish the requirements of the competitive market. Higher productivity with least manufacturing cost can be obtained by the selection of process parameters, so these optimum parameters play an essential role in the product quality.

Modelling and optimization of process is usually a very difficult task for the manufacturing process parameters, machine specifications, development of an effective optimization conditions, empirical equations to develop realistic constrains and knowledge of numerical and mathematical optimization techniques have to be essential [7]. Researchers have created a huge number of optimization techniques and solved the different models of parameter optimization problems.

5.2. Response Surface Methodology (RSM)

This is design and model methods which work consistently for finding the optimal goal (Oehlert 2000). Main objective of this method is to find the optimum response. If there are multiple responses then we have to find the significant compromise optimization, which do not optimize only one response (Oehlert 2000). When there is limitation in the data design, then the experimental design has to convene the requirements of that restricted data. Another objective is to recognize, how the response changes for the specified inputs by changing the design values [10].

If there is a curvature in the response surface, then a higher degree polynomial should be used. The approximating function with 2 variables is called a second-order model:

$y = \beta0 + \beta1x1 + \beta2x2 + \beta12x1x2 + \beta11x12 + \beta22x22 + \varepsilon$

In general all RSM problems use either one or the mixture of the both of these models.

$$\begin{aligned} y_{kerf\ width} = {} & 425.16425 + 63.2837x_1 - 5.24815E - 003x_2 + 37.58452x_3 \\ & - 497.8437x_4 - 8.87556E - 003x_1x_2 - 26.5022x_1x_3 \\ & + 63.00741x_1x_4 - 3.31378E \end{aligned}$$

Table 5.1: ANOVA [Partial sum of squares] for Kerf width

Source	Sum of Squares	d. f.	Mean Square	F-Value	Prob> F
Model	570.69	8	70.82	48.29	<0.0001
X_1	26.26	1	26.26	17.90	0.0005
X_2	3.05	1	3.05	2.08	0.1664
X_3	21.98	1	21.98	14.99	0.0011
X_4	226.06	1	226.06	154.14	<0.0001

X_1X_2	2.22	1	2.22	1.59	0.2250
X_1X_3	79.02	1	79.02	56.81	<0.0001
X_1X_4	40.20	1	40.20	28.90	<0.0001
X_2X_3	1.93	1	1.93	1.39	0.2560
X_2X_4	50.76	1	50.76	36.50	<0.0001
X_3X_4	145.94	1	145.94	104.93	<0.0001
Residual	22.25	16	1.39		
Cor Total	592.94	26			
Std. Dev.	1.18			R^2	0.9625
Mean	375.37			Adj. R^2	0.9390
* - Refers to Significant terms					

From Table 5.1, balanced R^2 Kerf width is discovered to be 0.9625. It can be watched that the estimations of R^2 and balanced R2 are closer to one another [11].

The created numerical models are further checked for their ampleness utilizing typical normal plot of residuals. Therefore the typical normal plot of residuals for the reactions, Kerf width was plotted. Ordinary normal plots are utilized to survey whether information originate from the typical distribution. Hence ordinary normal plots can give confirmation that the suspicion is supported. An investigation of ordinariness normally consolidates ordinary normal plots with speculation tests for typicality. In an ordinary normal plot, if all the information focuses fall close to the line, a presumption of ordinariness is sensible. Something else, the focuses will bend far from the line, and a suspicion of ordinariness is not adequate [12].

5.1.1. Normal plot of residuals for Kerf width

The normal probability plots and residuals to the output response of Kerf width are given below Fig.5.1.1. By this plot, the values of residuals are falls on the straight line which means that the errors are allocated normally [13]. This represents that the proposed model is satisfactory for the given conditions and it doesn't suspect that it is violate and the relationship between the predictor and response are variance assumption amongst the response.

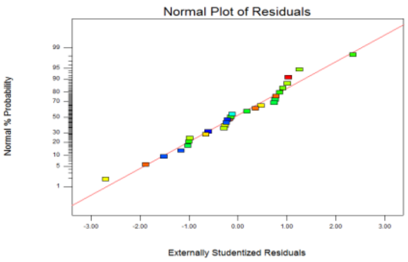

Fig. 5.1 Normal probability plot of residuals for Kerf Width

5.1.2. Residual Vs Run graph

Residual with reverence for the test data run for the value of Kerf width is studied. The residual do not illustrate the conspicuous pattern and they are allocated in the positive and negative directions. This implicatively indicate the models are satisfactory and there are no causes to suspect any correlation graphs attained for quality attributes with the different slots clearly demonstrates the prognostication made by the mathematical models are in excellent accordance with the experimental values.

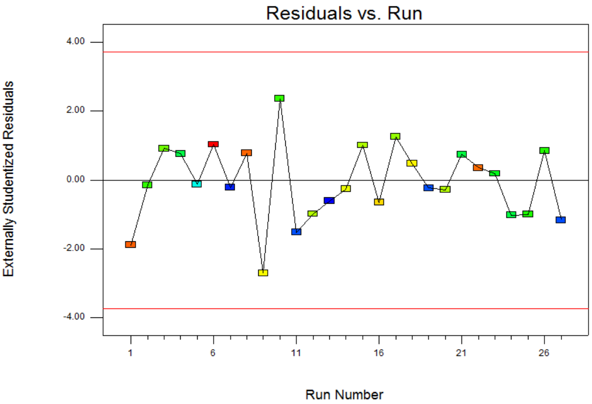

Fig. 5.2 Residual Vs Run graph

VI. RESULTS AND DISCUSSIONS

The following section explains the major interaction effects of the Cutting parameters on the chosen responses. The above developed models have been working to forecast the Kerf Width for the range of parameters used in the examination. By these models, the major effects of these process parameters on Kerf Width is calculated and plotted.

Design Expert, 9.1v, statistical analysis software is used for evaluating the effects. The result shows the normal tendency between the causes and effects.

CONCLUSIONS

In the present study, Design based experiments and analysis have been carried out in order to optimize Kerf width considering the effects of cut edge quality parameters like cutting speed, Laser power, gas pressure, focal distance. The experiments are carried out by as per Central Composite Design to significantly reduce the number of experiments.

- The initial process parameters to the optimal process parameters are 383.05 microns for Kerf width using RSM. Based on the results of conformation test, the Kerf width is reduced to 382.713 microns
- Regression methods are proposed statistically significant and satisfactory because of superior values of R^2. Normal probability plot vs. residuals of model shows that the residual values are reasonably nearer to a straight line implying the conditions mentioned in the model are significant.
- It is demonstrated that the multiple performance characteristics of laser cutting process like Kerf width is greatly reduced together by using this approache

REFERENCE

1. John C., "Laser processing of engineering materials". 1st edition 2005, Elsevier Butterworth Heinemann.
2. B.S. Yilbas., F. Al-Sulaiman., C. Karakas., M. Ahsan., "Laser cutting of multilayered kevlar plates" Journal of Materials Engineering and Performance, Vol. 16, No. 6, pp. 663-671, 207
3. William., Jyothimoy., Mazumdar., "Laser material processing" Springer 4th edition.
4. Huang Q, Hagstroem J, Skoog H, Kullberg G. "Effect of laser parameter variation on sheet metal welding". J Join Mater 1991;3(3):79–88.
5. K. Abdel Ghany., M. Newishy., "Cutting of 1.2 mm thick austenitic stainless steel sheet using pulsed and CW Nd:YAG laser", J. Mater. Process. Technol. 168 (3) (2005) 438–447.
6. Avanish kumar., Dubey.,Vinod yadav., "optimization of Kerf quality during pulsed laser cutting of aluminium alloy sheet" journal of material processing technology(2008) pg. No.412-418
7. Samanta., Chakraborty., (2011) "Parametric optimization of some non-traditional machining processes using artificial bee colony algorithm" Eng Appl Artif Intell 24(6):946–957.
8. Indrajit., Mukherjee., pradip kumar ray., "A review of optimization techniques in metal cutting processes" Volume 50, Issues 1–2, May 2006..
9. Tong KW., Kwong CK., (2004) "Process optimisation of transfer moulding for electronic packages using artificial neural networks and multiobjective optimisation techniques". Int J Adv Manuf Technol 24:675–685
10. K. Huehnlein., K. Tschirpke., R. Hellmann., "Optimization of laser cutting processes using design of experiments", Physics Procedia, Vol. 5, No. 2, pp. 243-252, 2010
11. A. I. Khuri., & J.A. Cornell., "Response Surfaces Design and Analysis", 2nd ed,Marcel Dekker, New York, (1996).
12. Adalarasan R., Santhanakumar M., (2015) "Application of Taguchi based response surface method (trsm) for optimization of multi responses in drilling Al/SiC/Al2O3 hybrid composite". J Inst Eng (India): Series C 96(1):65–71.
13. Santhanakumar M., Adalarasan., Rajmohan M., (2016) "Parameter design for cut surface characteristics in abrasive water jet cutting of Al/SiC/Al2O3 composite using grey theory based RSM". J Mech Sci Technol 30(1):371–379
14. Kosko B., (1994) "neural networks and fuzzy systems". Prentice-Hall of India, New Delhi, India.
15. Kim DH., Kim DJ., Kim BM., (1999) "The application of neural networks and statistical methods to process design in metal forming processes". Int J Adv Manuf Technol 15:886–894
16. MATLAB neural network toolbox, The MathWorks Inc., Prentice-Hall, Englewood Cliffs; 1998.