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Parametric Investigation and Modelling of Hardness and Surface Quality in CO_2 Laser Cutting Process of AISI 314 Stainless Steel

V. Senthilkumar[1,*] and G. Jayaprakash[2,†]

[1]Department of Mechanical Engineering, TRP Engineering College, Tiruchirapalli, India
[2]Department of Mechanical Engineering, Saranathan College of Engineering, Tiruchirapalli, India

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Abstract: *Laser cutting is the popular unconventional manufacturing method widely used to cut various engineering materials. In this work CO_2 laser cutting of AISI 314 satinless steel has been investigated. This paper focus on the investigation into the effect of laser cutting parameters like laser power, assist gas pressure, cutting speed and stand-off distance on surface roughness, hardness and kerf dimensions like kerf width, kerf ratio and kerf taper in CO_2 laser cutting of AISI 314 stainless steel.*

Keywords: CO_2 Laser cutting, laser power, assist gas pressure and cutting speed, stand-off distance, surface quality, hardness, AISI 314 stainless steel

I. INTRODUCTION

Laser machining is a widely used thermal based process. It is used for processing a wide variety of engineering materials which posses considerable advantages over conventional machining processes in terms of low cost, short processing time and precision [1]. Laser cutting process involves process of heating, melting and evaporation by focusing laser beam onto the workpiece surface. It is capable of cutting complex shapes on almost all the materials. Among all type of laser, CO_2 laser is able to cut metals with wide range of thickness and with good quality [2]. AISI 314 stainless steel plays a vital role in manufacturing of radiant tubes, furnace conveyer belts, insulation holding studs, annealing and carburizing boxes etc., due to its high temperature, corrosion and oxidation resistance. Machining of stainless steel with laser cutting is a difficult task as it exhibits reflective properties which resists narrow cutting. The objective of this work is to analyze the effect of the laser cutting parameters on hardness, surface roughness and kerf dimensions like kerf width, kerf taper and kerf ratio in CO_2 laser cutting of AISI 314 stainless steel.

2. LITERATURE REVIEW

Laser cutting has been a major research area for marking out exceptionally good quality of cut like reduced surface roughness, kerf dimensions like kerf width, kerf taper, kerf angle and it depends on the setting of process parameters like cutting speed, assist gas pressure, laser power, stand off distance etc. Dong-Gyu and Byun Kyung-Won [3] compared laser beam cutting assisted by nitrogen and oxygen. They found that nitrogen produces smaller kerf with good surface finish. Riveiro et. al. [4] investigated CO_2 laser cutting of 2024-T3 alloy and found that quality of cut can be obtained by high cutting speed and laser power. K.A. Ghany & M.Newishy [5] used pulsed and CW Nd:YAG laser to cut of 1.2 mm thick stainless steel sheet. They predicted that increasing the cutting speed & frequency and decreasing the laser power & gas pressure reduces the surface roughness value. Arun Kumar Pandey and Avanish Kumar Dubey [6] optimized kerf taper and surface roughness for the laser cutting of titanium alloy sheet. They observed that good surface finish can be obtained by lower pulse frequency, higher cutting speed and moderate gas pressure. N. Rajaram et. al. [7] considered CO_2 laser cut quality of 4130 steel and concluded that lower feed rate and high power produce products with good surface finish. Stournaras et. al. [8] examined the quality of laser cutting of aluminium and found that laser power and cutting speed are responsible for the amount of heat in the cutting regime and they play a major role on the cutting quality. Thawari, G. et. al. [9] studied the influence of pulsed Nd:YAG laser cutting of nickel-base superalloys and observed that surface roughness reduces with increase in cutting speed and decrease in gas pressure and laser power. Sundar et. al. [10] consid-

To whom correspondence should be addressed:
Email: *trpvsk12@gmail.com, †jayaprakashcad@gmail.com

ered lasox cutting of mild steel and made the following conclusions: lower gas pressure and laser power, higher cutting speed shows a good decrease in surface roughness and the effect of stand-off distance on surface roughness was less significant. Milos Madic et. al. [11] indicated that for obtaining minimal surface roughness the gas pressure should be kept at the lowest level, cutting speed at the highest level, and the laser power at an intermediate level. Yilbas[12] investigated the effects of laser power and cutting speed on the resulting kerf size and found that kerf width increases with increase in laser power and decrease in cutting speed. Ghany & Newishy [13] presented that kerf width reduces with increase in the frequency. Dhaval P. Patel and Mrugesh B. Khatri [14] indicated that kerf width increases with decrease in cutting speed and increase in assist gas pressure and laser power.

3. EXPERIMENTAL PROCEDURE

Dubey and Yadava [15] in their review showed that most of the experiments related to laser material processing were performed without using DOE approach. They concluded that for collecting and analyzing the data with limited use of available resources, design of experiments (DOE) approach proved to be a systematic and scientific way of planning the experiments. Ilzarbe [16] considered various DOE design like factorial, fractional factorial, central composite design, placket-burmann etc., and found that the taguchi method is the most widely used experimental design technique. The experiment is planned to set up with Taguchi's L16 orthogonal array with 4 input parameters and in 4 levels in order to cover wider range of laser cutting parameters. Table 1 shows the Taguchi L16 orthogonal array.

In this present study CO_2 laser cutting of AISI 314 stainless steel is carried out. Various input parameters like cutting speed (1.6 to 2.2 m/min), laser power (3.4 to 4kW), assist gas pressure (0.7 to 1.3 bar) and stand off distance (0.5 to 1.3 mm) are considered for investigation. Figure 1 shows TRUFLOW make of 4 kW CO_2 FO 4020 NT laser cutting machine with a focal position of -2mm, nitrogen assist gas with 99.5% purity and 1.5 mm diameter nozzle. Table 2 represents the specification of the laser cutting machine. The selected ranges and levels of inputs indicated in table 3 are given as an input to machine through FANUC controlled CNC program. Figure 2 shows the profile which has to be cut on the stainless steel plate of size 350 X 350 X 3 mm thickness. Figure 3 represents the specimen which is cut by the laser cutting machine controlled through CNC controller.

All the specimens are subjected to inspection in order to evaluate the responses. Rockwell hardness tester with diamond intendor of scale C is used to measure the hardness of the AISI 314

Figure 1. Truflow Laser cutting machine

Table 1. Taguchi L16 Orthogonal array

Expt no.	Power	Speed	Pressure	Stand off distance
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table 2. Specification of LASER Cutting Machine

Wavelength	10.6 µm
Laser power	4000 W
Beam quality K	0.55
Beam quality M²	1.82
Power stability	± 2 %
Dimensions beam source	
1. Length	1185 mm
2. Width	1150 mm
3. Height	650 mm

Table 3. Ranges of cutting parameter

Parameters / Levels	1	2	3	4
Power in kW	4	3.8	3.6	3.4
Cutting Speed in m/min	2.2	2	1.8	1.6
Pressure in bar	1.3	1.1	0.9	0.7
SOD in mm	0.5	0.8	1	1.3

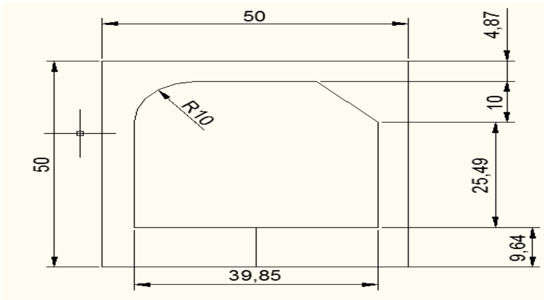

Figure 2. Workpiece profile

Figure 3. Specimen cut during the trials

stainless steel specimen. Likewise TR110 surface roughness tester is used to measure surface roughness and tool makers microscope is used to measure the upper and the lower kerf width. The ratio of the upper kerf to the lower kerf is calculated in each run and the kerf taper was calculated using the formula.

$$\text{Kerf Taper} = \frac{(\text{Top kerf width - Bottom kerf width})}{2\pi \times \text{Workpiece thickness}} \times 180°$$

4. RESULTS AND DISCUSSION

Detailed discussion is made on the influence of the processing parameters on the hardness and surface quality. The measured responses are shown in Table 4.

Figure 4 represents the influence of processing parameter on the hardness of the AISI 314 stainless steel material. It has been noticed that the value of the hardness of the material increases with increase in power and gas pressure, as the microstructure gets altered and the resolidification is not allowed. As the intensity of the laser beam is higher, the hardness of the material is found to increase with decrease in stand off distance. Moreover the hardness value increases with decrease in speed, as the exposure time of the laser beam onto the workpiece is more.

The developed mathematical model for the hardness generated using regression is

$$\text{Hardness} = 87.8 - 4.35\ \text{Power} - 4.15\ \text{Speed} - 6.00\ \text{Pressure} + 1.30\ \text{SOD}$$

Figure 5 illustrates the influence of each processing parameter on the roughness. It is observed that the measured value of roughness increases with decrease in power and pressure as laser cutting is less stable at low power levels and the heat is generated due to exothermic reaction. The roughness value decreases with decrease in speed, as the interaction time between the laser beam and metal is increased. Stiration is more due to high intensity of laser beam, so the roughness value increases and then decreases as the stand off distance value increases.

The developed mathematical model for the roughness generated using regression is

$$\text{Surface roughness (Ra)} = 1.18 + 0.0475 \times \text{Power} - 0.0060 \times \text{Speed} + 0.0525 \times \text{Pressure} - 0.0425 \times \text{SOD}$$

Figure 6 reflects the influence of processing parameter on the kerf width. It is found that the value of kerf width increases with increase in power and gas pressure due to burning in some regions and opened up at higher pressures. Increased cutting speed and stand off distance results in decreased kerf width due to limited exposure of the laser beam onto the metal.

The developed mathematical model for kerf width generated using regression is

$$\text{Kerf width} = 0.739 + 0.00325 \times \text{Power} - 0.00275 \times \text{Speed} - 0.0237 \times \text{Pressure} - 0.00200 \times \text{SOD}$$

Figure 7 illustrates the influence of processing parameter on the kerf ratio. It is concluded that the value of kerf ratio decreases with increased power and gas pressure as the kerf deepens at the bottom due to the increase in heat and the molten metal is expelled quickly. The kerf taper decreases with decrease in speed and stand off distance.

The developed mathematical model for kerf ratio generated

Table 4. Measurement of Responses

Expt. No.	Hardness (HRC)	Ra (μm)	Kerf Width (mm)	Kerf Ratio	Kerf taper (Deg)
1	67	1.02	0.73	10.18	1.07
2	69	1.75	0.695	9.69	1.01
3	54	1.11	0.695	9.76	1.02
4	45	1.34	0.59	8.95	0.94
5	67	0.94	0.66	8.94	0.94
6	66	1.39	0.695	9.69	1.01
7	45	1.57	0.63	10.03	1.05
8	52	0.99	0.65	10.44	1.09
9	67	1.44	0.675	9.70	1.02
10	48	1.04	0.685	9.92	1.04
11	76	1.04	0.68	9.09	0.95
12	45	1.59	0.71	10.28	1.08
13	39	1.59	0.645	10.44	1.09
14	44	1.59	0.645	9.63	1.01
15	48	1.39	0.695	9.76	1.02
16	44	1.21	0.73	9.82	1.03

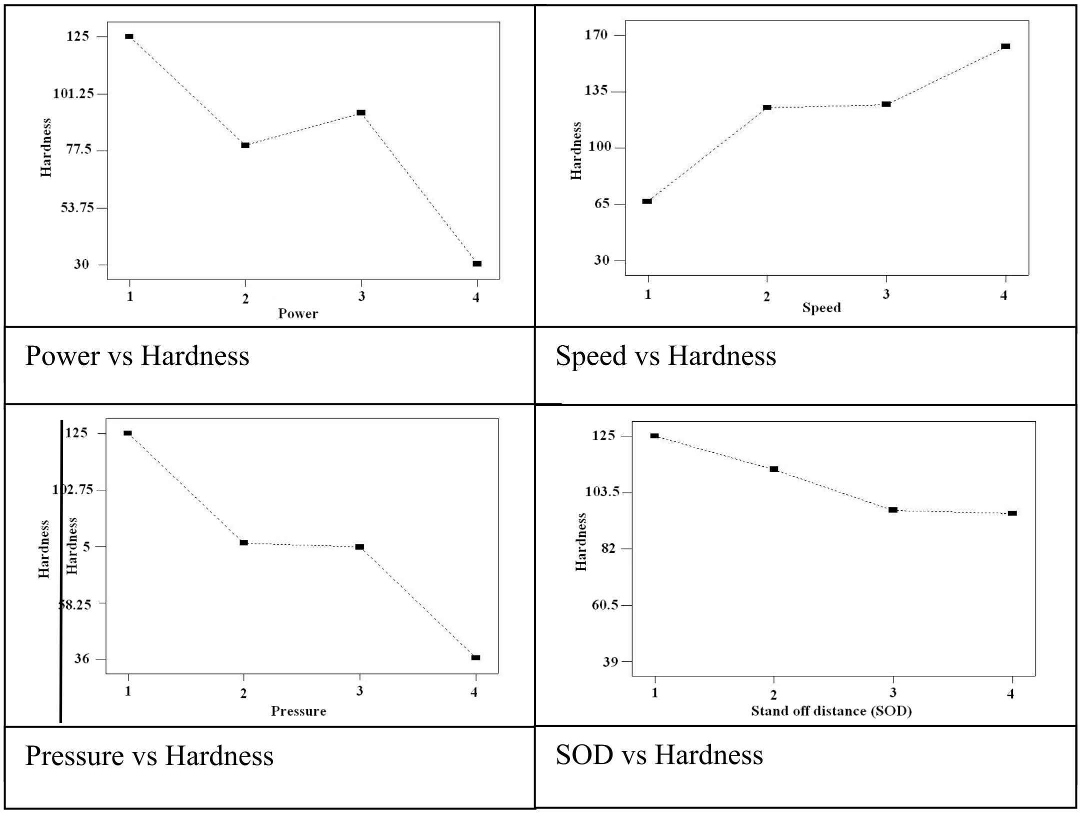

Figure 4. Influence of parameters on the hardness of the material

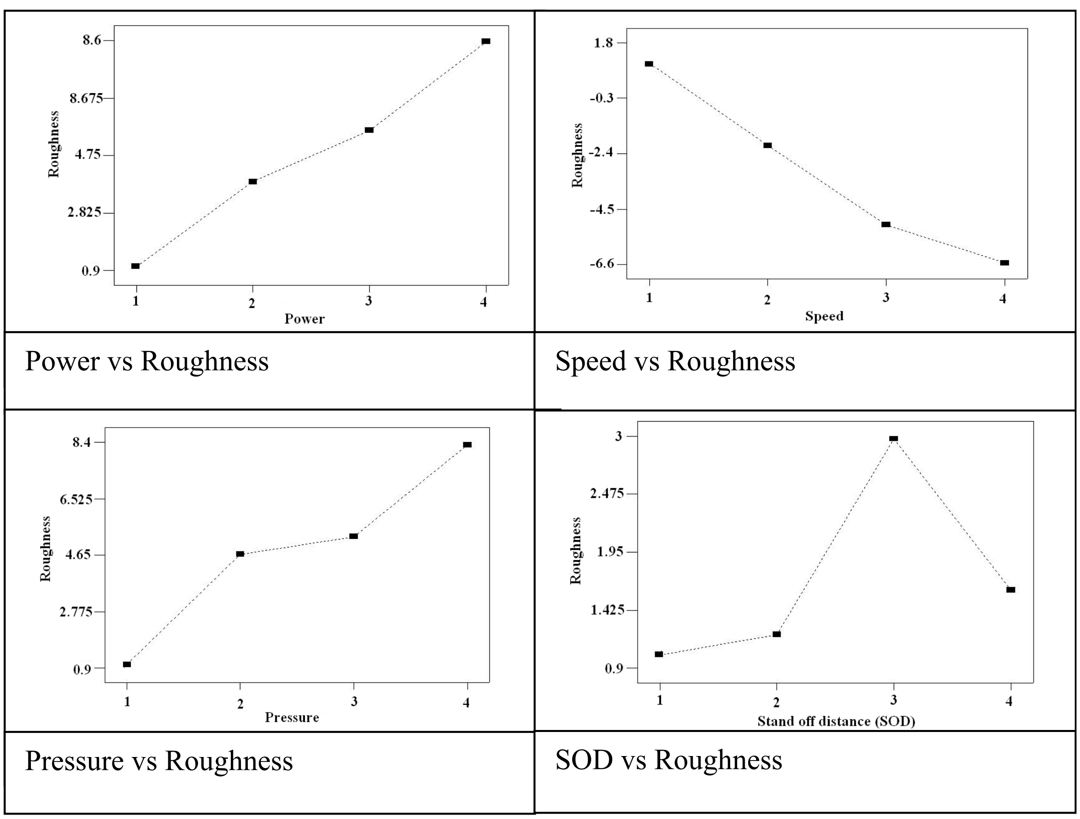

Figure 5. Influence of parameters on the roughness of the material

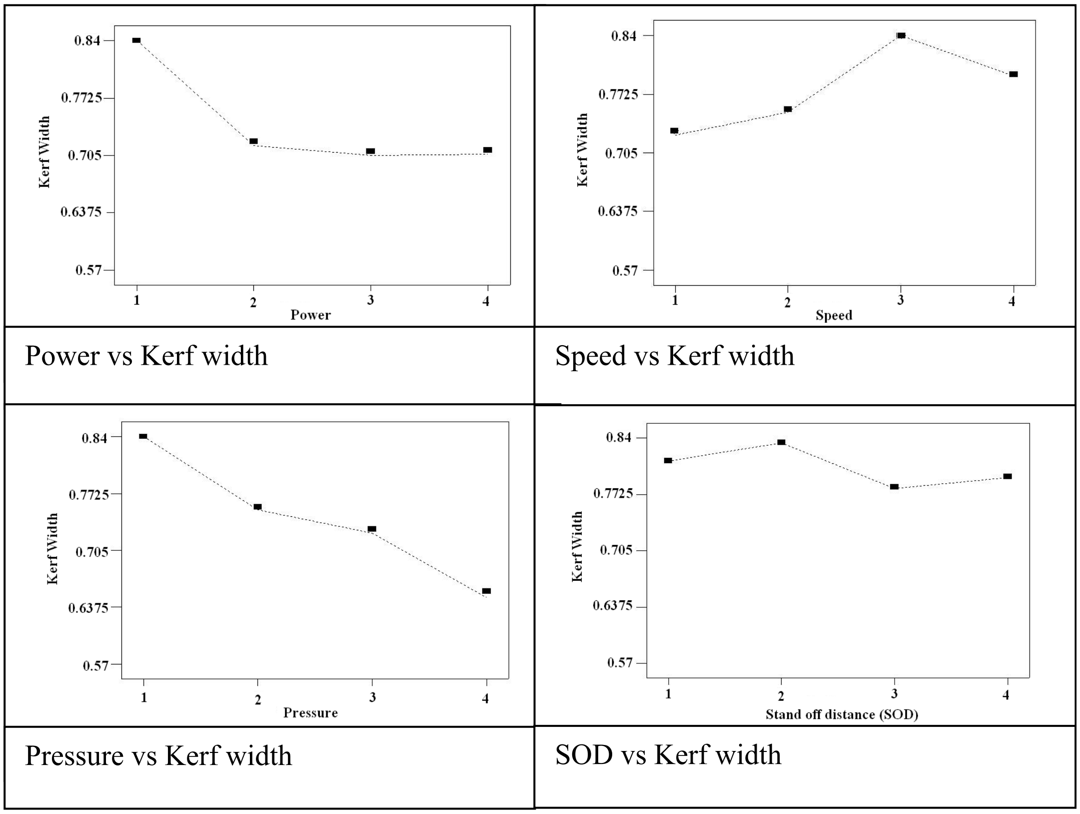

Figure 6. Influence of parameters on the kerf width

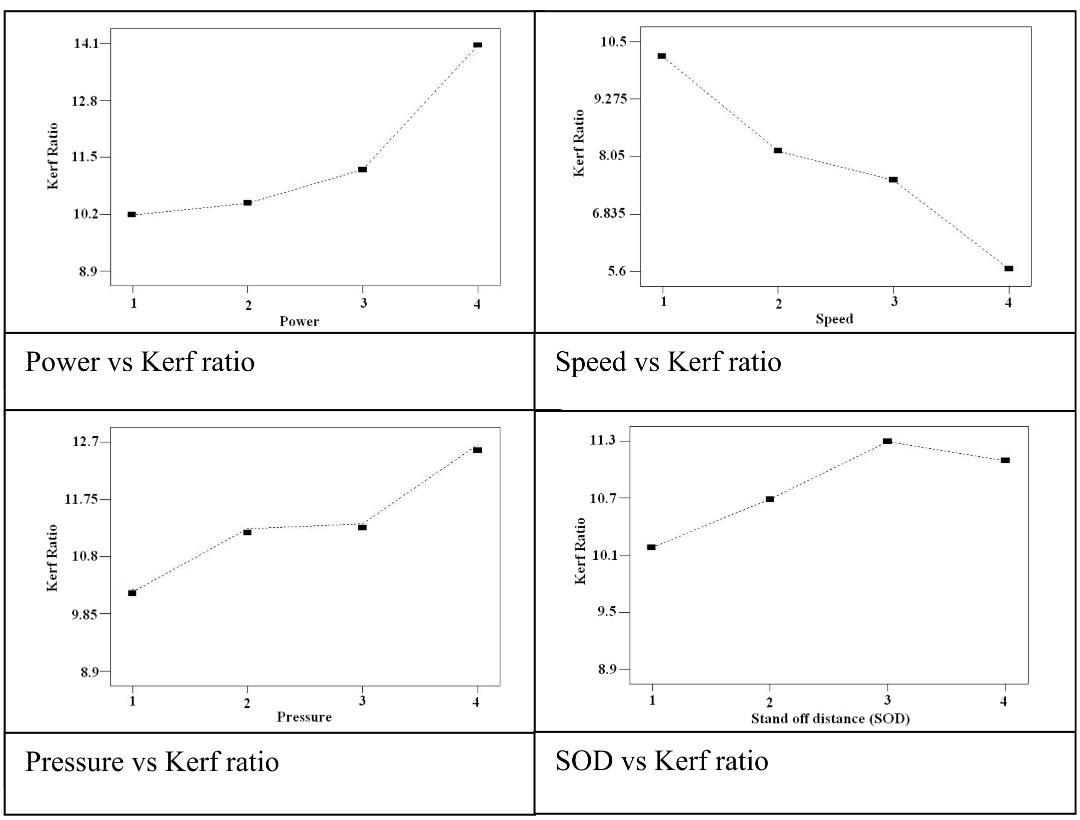

Figure 7. Influence of parameters on the kerf ratio

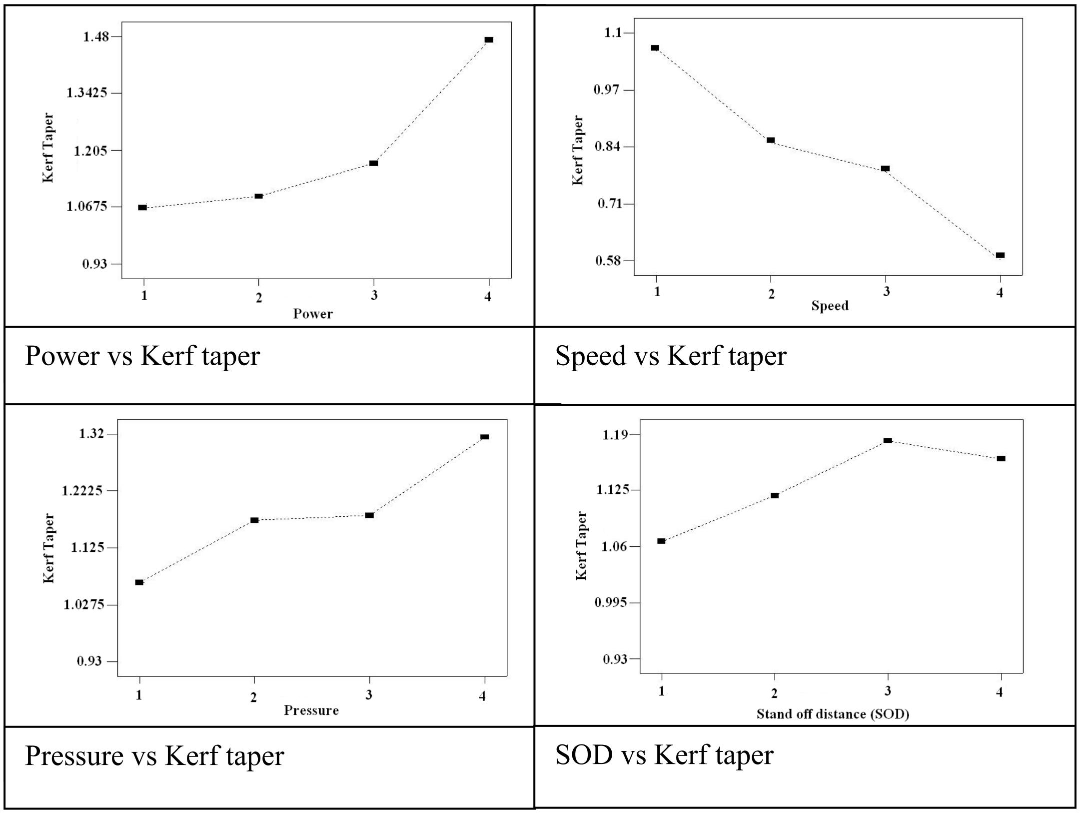

Figure 8. Influence of parameters on the kerf taper

using regression is

$$\text{Kerf ratio} = 1.03 + 0.0082 \times \text{Power} + 0.0007 \times \text{Speed} + 0.0068 \times \text{Pressure} - 0.0192 \times \text{SOD}$$

Figure 8 depicts the influence of processing parameter on the kerf taper. It is noted that the value of kerf taper increases with increase in power and gas pressure. The kerf ratio decreases with increase in speed, as the metal starts melting at the leading edge of the beam and much of the beam passes through the kerf without touching the sides. Moreover the value of kerf taper increases and then decreases with increase in stand off distance.

The developed mathematical model for kerf taper generated using regression is

$$\text{Kerf taper} = 9.85 + 0.077 \times \text{Power} + 0.010 \times \text{Speed} + 0.064 \times \text{Pressure} - 0.182 \times \text{SOD}$$

5. CONCLUSION

The present work deals with the parametric investigation of the influence of process parameters in laser cutting of AISI 314 stainless steel. The selected parameters were power, speed, pressure and stand off distance, while the responses were hardness, surface roughness, kerf width, kerf ratio and kerf taper. A simple mathematical model was generated for the laser cutting of AISI 314 stainless steel to predict the hardness and surface quality. Based on the experimental results it was found that

1. The maximum hardness, minimum roughness, minimum kerf taper and ratio was obtained for power = 4 kW, Speed = 1.6 m/min, Pressure = 1.3 bar and stand off distance = 0.5 mm.
2. The minimum kerf width was obtained for power = 3.4 kW, speed = 2.2 m/min, pressure = 0.7 bar and stand off distance = 1 mm.

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