Experimental Studies on Hastealloy C276 while Machining with CO_2 Laser Cutting Machine

Palleboina Madhava[1*], *K Dharma* Reddy[1]
[1]Department of Mechanical Engineering, Sri Venkateswara University, Tirupathi, A.P., INIDA

Abstract. Laser cutting process is well suitable process for the cutting applications of high strength temperature resistant alloys, that are very difficult to cut with conventional process. Moreover, the lasers are widely using now-a-days for variety of cutting operations in many varieties of industries. Because of its complex nature of its operation, it is not easy to control so as to get the desired quality of cut in case of laser beam cutting process. This necessitates the importance of research to be carried out on the various processes i.e cutting, drilling, and welding etc by using the laser apparatus. The research mainly concentrated on the conduction of experiments i.e the cutting operation on Haste alloy C276 with CO_2 laser beam. Total 31 trails are done using the CO_2 laser beam apparatus. Laser power, speed, gas pressure and focal distance were the parameters chosen to vary. The outputs measured are surface roughness and the burr height which are direct measure to the quality of the cut surfaces. Two dimensional plots are plotted and analyzed the reasons for the increase or decrease of output with either the increase or decrease of input process parameters. Also, 3D plots are plotted to know the interactions.
Key words. Laser Machining, Cutting process, Haste alloy C278, Process variables, Output responses

1. Introduction to Laser Cutting

Advances in Manufacturing technology is key to the development of a country's industrial growth and largely that is going to dictate the economy. Among al the machining processes widely available, LBM (Laser beam machining) is growing importance in recent years due to the following advantages with the lasers i.e High speed, accuracy, less tendency to cracking, less heat affected zone et. Moreover the availability and usage of advanced high strength temperature resistant alloys for various applications in industries, necessitates the usage of advanced machining processes. During cutting process of HSTR alloys, the major problem that the manufacturers are facing is the quality of cut achieving using the conventional cutting processes. Alternatively, the application of lasers improving the quality of cut, provided the entire process is controlled in a desired manner.

*Corresponding author: pvkmadhava@gmail.com

Also, Laser cutting does not need fixtures and jigs for holding and guiding the work piece because it is a non-contact operation. Moreover, it does not need costly or disposable tools and also it does not produce mechanical forces that can damage thin work piece. LASER stands for light amplification by stimulated emission of radiation [1]. Laser beam cutting (LBC) is a method uses the laser beam to cut the metals based on the thermal separation process. The LBC setup generates and directs the high-power laser on to the workpiece surface to be cut. The material then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish [2]. Laser cutting is the most widely used LBM process. Advantages of laser cutting over mechanical cutting include easier work holding and reduced contamination of work piece (since there is no cutting edge which can become contaminated by the material or contaminate the material). Precision may be better, since the laser beam doesn't wear during the process. There is also a reduced chance of warping the material that is being cut, as laser systems have a small heat-affected zone.The capability of the laser cutting mainly depends on the way how it operates i.e if the process parameters are controlled in a proper manner, the quality of cut is going to be at the acceptable level, other wise it produces inferior cut quality which may not be suitable for industrial applications. Hence it is very crucial to operate the LBC apparatus with full knowledge. But due to the arrival of new materials, it becomes very difficult for the manufacturing engineers to set the right combination of parameters at the right levels. Hence there is a need to develop some method to find the optimal process parameters to be set inorder to achieve high speed accurate cuts. So the research is mainly concentrated on carrying out the research which enables the future engineers to have clear picture and understanding of the cutting process using the Laser beam.

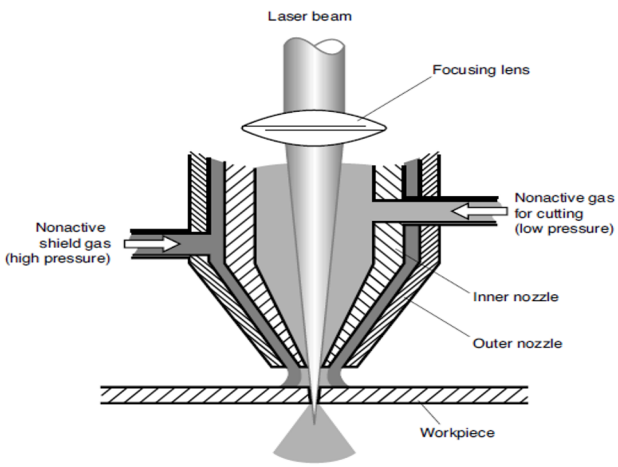

Fig.1. Schematic diagram of a laser cutting system

2. Literature Survey

Previously also, many researchers have carried out the investigations on the laser beam cutting process. A few of them were presented here; K. Abdel Ghany et. al. [3] investigated the laser cutting process on 1.2mm thick austenitic stainless steel sheet using pulsed and CW Nd:YAG laser. And Grey relational approach is proposed by Milos et. al. [4] for the optimization of the process. Hud Wahab et.al. [5] tested the design of experiments approach while cutting the work samples and the optimization module is also carried out. M.M. Noori et.al [6] carried out the cutting operations on Acryclic sheets and the RSM method is applied to develop the equations. Also analysed the plots between the input and the output responses.

H. A. Eltawahni et. al. [7] investigated the CO_2 laser cutting process parameters by considering the composite material. M. Zaied et. al. [8] carried out the analysis between the laser power, cutting speed, gas pressure on the quality of cut. Low carbon steel is taken as the workpiece. Milos Madici et. al. [9] applied Taguchi method and the surface roughness is measured at different levels of input variables. K.F.Tamrin et. al. [10] performed Multiple-objective optimization in precision laser cutting of different thermoplastics. Shaikh, B et. al. [11] conducted experiments using the Taguchi Design of Experiments. Omer Ozgur et. al. [12] carried out analysis on the rectangular profiles using the aluminum alloys. Kiran Kumar and P. Venkataramaiah [13] carried out the experimental investigation on the surface integrity of Inconel 718. The experiments are conducted for the Design matrix developed using Taguchi DOE. Dong-Gyu AHN et. al. [14] carried out the experiments on the Inconel 718 sheet applying the DOE. Also studied the surface roughness variations. Ahmet Cekic et. al. [15] has done experimentation on the CO_2 laser cutting. Alloys were considered as the workpieces. K. Venkatesan et. al. [16] conducted experiments on LBC apparatus for difficult to cut materials. Xavierarockiaraj.S et. al. [17] Investigated the effect of cutting forces, surface roughness and tool wear during Laser assisted machining on the tool steel. Yoshihiro Morimoto et. al. [18] analyzed the effects of vertical and high frequency oscillations and mainly focused on the quality of cut in thick plates. Vipul K Shah1 et. al [19] carried out the analysis on the input process parameters for the optimization of surface roughness.

As per the literature survey, in most of the experimental investigations of the LBC process researchers have considered only two or three input variables while carrying out the experiments. But this research considered four parameters and the levels are found for each of the process parameter by conducting the trial experiments. And also interaction effects among various input process parameters are not considered. To overcome these problems, this work is proposed to use Design of Experiments to reduce the number of experiments with the same accuracy. In the present work, a total of 27 experiments were carried out based on the Taguchi. with the aim of analyzing the effect of process parameters on cut geometry and cut surface quality. In this paper, after conducting the experiments, the graphs were drawn (both 2D and the 3D) using the design expert software. 2D graphs are drawn to know the exact trends between the input variables and the output responses. 3D graphs are also drawn to know the interaction effects.

3. EXPERIMENTAL WORK

The experiments were conducted on a 3 axes CNC controlled CO2 laser cutting machine which is available in Meera Laser Solutions, Ambattur, Chennai. The maximum average power produced at laser is 100W. The most widely used lasers for sheet cutting are continuous wave (CW), CO_2 and pulsed Nd.YAG laser [20]. High quality cutting surface is obtained by proper selection of parameters and application of appropriate assisted gases. As the laser cutting of steel, using N_2 gives brighter and smoother surface finish. For research purpose, the Laser light was developed by gaseous state CO_2 laser (Fig.1) with larger power up to 3200W, frequency10000 Hz, maximum gas pressure 8.0 bar, maximum cutting speed 5000 mm/sec and prepared with stand-off distance regulating by servo motor and sensory devices. The workpiece setup is shown in Fig.2 and the process is shown in Fig.3.

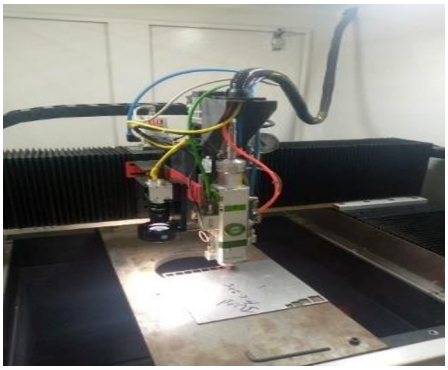

Fig. 2. Workpiece setup in Laser equipment

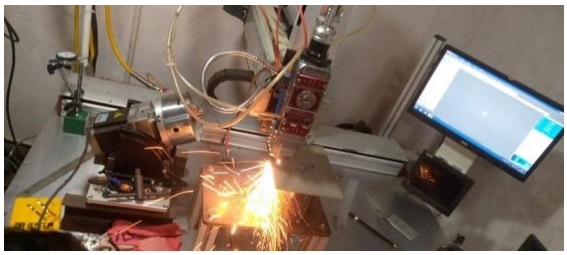

Fig.3. CO_2 Laser Machining process

3.1. Experimentation on HASTE ALLOY C-276

The material chosen for research is Hastelloy C-276 with a thickness of 2 mm. The chemical composition of the material is given in Table 1.

Table.1. Hastelloy C276composition in weight percentage

Element	Ni	Mo	Cr	Fe	Tn	Co	Mn	C	Vn	Ph	Su	Si
Percentage	57	15.0 -17.0	14.5 – 16.5	4.0 – 7.0	3.0 – 4.5	2.5	1	0.01	0.35	0.04	0.03	0.08

After going through the literature survey, it was found that Haste Alloy C-276 exhibits high resistance to uniform attack, outstanding localized corrosion resistance, excellent stress corrosion cracking resistance, and ease of machining, welding and fabrication. Also Haste alloy C-276 finds wide spread applications in Chemical process, Petrochemical, Oil & Gas, Mining, Nuclear Power, Solar Power etc. Keeping in view of the importance and applications of Haste alloy, the material is chosen as the work piece material to carry out the research on Laser beam machining.

Fig.4. Haste alloy C276 – Square profile cut profiles

3.2. Design of Experiment

The need of process development is to increase the performance of the process related to customer expectations. The purpose of DOE is to understand how to deduct and controls the variations of a process; however things must be made concerning which variables are affecting the performance of a process. The selected design matrix is a five-level, four-factor, central composite rotatable factorial design consisting of 31 sets of coded conditions. It comprises a full replication of 24(=16) factorial design plus seven center points and eight star points. All cutting variables at their intermediate level (0) constitute the center points, and the combinations of each of the cutting variables at either its lowest (-2) or highest (+2) with the other three variables at their intermediate level constitute the star points. Subsequently, the 31 exploratory runs permitted the estimation of the quadratic and two-way intuitive impacts of the cutting variables on the cut edge quality. The process parameters according to the experimental conditions are mentioned in table 2, and the experimental design matrix is shown in table. 4.

Table.2. Experimental Conditions

Process parameters	Units	Levels				
		-2	-1	0	1	2
Laser Power (x_1)	KW	1.7	1.75	1.8	1.85	1.9
Cutting Speed (x_2)	mm/sec	3	3.75	4.5	5.25	6
Focal Distance (x_3)	mm	0.4	0.5	0.6	0.7	0.8
Gas Pressure (x_4)	bar	2	2.25	2.5	2.75	3

The intermediate values are calculated from the following relationship;

$$x_i = \frac{2\left[2X - (X_{\max} + X_{\min})\right]}{(X_{\max} - X_{\min})} \quad (1)$$

where x_i is the required value of a variable X. X is any value of the variable from X_{min} to X_{max}. X_{min} is the lower level of the variable and X_{max} is the upper level of the variable.

After the experiments, the output responses i.e Surface roughness was measured using Talysurf (Mitutoyo) [fig.5] and Burr height was measured using Micrometer (Mitutoyo)..The controlled parameters have been the burr height and surface roughness. Surface roughness of the square grooves was measured in terms of the aggregate roughness *Ra*, using a Talysurf instrument. Roughness was measured along the length of cut at approximate medium of thickness. The size of burr height was measured using a 2 to 25 mm micrometer.

Fig.5. Talysurf equipment

Table. 4. Experimental design and measured Responses

Exp No	Laser Power	Cutting Speed	Focal Distance	Gas Pressure	Surface Roughness	Burr Height
	[KW]	[mm/sec]	[mm]	[bar]	[µm]	[µm]
1	1.75	3.75	0.5	2.25	3.575	0.815
2	1.85	3.75	0.5	2.25	4.64	1.88
3	1.75	5.25	0.5	2.25	3.543	0.783
4	1.85	5.25	0.5	2.25	3.803	1.043
5	1.75	3.75	0.7	2.25	3.539	0.779
6	1.85	3.75	0.7	2.25	3.548	0.788
7	1.75	5.25	0.7	2.25	3.548	0.788
8	1.85	5.25	0.7	2.25	3.697	0.937
9	1.75	3.75	0.5	2.75	3.05	0.29
10	1.85	3.75	0.5	2.75	3.879	1.119
11	1.75	5.25	0.5	2.75	3.308	0.548
12	1.85	5.25	0.5	2.75	3.398	0.638
13	1.75	3.75	0.7	2.75	3.646	0.886
14	1.85	3.75	0.7	2.75	3.551	0.791
15	1.75	5.25	0.7	2.75	3.317	0.557
16	1.85	5.25	0.7	2.75	3.127	0.367
17	1.7	4.5	0.6	2.5	3.21	0.45
18	1.9	4.5	0.6	2.5	4.589	1.829
19	1.8	3	0.6	2.5	4.425	1.665
20	1.8	6	0.6	2.5	3.44	0.68
21	1.8	4.5	0.4	2.5	3.256	0.496
22	1.8	4.5	0.8	2.5	4.245	1.485
23	1.8	4.5	0.6	2	3.07	0.288
24	1.8	4.5	0.6	3	3.789	1.029
25	1.8	4.5	0.6	2.5	3.345	0.456
26	1.8	4.5	0.6	2.5	3.968	1.208
27	1.8	4.5	0.6	2.5	3.635	0.875
28	1.8	4.5	0.6	2.5	3.595	0.835
29	1.8	4.5	0.6	2.5	3.471	0.711
30	1.8	4.5	0.6	2.5	3.223	0.463
31	1.8	4.5	0.6	2.5	3.21	0.489

4. Influence of the Process Parameters on Output Responses

4.1. Laser power influencing on the surface roughness:

The influence of laser power on the surface roughness is as shown in fig.6. [The effect of laser power on the surface roughness of cut reduces where the thicker sheet is considered to be cut]. The surface roughness values are investigated on the different laser power conditions. A very fast increment in surface roughness is occurred at low, medium and high values of

the laser power conditions. The power and surface roughness are directly proportional to each other.

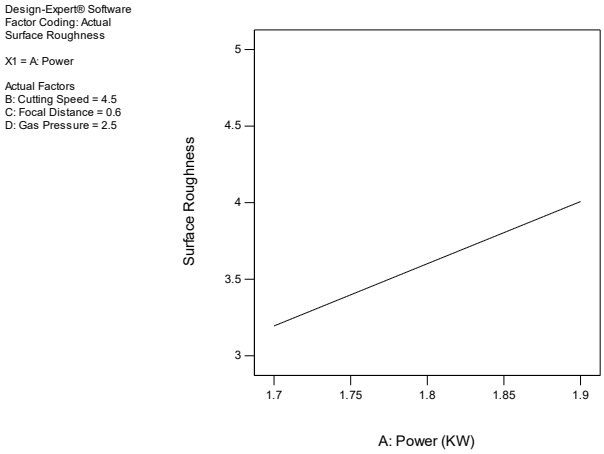

Fig.6. The Relationship between Laser power and surface Roughness

4.2. Cutting speed influencing on the surface roughness:

The influence of cutting speed on the surface roughness as shown in fig.7.The most favorable cutting parameters for a group of related steel is possible on the basis of presented indicators. The higher cutting speeds give maximum surface roughness. The good surface finish is to be obtained at optimal cutting speeds in this investigation.

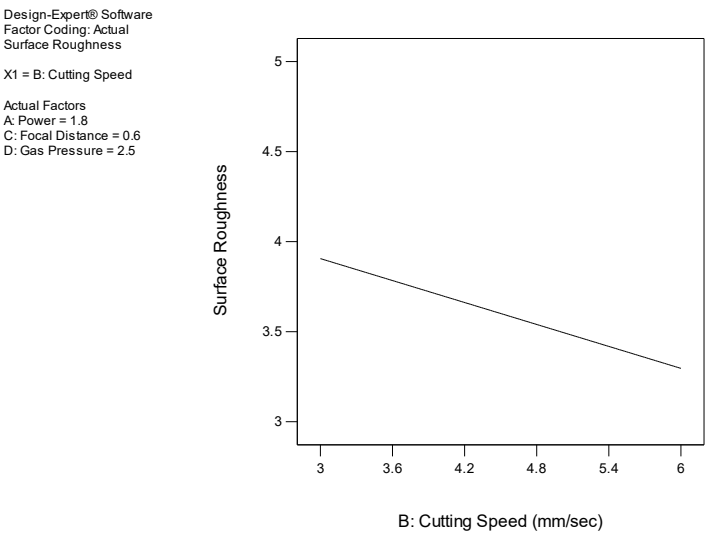

Fig. 7. The Relationship between cuttings speed and surface roughness

4.3. Gas pressure influencing on the surface roughness:

The influence of gas pressure on the surface roughness as shown in fig.8.The gas pressure is most significant parameter affecting the surface roughness variation. For obtaining the minimal roughness the gas pressure should be kept at low level.

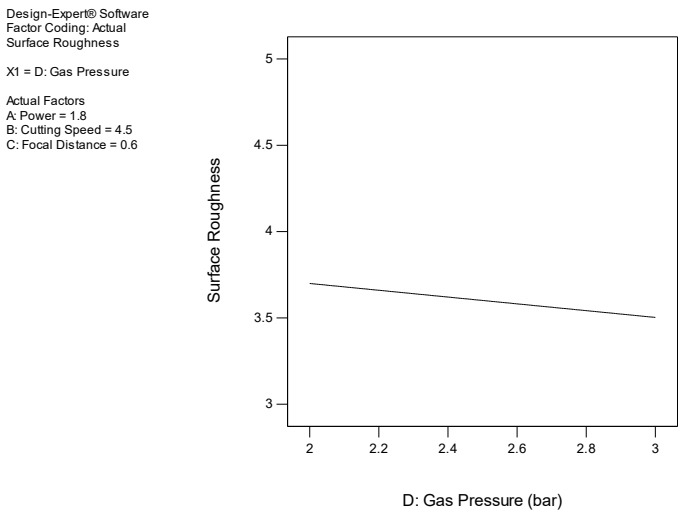

Fig. 8. The relationship between Gas pressure and surface Roughness

4.4. Focal Distance influencing on the surface roughness:

The influence of Focal distance on surface roughness as shown in fig.9.The surface roughness value increases if both laser power and focal distance increases. The focal distance has the most significant effect on the surface roughness.

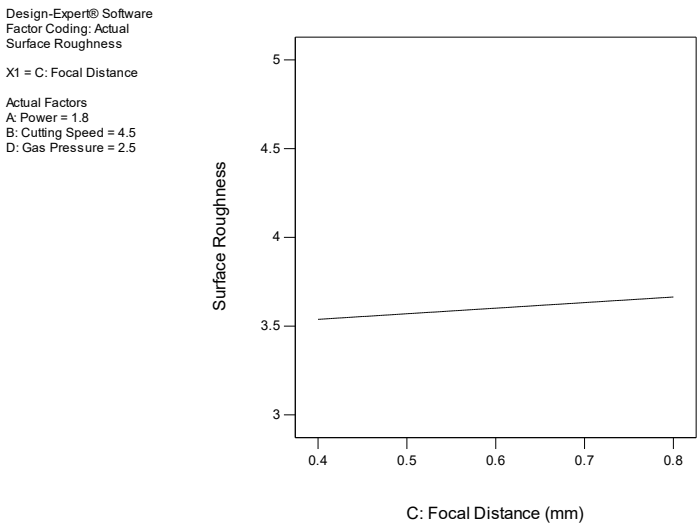

Fig. 9. The relationship between Focal Distance and surface roughness

4.5. Laser power influencing on the Burr height:

The influence of Laser power on the burr height as shown in fig.10.During cutting, the laser power develops a Very high temperature in the form of light wave. The laser power is directly proportional to the burr height because more power causes more metal removal. This large amount of metal removal gives an irregular solidification of the bottom surface. These burr height also varies with respect to power fluctuations.

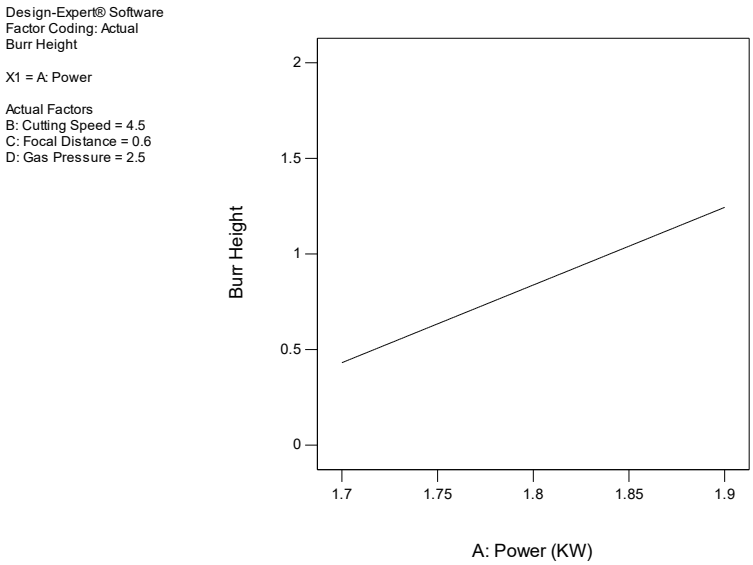

Fig. 10. The relationship between Power and burr height

4.6. Cutting speed influencing on the Burr height:

The influence of cutting speed on the Burr height as shown in fig.11.The curve slope is greater at the lower cutting speed because of at high speed there is no sufficient time to diffusion and melting grooves. The larger cutting speeds with in the tested range increase the burr height.

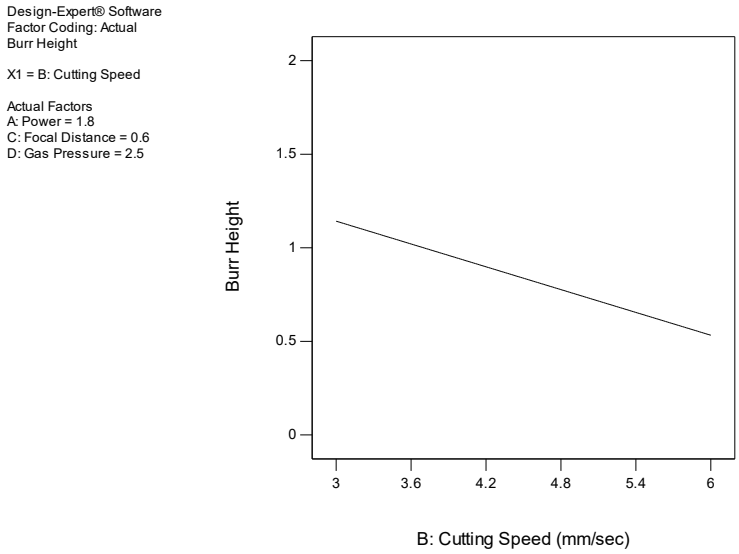

Fig. 11. The relationship between Cutting speed and burr Height

4.7. Gas pressure influencing on the Burr height:

The influence of gas pressure on the Burr height as shown in fig.12.The burr height can be explained by increase in some automatic force induce by gas pressure. Although growing the pressure of oxygen gas assures very smooth and burr less surface. The optimal gas pressure

even with some unnoticeable burrs is attached to lower surface. Increasing the gas pressure gives an increasing the burr height.

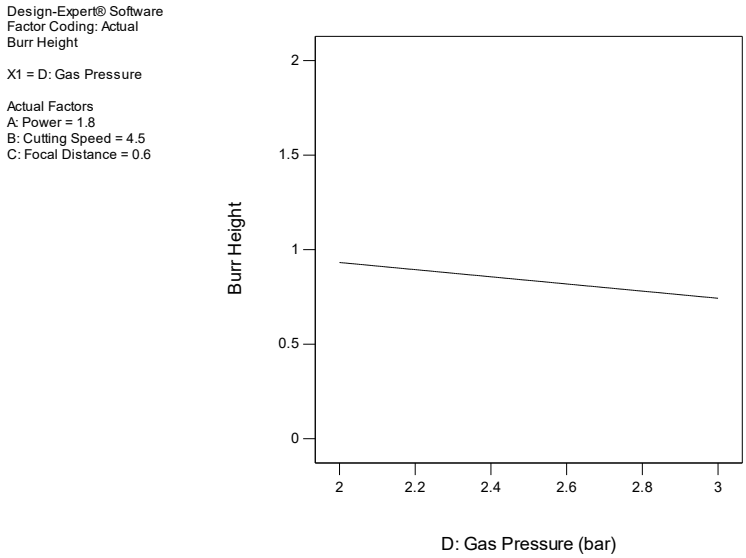

Fig. 12. The relationship between Gas Pressure and Burr Height

4.8. Focal Distance influencing on the Burr height:

Influence of the focal distance on burr height as shown in fig.13.The steady values, positive relations effect on burr height with increase in focal distance. Focal distance has the dominant effect on the burr height improvement. For obtaining the optimal burr height while using the maximum focal distance.

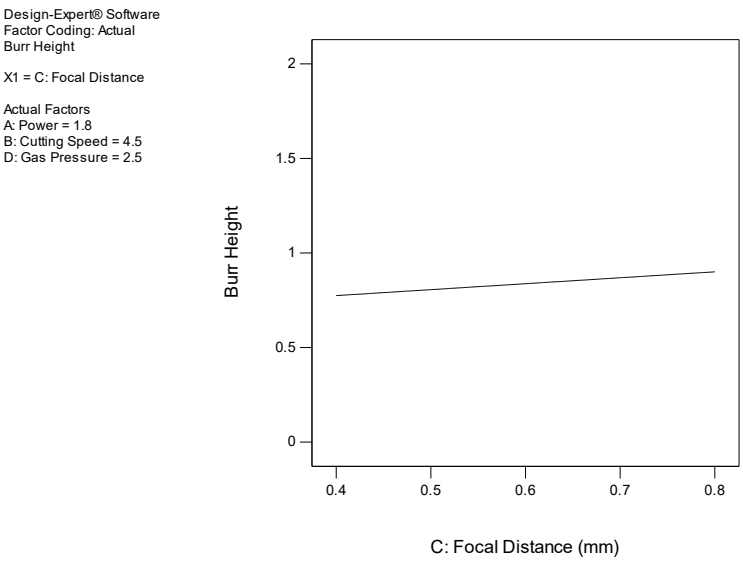

Fig. 13. The relationship between Focal distance and Burr Height

5. Interaction Effects

The Fig.14 shows the interaction effects of laser power and cutting speed on surface roughness.

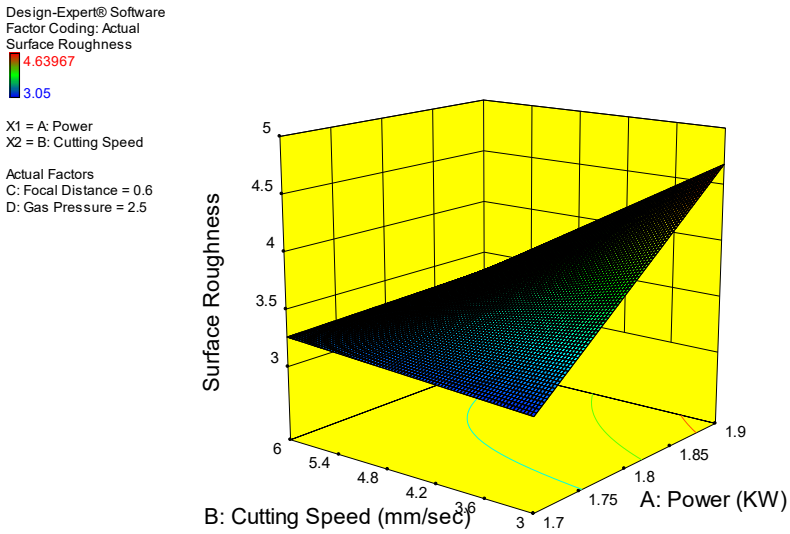

Fig. 14. Interaction effect of laser power and cutting speed on surface roughness

The laser power and cutting speed are to be taken as a constant. It can be observed that as the Laser power increases from minimum to maximum, the surface roughness is found to increase and as the cutting speed increases.

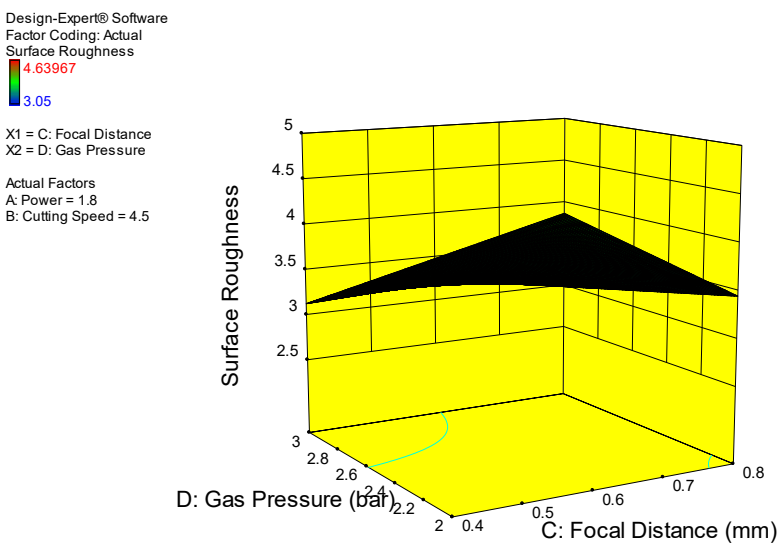

Fig. 15. Interaction effects of focal distance and gas pressure on surface roughness

The Fig.15 shows the interaction effects of laser power and gas pressure on surface roughness. Roughness increases with increase of laser power and when gas pressure decreases from maximum to minimum.

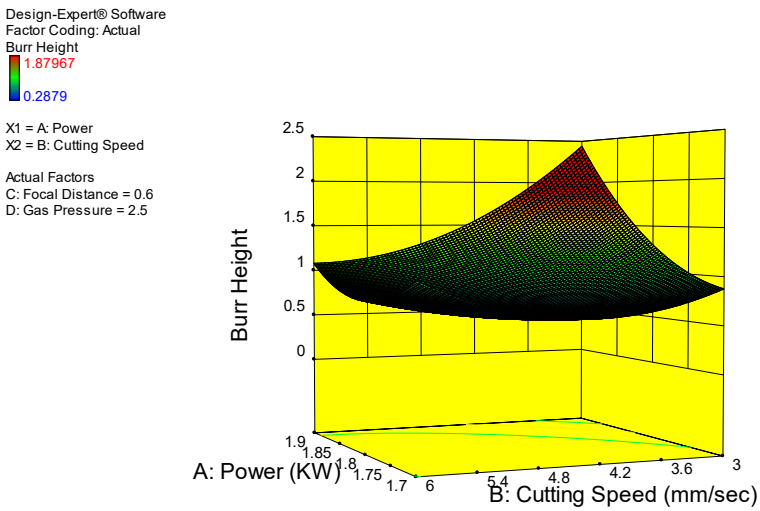

Fig. 16. Interaction effect of Laser power and cutting speed on Burr height

The Fig. 16 shows the interaction effects of laser power and cutting speed on burr height. Burr height increases with increase of laser power and when cutting speed decreases from maximum to minimum.

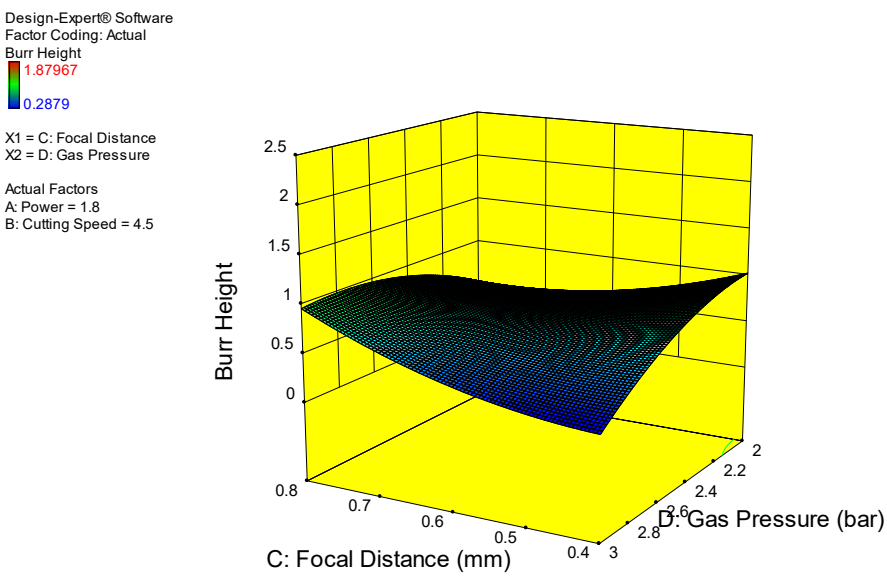

Fig. 17. Interaction effect of gas pressure and focal distance on burr height

Fig.17 shows the interaction effects of Laser power and gas pressure on Burr height. The burr height gradually decreases with the decrease laser power and increases with increasing the cutting speed.

6. Conclusions

In the present study, Design based experiments are carried out on the Haste alloy C276 using the laser beam cutting apparatus. Further 2D plots are drawn using the Design Expert software to know the effects of the individual process parameters on the chosen responses Surface roughness and the Burr height. Also the interaction effects were studied. Based on the above research, the following conclusions were drawn

1. The material chosen for research is well suited for the cutting operation using the laser beam cutting equipment. Overall the quality of cut obtained is satisfactory.
2. Design of Experiments concept proved to be the useful one to reduce the number of experiments without losing the accuracy.
3. The power and surface roughness are directly proportional to each other.
4. Increasing the gas pressure gives an increasing the burr height.
5. It can be observed that as the Laser power increases from minimum to maximum, the surface roughness is found to increase and as the cutting speed increases.
6. The burr height gradually decreases with the decrease laser power and increases with increasing the cutting speed.

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